INFORMATION TECHNOLOGY AND FIRM PERFORMANCE

The Role of Innovation

Fardad Zand

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To my beloved parents, Azin and Farhad,
for their unconditional sacrifice, love,
encouragement, and support

Nothing in life is to be feared, it is only to be understood.
Now is the time to understand more, so that we may fear less.

-- Marie Curie

If I have seen further it is by standing on the shoulders of giants. -- *Isaac Newton*

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Contents

The greatest challenge to any thinker is stating the problem in a way that will allow a solution.
-- Bertrand Russell

INTRODUCTION

1. Prologue

The present thesis analyzes the role of innovation in the process of creating business value from Information Technology (IT) assets of the firm. Many scientists, managers, economists and politicians argue that innovation is the engine of economic growth. This engine is fueled by creative ideas and numerous efforts to search for new solutions. Although technology is a product of innovation, it can also be a fuel for it. In particular, General Purpose Technologies (GPTs) such as the steam engine, electricity and telephony are drivers of an enormous number of innovations (Bresnahan and Trajtenberg, 1995; David and Wright, 2003). As a GPT, IT has spectacularly changed the world we live in. All these changes have happened in less than half a century since the proliferation of computers in our daily life and business.

The relationship between IT and innovation is complex and has a number of facets:

(A) *IT is an innovation.* IT itself is one of the most remarkable innovations of the previous millennium. As a GPT, IT is an umbrella term capturing a wide variety of modern technologies and application areas dealing with generation, processing and/or dissemination of information and knowledge. Predicted by Moor's Law, continuous innovations in making electronic chips have so far led to tremendous improvements in the speed and power of computers and, at the same time, incredible declines in their relative size and price. Nowadays, most of our innovations, especially revolutionary innovations, are either an IT themselves or highly IT-related (for examples, see the list of Wall Street Journal 2009 Innovation Awards (WSJ, 2010)).

(B) *IT leads to innovation.* Innovation is much indebted to IT. IT spawns innovations and pushes out the invention-possibility frontier (Brynjolfsson and Saunders, 2010). IT connects people together and allows them to share ideas. IT enables processing of huge volumes of information in a precise and quick fashion that would be otherwise simply impossible. IT accelerates the design and development of new products and services. IT supports new, emergent forms of organizing work and delivering service. In other words, IT is capable of transforming the organization and functioning of our contemporary society and economy in many ways. IT is *wired* for innovation (Brynjolfsson and Saunders, 2010) or the centerpiece of the new wave of innovation (Gates, 2005).

(C) *IT is mediated by innovation.* The quote of the Nobel laureate, Robert Solow, in the New York Times "You can see the computer age everywhere but in the productivity statistics," (Solow, 1987: 36) ignited a great deal of debate among scholars and practitioners on the impact of IT on economic growth. The *productivity paradox* (Brynjolfsson, 1993) encouraged many researchers, in late 1980s and throughout 1990s, to find the answer to an important "what" question: "what is the impact of IT investment on productivity growth?" This question was tackled at multiple levels (i.e. worker, plant, firm, industry and country) and produced evidence for a general consensus to refute the paradox. Yet, there were still critics who questioned or denied the competitive potentials of IT. For instance, Carr (2003; 2004) argued that IT is such ubiquitous and accessible to everyone that although essential for the functioning of any system or organization, it does not provide sustainable merits or distinctions for a single adopting unit against the others. His opponents in return argued that the magic of IT lies in its versatile capabilities and that the question whether or not IT results in superior distinction depends on how and for what purpose we use it (Melville et al., 2004).

Initially, the IT value creation process was merely a *black box*, with technology investments as the input and performance improvements as the outcome. Later on, researchers started to open up the black box of IT by asking "how are IT effects translated to performance measures?" The "how" question aimed at increasing our understanding of the process through which IT creates business value and at unraveling some of the if-conditions under which "IT does matter." Innovation is among those usual suspects that mediate IT effects. In the nutshell, IT is argued to create and support innovations, particularly service, process and product innovations, which in turn lead to performance improvements and competitive advantages. Introduction of ATM machines, for example, revolutionized the retail banking industry. These systems enabled financial institutions to provide their customers with 24 hours a day, 7 days a week (24/7) service at minimum costs, thereby increased their profitability substantially. A company website provides a comparable service innovation by giving customers 24/7 access to complementary information and technical manuals. The result is a higher customer satisfaction that can be translated to a higher market share for the company. Adoption of an EDI (Electronic Data

Interchange) or ERP (Enterprise Resource Planning) system changes the routine of how to keep track of the inventory and to generate new orders. A similar process innovation takes place on the sell side of the company when it installs an e-shop to receive and process incoming orders. The performance result is higher productivity or sales. Digital content/media such as e-books and music are examples of product innovations enabled by IT. Application of CAD/CAE (Computer-Aided Design/Engineering) systems in manufacturing firms is another example where IT enables flexible design and rapid prototyping of new products and hence shortens the time-to-market of firm innovations.

(D) *IT is complemented by innovation.* A recent question concerning the process of IT value creation targets the organizational context under which IT is used: "why do some IT adopters manage to gain substantial benefits from their spending while others do not?" It is argued that for IT investments to be productive, certain organizational factors and practices should preexist or at least be developed in parallel with investments in technology (Bresnahan et al., 2002; Brynjolfsson and Hitt, 2000; Milgrom and Roberts, 1995). These are called organizational complementarities. Innovation, especially organizational and marketing innovation, is an important complementarity. To optimize the value of IT investments, internal and external processes and structures of the firm need to be changed according to the objectives and requirements of the new technology. These organizational innovations create coherent clusters where technological and non-technological aspects of the firm *fit* together to create value. More specifically, a fit among three elements is required: "the strategy of the firm, its organizational design, and the environment in which it operates" Roberts (2004: 12).

This thesis deals with all the four aspects (A)-(D) above. Its primary focus is on the "how" and "why" dimensions of IT business value. It consists of four related studies at the firm-level, two of which perform a cross-sector analysis. Chapter 2 presents a comprehensive literature review and a theoretical attempt to model the value creation process of IT by identifying and classifying the *organizational roles* of IT. With regard to point (A), different IT applications exhibit different roles with differing degrees of innovativeness. In other words, different IT applications can each be considered as innovation up to a certain extent depending on the information processing capacity and organizational change intensity they bring with themselves to the adopting firm. The framework developed in this chapter is evaluated based on qualitative, semi-structured interviews with a large panel of experts. Chapter 3 addresses point (B) by looking at the indirect contribution of IT to innovation performance of the firm through supporting more diverse R&D partnerships with external partners. The empirical data is for Dutch firms during 1994-2006. Chapter 4 concentrates on point (C) by analyzing the post-implementation phase of enterprise systems and the mediating role of process and product innovation therein. Empirical data for this chapter belongs to 29 European countries over a time span of five years (2003-2007). Chapter 5 deals with point (D) and analyzes the patterns of complementarity and clustering between the IT capital and organizational change efforts of the firm. The data are based on multinational firms in the Netherlands over the period 1994-2006. Finally, chapter 6 concludes the thesis and provides recommendations for future research.

2. Outline of the Thesis Chapters

Figure 1 below illustrates how the conceptual building blocks of the thesis connect to each other.

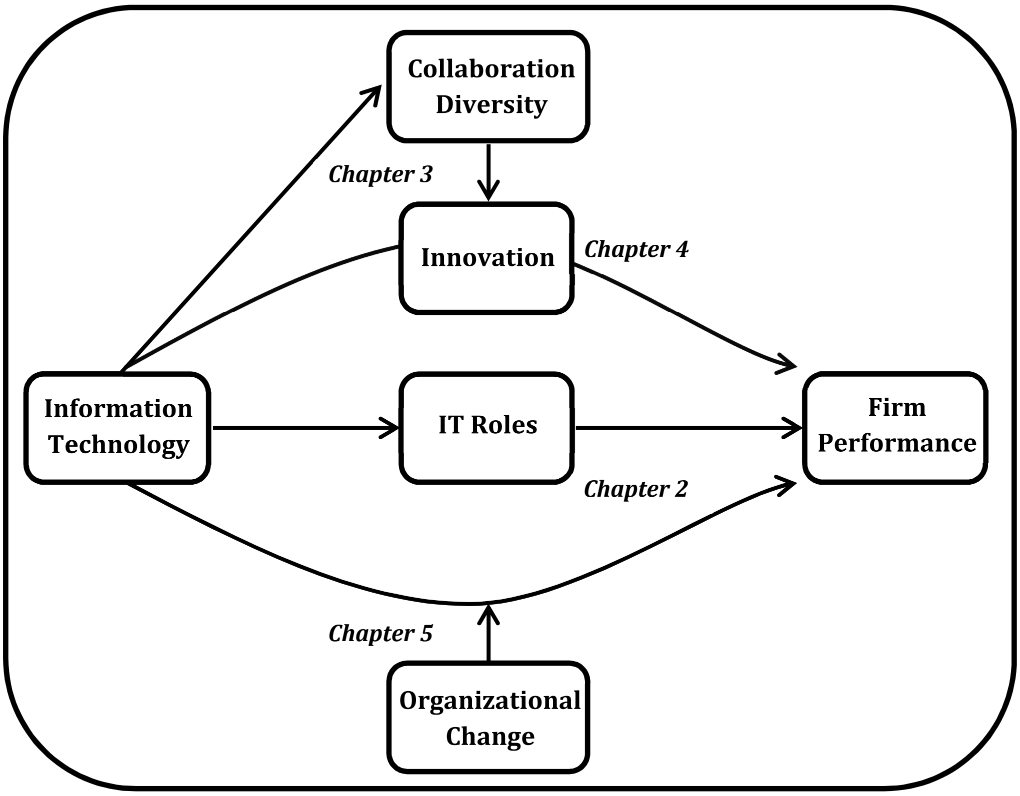

Figure 1: Outline of the thesis chapters

The present chapter introduces the topic of inquiry in this thesis and presents a concise outline of the remaining chapters. The second chapter is a step towards opening the black box of IT and understanding details about the process that transforms IT assets of the firm to performance outcomes. This chapter addresses the "how" question by developing a theoretical framework that identifies the primary roles of IT in organizations. Six categories of roles organized in three classes are identified: (1) First-order roles: Information and Communication roles, (2) Second-order roles: Automation and Coordination roles, and (3) Third-order roles: Integration and Transformation roles. These roles manifest the intermediary mechanisms through which IT creates value. The framework takes a process-oriented approach (Barua et al., 1995; Melville et al., 2004; Mukhopadhyay and Cooper, 1993), has roots in management theories of the firm (i.e. Organizational Information Processing Theory (OIPT) and Resource Based View (RBV)) and evaluates IT-based capabilities of the firm from both operational and strategic perspectives. Fifty-four qualitative, semi-structured interviews with senior IT managers and consultants were conducted in order to validate comprehensiveness and usefulness of the theoretical model in practice.

Chapter three explores one of the channels through which IT leads to higher levels of innovation. Ever increasing costs and risks of innovation projects, high complexity and short lifecycle of technologies, fast changing demands of the market, and pervasive waves of globalization make it more difficult, risky and expensive for a single company to manage an innovation project on its own without reliance on other parties' resources and knowledge. In response, open modes of innovation are becoming ever more popular (Chesbrough, 2003; Chesbrough et al., 2006). Companies' portfolio of innovation partners are becoming more diversified over a wider range of partners from different categories and different countries. Still, the crucial question is whether or not diversity of partners matters to innovation performance (and if yes, why). It is also important to know what organizational factors stimulate the adoption of a diverse portfolio of partners.

Diversity of partners leads to two distinct learning effects, learning cooperation skills and learning innovation skills, both of which affect innovation performance positively. Firms cooperating with a diverse set of partners are more prepared to attract and select right partners and work with them efficiently. In addition, these firms enjoy knowledge intake and synergetic effects to a higher extent, making them more likely to develop and/or introduce successful innovative products. For the empirical part of the research, a panel dataset of 12,811 innovating firms over 11 years (1994-2006) was used. Stakeholder diversity was found to contribute to radical innovations while geographic diversity to incremental innovations of the firm. Further investigation revealed a *sigmoid* relationship between partner diversity and innovation performance

The research also serves as a first step towards identifying the organizational determinants of R&D partner diversity. IT capital intensity of the firm was found to be the most significant determinant of partner diversity as communication, coordination and integration roles of IT seem to be vital assets for developing and managing diverse alliance portfolios. Furthermore, the research sheds light on major differences between the manufacturing versus services and the high-technology/knowledge-intensive versus low-technology/non-knowledge-intensive sectors of the economy with respect to how they engage in inter-organizational collaborations and how much benefit then gain from them.

The fourth chapter primarily addresses the "how" question from a rather different perspective. It focuses on a specialized class of information technologies. Enterprise Systems (ES) constitute the largest part of the IT portfolio of companies. Their implementation imposes considerable costs on organizations and takes a very long time to complete. Previous research shows that the majority of ES projects are doomed as catastrophic failures for two reasons (e.g. Hong and Kim, 2002). First, these systems are extensive in size and complex in nature, which makes their understanding, adaption, and use very cumbersome and time-consuming. Second, they are structurally rigid as they impose built-in, quasi-fixed routines (known as *best practices*) into the adopting firm, which may misfit its culture, structure or strategy. These characteristics make it highly crucial for managers to have a certain degree of confidence about what specific systems to invest in and how to use them when they decide on implementing enterprise systems.

A rich dataset was developed to analyze the process leading to performance impacts from enterprise systems and the role of product and process innovation therein. The data originates from 33,442 enterprises in 29 European countries, represents all the major sectors of the economy, and spans over five years (2003-2007). The data concerns the post-implementation stage of five ES types: ERP (Enterprise Resource Planning), SCM (Supply Chain Management), CRM (Customer Relationship Management), KMS (Knowledge Management System), and DMS (Document Management System). Six performance indicators are considered relevant: product innovation, process innovation, revenue growth, productivity growth, market share growth, and profitability likelihood.

The findings show that enterprise systems are important enablers of product and especially process innovation in Europe. In particular, investments in enterprise systems pay off in performance measures insofar as they lead to new solutions and/or services. Facilitating the current routines and offerings of the firm without generating new solutions or services seems not to be worth investing in these expensive software applications. As to another finding of the research, simpler and smaller enterprise applications such as CRM systems are found to be more effective (at least in the mid-run) compared to more complex and extensive systems such as ERP. While more sophisticated systems hold greater promises and are expected to lead to more profound effects in theory, simpler systems are seemingly easier to install, less complex to adjust and faster to learn and therefore more likely to be implemented successfully in practice.

Chapter five investigates the "why" aspect of the IT productivity paradox. Why some firms manage to reap substantial benefits from their IT investments while others fail, despite comparable levels of expenditure and similar patterns of adoption? The answer is related to the notion of complementarities. For IT resources to be utilized effectively, certain non-IT resources are needed to be in place in time. These non-IT resources complement the productivity effects of IT. Relying on complementarity and configurational theories of the firm, this chapter investigates systematic clusters among organizational practices and assesses their productivity contribution. It further suggests guidelines for extending the complementarity theory to account for the enabling effects of technology.

Organizational Change (OC) is at the center of attention in the fifth chapter. The central argument is that change initiatives of the firm complement its technology investments. Three dimensions of OC are considered important: changes in processes, structures, and boundaries of the firm. A unique and detailed dataset of 32,619 firms in the Netherlands, over the period 1994-2006, is used to test the research hypotheses. As the sample represents the whole Dutch economy, a careful cross-sector analysis is also conducted in order to highlight sector-specific patterns of complementarities. Three methods are employed: interaction method, systems method, and two-stage method. The latter is a new approach to address the endogeneity or simultaneity problem intrinsic to most of IT business value studies. The results imply significant marginal productivity of computer capital (in comparison with ordinary capital) and significant complementarities between IT and different dimensions of OC. The output elasticity of IT and the intensity of complementarities are stronger for the services than for the manufacturing firms. Information technology is found to play two distinct roles: to generate/stimulate change and to complement change. The first role is more prominent in the manufacturing sector while the second in the services. This is an important finding and opens up new doors for future research.

Furthermore, organizational changes are found to be contributor to firm productivity only when they are coupled with large stocks of IT capital (at least as large as the sectoral average). IT enables or facilitates different types of change in organizations. BPR (Business Process Reengineering), TQM (Total Quality Management) and JIT (Just-in-Time) are examples of IT-enabled process changes. Flattening organizations by breaking down the hierarchies of authority and delegating decision rights and responsibilities to lower-level workers and plant managers is among those structural changes that have been primarily induced in the past years due to availability of IT in organizations. With regard to another type of change, increased reliance on outsourcing/offshoring of services and activities, made possible through inter-organizational IT-based systems, results in major boundary changes for the firm.

Different types of change demonstrate complex dynamics among themselves too. Process changes need to be combined with either structure changes (especially, for manufacturing) or boundary changes (especially, for services) to generate positive productivity effects. Overall, the results of chapter 4 and 5 together endorse the message of McAfee and Brynjolfsson (2008: 103) who suggest corporate managers to "deploy, innovate, and propagate" IT in order to make a competitive leap against the rivals. Following investments in IT, managers should think of ways to innovate their processes and/or products with IT. They further need to propagate and replicate the new practices and policies throughout their company through proper organizational change efforts in order to attain competitive edge. These steps allow them to escape from the trap of IT as only a commodity factor of production: "…costs of doing business that must be paid by all but provide distinction to none." (Carr, 2003: 6).

The final chapter of the thesis concludes the research, provides a number of managerial and policy implications, and recommends avenues for future research.

References

Barua, A., C. H. Kriebel and T. Mukhopadhyay (1995). Information Technologies and Business Value- an Analytic and Empirical Investigation. *Information Systems Research* 6: 3-23.

Bresnahan, T.F., E. Brynjolfsson and L.M. Hitt (2002). Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence. *The Quarterly Journal of Economics* 117: 339-376.

Bresnahan, T.F. and M. Trajtenberg (1995). General Purpose Technologies: Engines of Growth. *Journal of Econometrics* 65(1): 83-108.

Brynjolfsson, E. (1993). The productivity paradox of information technology. *Communications of the ACM* 36(12): 66–77.

Brynjolfsson, E. and L.M. Hitt (2000). Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives* 4: 23-48.

Brynjolfsson, E. and A. Saunders (2010). Wired for Innovation: How Information Technology is Reshaping the Economy. MIT Press, Cambridge, MA.

Carr, N.G. (2003). IT Doesn't Matter. *Harvard Business Review* 81: 5-12.

Carr, N.G. (2004). Does IT Matter? Information Technology and the Corrosion of Competitive Advantage. Harvard Business School Press, Boston, MA.

Chesbrough, H.W. (2003). Open Innovation: The new imperative for creating and profiting from technology. Harvard Business School Press, Boston, MA.

Chesbrough, H.W., W. Vanhaverbeke and J. West (2006). *Open Innovation: Researching a New Paradigm*, Oxford University Press, New York, NY.

David, P.A. (1990). The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox. *American Economic Review* 80(2): 355-61.

David, P. A. and G. Wright (2003). General Purpose Technologies and Productivity Surges: Historical Reflections on the Future of the ICT Revolution. in *The Economic Future in Historical Perspective,* P. David and M. Thomas (eds.), Oxford Press, New York, NY.

Gates, B. (2005). The PC Era Is Just Beginning. *BusinessWeek* March 22.

Hong, K.K. and Y. G. Kim (2002). The critical success factors for ERP implementation: an organizational fit perspective. *Information & Management* 40: 25–40.

McAfee, A. and E. Brynjolfsson (2008). Investing in the IT That Makes a Competitive Difference. *Harvard Business Review* 86(7/8): 98-107.

Melville, N., K. Kraemer and V. Gurbaxani (2004). Review: Information technology and organizational performance: An integrative model of IT business value. *MIS Quarterly* 28: 283-322.

Milgrom, P. and J. Roberts (1995). Complementarities and fit: Strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics* 19(2,3): 179-208.

Mukhopadhyay, T. and R.B. Cooper (1993). A Microeconomic Production Assessment of the Business Value of Management Information Systems: The Case of Inventory Control. *Journal of Management Information Systems* 10: 33-55.

Roberts, J. (2004). The Modern Firm: Organizational Design for Performance and Growth. Oxford University Press, New York, NY.

Solow, R. (1987). We'd better watch out. *New York Times Book Review* (July 12): 36.

WSJ (2010). *Wall Street Journal 2009 Innovation Awards*. accessible at: http://s.wsj.net/public/resources/documents/Innovation-Awards-Winners.pdf

Important thing in science is not so much to obtain new facts as to discover new ways of thinking about them. -- *William Bragg*

THE ROLE-BASED TYPOLOGY OF INFORMATION TECHNOLOGY: MODEL DEVELOPMENT AND ASSESSMENT*

Abstract. Recent calls in the literature highlight an essential quest for researchers to open up the black box of IT by identifying and explaining how and why IT creates business value for the firm. Equally important, it is a big challenge for corporate and IT managers to recognize their required IT-based capabilities and select the appropriate IT systems from the abundance of technologies and applications available in the market to enable or enhance those capabilities. The existing tools and models in the literature bear a number of shortcomings such as context-specificity, incomprehensiveness and lack of theoretical foundation. To address these limitations, this paper attempts to synthesize the operational and strategic perspectives of analysis and integrates them into a descriptive typology of IT roles. On the basis of these roles, the core features and functions of the firm's IT resources can be analyzed and linked to its business objectives. The proposed typological framework serves academic

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scholars as a basis for theory development and discussion on why and how specific IT assets and competencies lead to certain organizational outcomes. Furthermore, it assists managers in assessing the maturity level of their organization in utilizing information technology as well as in designing the appropriate roadmap to escalate this level. Hence, the model is useful for IT portfolio management. The suggested typology draws on two management theories, Organizational Information Processing Theory and Resource-Based View. In order to empirically support the construction of the typology and to evaluate its adequacy, validity and applicability, in-depth problem-centered, qualitative interviews in two rounds were conducted with a panel of 54 senior IT managers and consultants. The expert opinions indicated that the framework is simple, comprehensible, pragmatic, comprehensive, and practical. The paper discusses the theoretical and practical implications of the model and recommends areas for future research.

Keywords: IT Roles, Classification Typology, IT Business Value, Organizational Information Processing Theory, Resource Based View

1. Introduction

Information Technology Business Value (ITBV) lays at the core of the Information Systems (IS) discipline (Agarwal and Lucas, 2005). Demonstrating the value of investing in IT has become fundamental to the field since studies were published that documented diminishing importance of IT managers (Martin, 2007) or devastating failures in IT projects leading to organizational bankruptcy (Davenport, 1998; Keil, 1995). Most of the studies so far take a holistic approach and treat the process leading to value creation from IT investments as a "black box" (e.g. Brynjolfsson and Hitt, 2003; Ko and Osei-Bryson, 2004; Sircar and Choi, 2009; Sircar et al., 2000). Even when implementation of IT does not fail, its contribution to competitive advantage of the firm has been questioned (Carr, 2003; 2004). Kohli and Grover (2008) recently challenged the current trajectory of IS research and suggested a discontinuity in thinking how IT value creation should be studied in order to address existing doubts and concerns. We consider their research guidelines seriously as "if IT is not valuable, then we [IS scholars] are engaging in research on something that is not valuable, and hence *we are not valuable*!" (Kohli and Grover, 2008: 24).

The present paper attempts to develop and test a typology of IT roles in organizations. IT roles relate to basic mechanisms and functionalities through which information systems enable or facilitate a firm to buildup operational or strategic capabilities that can be transformed into business value. Kohli and Grover (2008) emphasize that it is not enough to show whether or not IT creates value but it is more important to demonstrate *how*, *when* and *why* it does. By identifying and analyzing the organizational roles of IT, we aim to address the "how" and, to some extent, the "why" question. The central question of the present research is: "what are the primary roles of information systems and how do they lead to value creation in organizations?"

Existing typologies of IT are incomprehensive, context-specific and/or lacking solid grounds in the (management) theory of the firm. Moreover, they take either an operational or a strategic perspective towards analyzing and/or classifying the IT-based capabilities of the firm. The typology proposed in this paper synthesizes the operational and strategic levels of analysis into a single framework. In order to integrate the operational and strategic perspectives into one model, two key attributes are used to characterize and classify IT roles. First, *information processing capacity* characterizes the ability of information systems to process and assimilate data and generate rich information and new knowledge at an operational level. Second, *organizational change intensity* indicates the strategic value of information systems with respect to the magnitude of organizational change(s) they cause or enforce. These two attributes are essential determinants of organizational performance based on the *Organizational Information Processing Theory* (Galbraith, 1974) and the *Resource Based View of the Firm* (Barney, 1991), which constitute the theoretical foundations of the typology.

A three-stage qualitative research design (Miles and Huberman, 1994; Myers, 2009; Silverman, 2000) was followed for constructing the typology. In the first stage, the attribute space of the typology is conceptualized based on a literature review of existing process-oriented models of IT and followed up by confirmatory interviews with experts. In the second stage, a classification system is developed and different types of IT roles are characterized based on existing theory. In the third stage, the proposed framework is validated through external audits with a panel of experts. The study identifies and defines six types of IT roles, categorized in three general classes: 1st-order roles (*Information* and *Communication*), 2nd-order roles (*Automation* and *Coordination*), and 3rd- order roles (*Integration* and *Transformation*). Evaluation of the framework corroborates that the participating experts find it simple, comprehensible, pragmatic, and useful in practice. The typological framework was especially considered valuable for (1) analyzing the process of IT business value creation through linking IT assets to emergent capabilities they can create or enhance and (2) (re)structuring the mind of corporate managers to explore and examine their IT needs and to make informed investment decisions to meet those needs.

The paper is structured as follows. The next section motivates the research by identifying a number of related gaps in the literature and explaining why and how a new typology is a valuable contribution to fill the gap. Section 3 explains the research methodology. Section 4 reviews the literature on IT value creation and IT categorization models in order to spot weaknesses of the existing typologies. The first round of confirmatory interviews with experts is discussed in section 5. The theoretical foundations of the model are explained in section 6. In section 7, different types of IT roles are defined and characterized based on the theory. A descriptive typology to classify IT roles and to link them to business objectives of the firm is suggested in section 8. The results of qualitative interviews with senior IT managers and consultants are reported and analyzed in section 9. This second round of evaluative interviews is used to validate the proposed framework. Finally, conclusions and implications for future research are presented.

2. Why and How Are IT Typologies Useful?

Most of studies in the ITBV research restrict their analysis to IT impacts on end-product measures of business performance at the overall level of organization. This imposes limitations on understanding of *why* and *how* IT actually affects firm performance. In response, many researchers have called for more in-depth understanding by opening the black box of ITBV through process-oriented, multistage studies of IT value creation. These can highlight the specific intermediary channels and mechanisms through which firms use IT to support their core capabilities and their strategic moves (Barua et al., 1995; Kohli and Grover, 2008; Mukhopadhyay and Cooper, 1993; Rivard et al., 2006; Tanriverdi, 2005). Recent attempts in response to these calls introduce theoretical frameworks and empirical models that aim at opening the box of ITBV. They try to do this by explaining the mechanisms and stages through which IT assets become effective and hence influence the performance and/or competitive position of the firm (e.g. Cao, 2010; Melville et al., 2004; Ravichandran and Lertwongsatien, 2005; Wade and Hulland, 2004).

Most recently, Kohli and Grover (2008) identity a number of gaps in the literature. They put forward four central themes and accordingly formulate specific thrusts that need to be incorporated in future IS research. One of their suggested themes is what they call IT-Embeddedness. It has been a long tradition among ITBV researchers to start their analysis from IT investments, link them to organizational capabilities and intermediate impacts, and finally end with firm performance effects (e.g. Melville et al. 2004). Kohli and Grover (2008), however, argue that research should first begin with asking about specific (digital) business capabilities that the firm requires for increasing its performance and bypassing the competition. The question of which IT resources are needed to build those capabilities comes next. They conceptualize this way of thinking about and studying IT as a process of "IT-izing". This refers to using IT to enable, magnify or accelerate organizational capabilities that are required to execute a business imperative. This means that IT is a catalyst for changing and leveraging organizational capital to harness business value (Radhakrishnan et al., 2008). For example, consider the customer service department of a company that is run through traditional structures and facilities. For tracking and resolving customer problems, complaints are received by company agents in a telephone-based call center, (if needed) they are assigned to experts, and later on their status is traced manually. The company can IT-ize its capability to track and resolve customer inquiries more accurately and quickly through computerizing its call center by implementing such features as computer telephone integration, intelligent call routing, automated voice response, complaints tracking software and customer relationship management. The performance result will be an increase in service quality and, consequently, higher customer satisfaction.

Yet, the research direction recommended above requires answering a set of new questions. Even if we know what business capabilities are required, we still need to understand what IT resources are appropriate or even necessary to build those capabilities and how they lead to IT-izing business processes. This includes identifying various functional processes through which firm capabilities are digitized. Kohli and Grover (2008) come up with a series of concrete recommendations to address this gap. According to them, better models and typologies are required to broaden our understanding of diverse manifestations of IT in practice and mechanisms through which capabilities accrue. Theoretical developments should identify various types of functional processes involved in the course of IT-izing firm capabilities. Frameworks are also needed to match capabilities of IT resources to those of business processes they support or empower. These developments are also important in line of previous calls to theorize the IT artifact in IS research (e.g. Orlikowski and Iacono, 2001).

In an attempt to address the issue of IT-embeddedness and IT-izing, Nevo and Wade (2010) develop a conceptual framework to establish how ITBV is created and sustained. By synthesizing the resource-based view and systems theory, they try to expose part of the content of the IT-izing process. Central to their framework, IT-enabled resources and their emergent capabilities are the IT-ized business capabilities that Kohli and Grover (2008) refer to. For instance, consider the R&D and product design teams of a company which are globally dispersed. Without proper IT-based multimedia applications, the capability of the project teams to communicate and make decisions, coordinate related tasks and reach project objectives is very limited and sometimes ineffective. Once a group or collaborative support system with such features as videoconferencing, task and document tracking software, electronic meeting functionality, group work support and project management tools is implemented, new capabilities emerge. Team members can now more effectively communicate with each other, better follow project plans, and organize real-time meetings without respect to geographical distances and temporal differences among themselves. With global projects of the company run more smoothly and coherently, the emergent capability of virtual interconnectedness leads to significant performance improvements over time.

However, Nevo and Wade (2010) only explain the general process through which IT assets can be used to adapt and modify organizational resources without exploring explicit paths through which this process takes place. They emphasize on compatibility between IT and organizational resources as a necessary assumption to realize emergent and synergistic capabilities. But, they do not explore the underlying conditions for this kind of resource compatibility. We argue that a clearer understanding of the primary features and functionalities of different IT resources is required before we can assess their compatibility with organizational resources. Compatibility is in fact realized when features and functionalities of the specific IT resource(s) that is (are) used to IT-ize an organizational resource fit, or are aligned with, those business features and functionalities that are needed to create emergent capabilities and improve performance of the firm. It is only under these compatibility conditions that the potential value of IT can be practically realized.

This study introduces a *descriptive typology* of IT roles. Typologies, taxonomies, classification systems, and categorization models are effective in shedding light inside the black box of ITBV.[1] In general, typologies are those generic classification schemes that are *multidimensional* and *conceptual* (Baily, 1994; Marradi, 1990). In particular, a descriptive typology defines and characterizes different types (or compound concepts) of a phenomenon or entity on the basis of an attribute space (or property domain). The attribute space includes the primary characteristics of the typology and their dimensions that are used for division and description of different types. These characteristics are important for studying the phenomenon under study and provide a good level of differentiation to distinguish different types from each other (i.e. *internal homogeneity* on the level of each type vs. *external heterogeneity* on the level of the typology). As an example, Hofstede's (2001) typology of cultures is a descriptive typology that characterizes and classifies different (national and organizational) cultures based on multiple dimensions. Hofstede's attribute space is constituted by

[1] The IS literature is not always clear about the differences among these concepts and frequently uses them interchangeably.

five core attributes (i.e. power distance, individualism, masculinity, uncertainty avoidance, and long-term orientation). Descriptive typologies are common and versatile in social sciences as they (Baily, 1994; Marradi, 1990): (1) reduce complexity and lead to parsimony, (2) identify similarities and differences, (3) assist researchers to compare types and study relationships, and (4) assist researchers to develop and/or validate theories.

We argue that IT roles link IT assets to organizational capabilities in the process of IT-izing or digitizing those capabilities. As to the scientific literature, the paper sheds light on the process of IT-izing in firms and spells out the underlying mechanisms through which organizational capabilities are indeed IT-ized. As to the management practice, it provides explanations for *how* and *why* certain IT applications influence certain business capabilities and performance measures of the firm and thereby supports IT and corporate leaders in assessing and managing their IT investment portfolio. Managers can use this typological framework to match their required capabilities with the features and functionalities of diverse IT resources they have access to and choose appropriate IT systems (that best suit their requirements) from abundant options available to them in the market. This is crucial because if a manager cannot identify how and where IT is contributing to value creation, (s)he cannot measure its impacts; unless (s)he can measure the impacts, (s)he cannot manage its effective use.

3. Research Method

Following a common approach in qualitative research, we design the research in three stages (Miles and Huberman, 1994; Myers, 2009 Silverman, 2000).

1. Selection of key attributes and development of the attribute space

In the first stage of the research, we need to identify key attributes that form the dimensions of the typology to be developed. The objective is in fact to identify those basic characteristics of IT that can best support us to understand, study and evaluate different roles of IT in the organization. Therefore, we initially review the existing body of the literature on process-oriented models of ITBV, with a focus on IT-based typologies (see section 4 for this literature review). However, since we aim to construct the typology such that it can also serve as a practical management tool, we combine and extend theoretical knowledge with empirical investigation. This is done through a series of qualitative, confirmatory interviews with senior IT experts (see section 5 for the interview results).

2. Construction of the typology and theoretical characterization of types

In the second stage, construction of the entire attribute space is done by cross tabulating the typological dimensions, which allows for characterization of different types according to their properties. Existing management theories are used to conceptualize the dimensions of the typology (see section 6 on theorizing the dimensions). Following this conceptualization, different IT roles are identified, defined and characterized (see section 7 for a discussion on IT roles). We then develop the typology, introduce a hierarchy of IT roles on that basis, and position the typology in relation to other elements of the ITBV process (see section 8 for details of the proposed typology).

3. Empirical evaluation of the typology and assessment of its usability

The third stage concerns qualitative validation of the typology and assessing its practicality. This is done through a number of evaluative interviews with IT experts. Through these interviews, characteristics of the typology are verified against the standard criteria for evaluation of typologies. Furthermore, the interviews can be used as a testbed to operationalize and document IT roles: can IT systems be considered as a proper proxy for IT roles? Section 9 reports the interview results of this stage.

4. Process Models and Typologies of IT Business Value

Among existing typologies and taxonomies of ITBV, earliest models are typically technically-based, employ machine-technology conceptualizations of IT and ignore adoption issues and business impacts entirety (see Fry, 1982 for a review of the relevant literature). Earlier non-technical typologies are usually too generic to distinguish potential uses of various types of information technology (Malone and Crowston, 1994). Capability-based models of ITBV are a response to this gap in the literature. Among this group of models, the existing classifications adopt either an *operational* or a *strategic* perspective towards analyzing corporate IT. Operational models define IT capabilities at a lower level of organization, according to functionalities or attributes of individual IT applications with respect to how they support the operational routines of the company. This level of analysis is vulnerable to fragmentation issues as the integrated, strategic value of IT might be ignored (Sambamurthy et al., 2003; Tallon et al., 2000). As a result, operational typologies typically fail to explicitly recognize and value the strategic objectives of IT (as a collection of organizational assets and competencies). Strategic models define IT capabilities at a higher level, according to strategic values of IT in an integral form, and try to explain how they support specific business goals and lead to competitive advantage. This level is vulnerable to aggregation issues as IT effects might be best observable at or near the site where the technology is actually being used (Barua et al., 1995; Mukhopadhyay and Cooper, 1993). As a result, strategic typologies typically fail to identify and observe concrete, measurable impacts of IT at different functional levels of the organization.

Below, we review existing typologies and classification schemes of IT and ITBV process in order to achieve two goals. First, we need to gain theoretical knowledge on the attributes that are important for the analysis of ITBV process and can serve as the key categorization variables in the dimensionalization phase of typology construction (where the attribute space is formed). Second, this literature review allows us to identify the common shortcomings of the available models.

4.1. Operational typologies and classification systems of IT and ITBV

From an operational perspective, four groups of IT typologies can be recognized: (1) context- or domain-specific models, (2) task-oriented models, (3) business process-oriented models, and (4) structural or functional models.

As to domain-specific models, one of the simplest classifications is based on the application domain of IT: internal vs. external (Turban et al., 2009). Another abstract classification is based on IT use in different parts of the supply chain (Turban et al., 2009): Internal IT (e.g. ERP), Upstream IT (e.g. e-Procurement), and Downstream IT (e.g. CRM).This model relies on the concept of supply chain and therefore is not practical in other contexts of IT use (for instance, in operations, administration, or R&D). As to another context-specific framework, Davenport and Short (1990) propose one of the earliest classifications of IT. Their model focuses on IT application for process redesign by suggesting nine capabilities: transactional, geographical, automational, analytical, informational, sequential, knowledge management, tracking, and disintermediation. Bardhan et al. (2007) suggest another context-specific classification based on the concept of project management. Basic communication technologies (BCT), such as email, internet search engines and mobile communication are used for simple tasks. Groupware and collaboration technologies (GCT), like instant messaging software, videoconferencing, VoIP and groupware applications are flexible for unstructured and volatile project works. Enterprise software technologies (EST), for example document/knowledge management systems, project management tools and CRM, are used for well-structured projects that are characterized by formal guidelines and standard operating procedures. Among other context-specific typologies, Nambisan (2003) studies IT application for new product development and suggests four primary areas where IT can have a contribution: information/knowledge management, collaboration/communication enhancement, process management, and project management.

Among more context-free, general-purpose (or wide-scope) classifications of IT, a group of models takes a rather system-or task-oriented approach. Mulligan (2002) identifies three principal levels of IT capability and categorizes IT systems accordingly. Information management systems focus on the execution of specific production tasks. Network coordination systems combine multiple tasks or task outputs in support of a common business function. Enterprise management systems are used for knowledge and workflow management; they may incorporate elements of task execution and communication. McAfee (2006) proposes a similar capability-based classification of IT systems, based on different classes of management interventions they demand. The first class is function IT (e.g. CAD systems, simulators and spreadsheets), which assists the execution of discrete tasks. Second, network IT (e.g. email, instant messaging, wikis and weblogs) facilitates interactions without specifying any specific parameters. Third, enterprise IT (e.g. ERP, CRM and SCM) specifies business processes at the corporate level. Due to their task-oriented nature, these two models are not very well suited for disentangling the basic functions of information technology in general organizational settings (without considering specific task characteristics).

There are also classifications that focus on IT support to business processes. Traditionally, information systems were classified into transaction processing systems (TPS), management information systems (MIS), and decision support systems (DSS) (Ward et al., 2002). Straub and Wetherbe (1989) also proposed a very early model in the field based on the essence of the contribution of IT applications to different types of firm processes. They identify three primary groups: human interface technologies (e.g. executive information systems), communications technologies (e.g. EDI, E-mail), and system support technologies (e.g. computer-aided systems engineering tools, databases). Likewise, Sabherwal and Chan (2001) define four information system types. In their view, operational support systems monitor and control the day-to-day operations of the company. Market information systems focus on the company's markets and product sales. Strategic decision support systems support the decision-making and planning processes of the firm. Finally, interorganizational systems establish and manage inter-company relationships with business partners. They further link these system types to three IS types: IS for efficiency, IS for flexibility, and IS for comprehensiveness.

IT systems can also be classified with respect to their relation with the organizational structure of the firm. Turban et al. (2004) categorize organizational IS systems based on the functional area(s) they provide service to: accounting and finance, production and operations management, marketing and sales, and human resource management. Laudon and Laudon (2009) define three levels of IS implementation: departmental, enterprise and interorganizational.

4.2. Strategic typologies and classification systems of IT and ITBV

From a strategic perspective, there exist IT typologies that analyze IT-based capabilities at a high level of business organization and describe them based on their strategic value for the firm. Overall, four groups of studies can be distinguished: (1) studies that take a design perspective and explicate how IT can be used for organizational design, (2) studies that take a resource-based perspective and link IT capabilities to firm performance, (3) studies that take a management perspective by focusing on IT investment objectives, and (4) studies that take a transformation perspective by focusing on competitive implications of IT.

Earlier studies take a design perspective and recognize how IT can be used for business and organizational design. Keen (1991) identifies four primary areas where IT can be supportive to business design: competitive positioning, geographic positioning, organizational redesign, and human capital redeployment. Similarly, Sambamurthy and Zmud (2000) propose a platform where six key IT capabilities related to organizational design are articulated: value innovation, knowledge work leverage, IT-enabled business platform, operational excellence, value chain extension, and solutions delivery.

Another group of classifications adopt a resource-based view to link IT capabilities to financial performance and competitive advantage of the firm. Bharadwaj (2000) distinguishes three key IT resources. IT infrastructure includes physical IT components such as computers and telecommunication technologies, shared technical platforms, and databases that form the core of a firm's IT assets. Human IT (technical and managerial skills) includes training, learning, experience, relationships and insights of a firm's employees with respect to implementation and deployment of IT. IT-enabled intangibles are tacit, idiosyncratic, and deeply embedded in the organization's social structure and comprise of customer orientation, knowledge assets, and synergies among IT and organizational resources. In a similar approach, Bhatt and Grover (2005) divide IT capabilities of the firm into: IT infrastructure, IT business experience (e.g. alignment between IT and business strategy), and relationship infrastructure (e.g. partnership between IT and business groups). Contrary to previous models, these two classifications have a theoretical base (i.e. RBV) and provide more generalizable insights for studying corporate IT in practice. However, these classifications do not break down IT capabilities of the firm into the underlying mechanisms that link technology investments to process-level effects.

A group of IT classification models take a different perspective by focusing on IT investment objectives from a manager's perspective. Tallon et al. (2000) classify corporate goals for IT investments into four classes. Operations-focus includes specific goals aimed at cost reduction, improving quality/speed and enhancing overall firm effectiveness. Market-focus constitutes of goals that are meant for extending market/geographic reach of the firm and changing industry/market practices. Unfocused and dual-focus investments are made based on none or a combination of the above two aspects respectively. Weill (1992) defines three distinct management objectives for IT investments. First, transactional IT processes the firm's transactions and is usually used to cut costs by substituting capital for labor. An example is the automation of payroll, accounts receivable and order entry. Second, strategic IT comprises of new applications for the industry at the time of implementation and is typically meant for expansion rather than efficiency improvement. This type of IT enables the firm to better meet market demand, to spawn new businesses, or as an industry platform to restructure the industry. The electronic ordering and booking systems of American Hospital Supply and American Airlines at the time of introduction to the health and aviation industry respectively can serve as good examples of strategic IT. Informational IT, as the third type, constitutes the backbone of the information management of the firm and includes IT infrastructure as well as budgeting, production planning, communication, and accounting tools. In a similar study, Mooney et al. (1996) introduce a model of IT impacts on firm processes. They identify three types of IT effects. First, automational effect refers to the value created through efficiency advantages, productivity improvements, labor savings, and cost reductions when IT substitutes for labor. Second, informational effect emerges from the ability of IT to collect, store, process, and disseminate information, which leads to improved decision quality, employee empowerment, decreased use of resources, enhanced organizational effectiveness, and better quality of products/services. Third, transformational effect reflects the capability of IT to support process innovation and restructuring, which results in reduced cycle times, improved responsiveness, and downsizing.[2] The above models are valuable as they provide insights into specific paths through which IT affects business processes and organizational outcomes of the firm. Yet, they can be more comprehensive in identifying the basic functions of IT in the organization. They also lack a solid theoretical foundation, based on which IT assets of the firm to be categorized.

There are also a few models that explicitly treat IT as a strategic resource with certain transformation implications and competitive benefits for the firm. Focusing on the specific context of organizational transformation, Venkatraman (1994) presents a framework to categorize IT-enabled business transformation into five levels: localized exploitation, internal integration, business process redesign, business network redesign, and business scope redefinition. Sambamurthy et al. (2003) define IT as a digital options generator with four possibilities: (1) IT systems can digitize business processes to improve their reach (e.g. ERP, SCM, CRM), (2) IT systems can digitize business processes to improve their richness (e.g. DSS, expert systems), (3) IT systems can digitize knowledge assets to improve their reach (e.g. intranets, databases), and (4) IT systems can digitize knowledge assets to improve their richness (e.g. KMS, video-conferencing and collaborative tools). Wade and Hulland (2004) categorize the IT resource of the firm into three classes: outside-in IS resources including external relationship management and market responsiveness, spanning IS resources including IS-business partnerships and IS planning/change management, and inside-out IS resources including IT infrastructure, technical skills and IS development/operations. They further show how each of these IS resource types can contribute to (i.e. create or sustain) competitive advantage of the firm.

[2] This can be very much related to the 3-stage framework of Remenyi et al. (1994) which identifies three general uses for IT: automation (efficiency), information (effectiveness), and transformation (flexibility).

Table 1: Operational and Strategic Typologies of IT

Typological Criteria	Literature Source	Classes/Components of the Model
Operational Typologies		
IT Application in Project Management	Bardhan et al. (2007)	• Basic communication technologies • Groupware and collaboration technologies • Enterprise software technologies
IT Application for Process Redesign	Davenport & Short (1990)	• Transactional • Geographical • Automational • Analytical • Informational • Sequential • Knowledge management • Tracking • Disintermediation
IT with Regard to Organizational Structure of the Firm	Laudon & Laudon (2009)	• Departmental information systems • Enterprise information systems • Interorganizational information systems
Required Operational Management Interventions for Using IT	McAfee (2006)	• Function IT • Network IT • Enterprise IT
IT in Relation to Organizational Task Characteristics	Mulligan (2002)	• Information management systems • Network coordination systems • Enterprise management systems
IT Use for New Product Development	Nambisan (2003)	• Process management • Project management • Information/knowledge management • Collaboration/communication enhancement
IT Support to Business Processes of the Firm	Sabherwal & Chan (2001)	• Operational support systems • Market information systems • Strategic decision support systems • Interorganizational systems
Nature of IT Contribution to Organizational Processes	Straub & Wetherbe (1989)	• Human interface technologies • Communications technologies • System support technologies
IT Application in Supply Chain	Turban et al. (2009)	• Internal IT • Upstream IT • Downstream IT
Functional Area of IT Adoption	Turban et al. (2004)	• Accounting and finance • Production and operations

		management • Marketing and sales • Human resource management
Type of IT Service Provided to the Organization	Ward et al. (2002)	• Transaction processing systems • Management information systems • Decision support systems
Strategic Typologies		
Tangibility and Value of IT Resources	Bharadwaj (2000)	• IT infrastructure • Human IT • IT-enabled intangibles
Strategic Attributes of IT Resources	Bhatt & Grover (2005)	• IT infrastructure • IT business experience • Relationship infrastructure
IT Support to Business Design	Keen (1991)	• Competitive positioning • Geographic positioning • Organizational redesign • Human capital redeployment
IT Impacts on Business Processes	Mooney et al. (1996)	• Automational effects • Informational effects • Transformational effects
Organizational Use of IT	Remenyi et al. (1994)	• Automation • Information • Transformation
Digital Options of IT for the Firm	Sambamurthy et al. (2003)	• Digitized process reach • Digitized process richness • Digitized knowledge reach • Digitized knowledge richness
Organization of IT for Business Value Creation	Sambamurthy & Zmud (2000)	• Value innovation • Knowledge work leverage • IT-enabled business platform • Operational excellence • Value chain extension • Solutions delivery
Corporate Goals for IT Investments	Tallon et al. (2000)	• Operations focus • Market focus • Dual focus • Unfocused
Enabling Support of IT to Business Transformation	Venkatraman (1994)	• Localized exploitation • Internal integration • Business process redesign • Business network redesign • Business scope redefinition
Focus of Capability-based Effects of IT	Wade & Hulland (2004)	• Outside-in IT • Inside-out IT • Spanning IT
Management Objectives for IT Investments	Weill (1992)	• Transactional IT • Strategic IT • Informational IT

Table 1 summarizes the results of the literature study in this section. The review allowed us to recognize important, basic attributes that can form the basis of the typology. With the help of these attributes, similarities and differences among different types of IT systems (and their organizational roles) can be adequately grasped and thus they can be categorized. These attributes relate to either operational or strategic functions and/or impacts of IT at the level of organization (i.e. intra-organizational). Some of these attributes are intrinsic to IT systems themselves (such as the level of complexity of the system) while others become apparent as a result of interactions between IT and other organizational elements (such as the level of training required for using the system).

The review also reveals that the existing models bear at least one of the following five shortcomings: (1) the model either adopts an operational or a strategic perspective to study IT and/or its value creation process and hence provides an incomplete account of the ITBV phenomenon; (2) the model is context-specific, i.e. it focuses on the application of IT in a specific discipline or organizational/task context and thereby cannot serve as a wide-scope management tool in diverse settings; (3) the model is incomprehensive, i.e. it is not complete in recognizing all the different intermediate mechanisms thorough which IT leads to business capabilities and creates value for the firm; (4) the model classifies IT resources without explicitly linking them to business objectives or organizational performance of the firm and thereby is not practical for ITBV assessment; and/or (5) the model lacks well-founded roots in management theories of the firm.

5. Confirmatory Interviews with Senior IT Experts

As a common approach in IS qualitative research (cf. Strauss, 1987), we confronted the results of our literature review with thoughts and opinions of experts. This empirical investigation makes it more plausible that the suggested typology is empirically grounded and hence is useful in practice.

5.1. Problem-centered interviews

From different qualitative research methodologies, semi-structured problem-centered interview (SS PCI) with a panel of experts was chosen as the appropriate method. This is a commonly-used method for empirical investigation and content validity among IS scholars (Emory and Cooper, 1991; Silverman, 1997; 1998). To construct our panel of experts, we initially compiled a list of 78 senior IT managers and consultants. The list was drawn from university and colleague contacts with companies and individuals. Two primary criteria were used for selecting the panelists. First, each expert should have had at least five years of relevant work experience in managing and/or consulting large IT projects. Second, s/he should have been employed by a medium or large organization with at least 50 full-time employees. Seniority of the interviewees was a primary concern, as senior practitioners tend to have a broader experience with various IT projects/systems and deeper knowledge of the business value they deliver (in diverse sectoral contexts). We opted for larger firms, as small firms have a rather limited internal IT and external client portfolio and hence could not provide us with the broad overview and deep insight we aimed for. For initial screening, the portfolio/resume of the IT managers/consultants was obtained through internet search or contact persons in their companies and was strictly verified against the above two criteria. Out of 78 experts, 61 were proved to be eligible for further contacts. Preliminary telephone calls were used to introduce the researchers, content of the research and objectives of the interview. Standard guidelines as suggested by Czaja and Blair (2005) were followed to increase the response rate. The experts were assured about confidentiality and anonymity of their inputs and were promised to receive final results of the research. Thanks to informal/personal contacts of our university colleagues to most of the contacted experts, we finally managed to have interview agreements with 54 experts (i.e. a response rate of 89%). The remaining 7 experts declared no interest or time availability to conduct the interview within the time frame of our interest.

The sample of 54 experts was then divided randomly into two equal parts. The members of the first sub-sample were interviewed in the first stage of the research in order to confirm the key categorization variables used to construct the typology (i.e. dimensionalization phase). The experts in the second sub-sample were interviewed later in the third stage in order to appraise the typology (i.e. validation phase). Individual meetings were scheduled with each of the experts at their workplace. The interviews were conducted in person. Members of the full panel represented the following sectors: chemical/pharmaceutical, steel and automobile manufacturing, computer and business services, construction, energy and public supplies, financial intermediaries, telecom, logistics and transportation tourism, and healthcare. The average relevant experience of the full sample is 11.2 years. Table 2 shows the composition of the samples in the first and third stages of the research.

Table 2: Interviewed Experts by their Job Title and Country (1st/3rd Stage)

Job Title* / Country**	BE	FR	DE	LU	NL	CH	Total
CEO, CIO or CTO	1/0	0/0	1/0	0/0	2/4	0/0	8
VP Innovation or Technology Development	0/1	0/0	0/1	0/0	3/1	0/0	6
IS Director or Senior IT Manager	0/1	0/1	0/0	0/0	2/3	0/0	7
IT (Project) Manager	0/0	0/1	0/0	1/0	3/3	0/1	9
Consulting Partner	0/0	1/0	0/0	0/0	3/2	0/0	6
Senior Consultant	0/1	0/0	1/0	0/0	2/4	1/0	9
IT Consultant	0/0	1/0	1/0	1/0	3/3	0/0	9
Total	4	4	4	2	38	2	54
Total = 54 informants (1st stage = 27, 3rd stage = 27)							

*CEO= Chief Executive Officer, CIO= Chief Information/Innovation Officer, CTO= Chief Technology Officer, VP= Vice President

** Country Codes: Belgium (BE), France (FR), Germany (DE), Luxemburg (LU), the Netherlands (NL), Switzerland (CH)

Interviews in both stages are problem-centered (i.e. centered around a given issue). To improve performance, suggested guidelines in Lindlof and Taylor (2002) and Myers and Newman (2007) were followed. As to PCIs, the interview process in each case was not obstructed or bounded by a predefined set of concrete questions in the form of a fully structured Q&A (Question and Answer) scheme. Instead, open-ended questions were mainly asked, sometimes in an ad hoc manner, to give enough room to the interviewee to explore and examine different aspects and dimensions of the central issue under question. Yet, a moderate level of structure was maintained. To facilitate starting a conversation in early stages of the interview, a short questionnaire had been prepared prior to each interview (partly adapted to the function and position of the interviewee). The interviews had also a general, pre-formulated guideline to ensure comparability of interviews. This protocol in fact provided a framework of orientation for interviews and supported the interviewer's memory on important issues that shall be covered. Additional observations were noted immediately after each interview was concluded. All the interviews were tape recorded and fully transcribed afterwards.

Each interview in the first stage lasted between 50 to 80 minutes. Following the opening and introductory conversation, we engaged in a broadly-formulated dialogue with the interviewee:

> *Tell us about different IT projects you've led or consulted in the past two to three years. What specific IT systems or applications were involved? Can you specify some examples? What was/were specific about those applications? What business objectives were at stake? Based on your experience, how would you distinguish different IT implementations in terms of their inherent attributes (such as the level of complexity or sophistication of the installed systems) or in terms of interactions with organizational entities (such as the level of required training or knowledge for adopting those systems)? How would you distinguish different IT implementations in terms of their operational and strategic impacts on the adopting organization or in terms of the process leading to creation of these impacts?*

During the story-telling process of the interview, we also asked the participants on their thoughts and opinions about different attributes and characteristics that a priori had been compiled on the basis of the literature review:

> *What do you think about [this attribute]?Based on your experience and expertise, do you think it is an important criterion or property for differentiating or characterizing different roles played by IT in the firm? Can you give examples on how different IT systems perform different tasks or perform similar tasks differently in terms of [this attribute]? Based on your experience and expertise, is the significance of the IT functions for the organizations or their business impact dependent on this attribute? To what extent?*

In the course of the interview, at all times, the interviewee was repeatedly encouraged to take the liberty to correct his/her own statements and oppose those of the interviewer. At the end of each interview, the interviewee was confronted with a specific question:

> *Suppose that you would like to construct a classification scheme or categorization model of different roles played by IT in organizations. These roles imply different basic functions and mechanisms through which IT affects operations and/or strategies of the firm. They also cover both the enabling and facilitating effects of IT. What key attributes or properties would you choose as the primary dimensions of your classification system, based on which to compare and categorize different IT roles? What led you to this specific choice*

of attributes? Can you specifically explain to me how you arrived at this decision?

After all the interviews were transcribed and their individual content was extended with corresponding notes and memos that were taken during each interview, we started the analysis. Each case (i.e. interview transcript) was carefully parsed to mark relevant keywords. These keywords implied attributes or criterions that, in the eyes of the interviewee, seemed important or determining in differentiating and/or characterizing different IT implementations (i.e. systems, applications, or projects). Following this segmenting process, the keywords derived from the transcripts were grouped into a few thematic aspects, each of which referred to similar properties with a common root. Finally, these thematic aspects were assessed in terms of their frequency of appearance and degree of consistency in each interview individually as well as in all interviews collectively. The analysis led us to confirm two attributes that were among the theoretically important attributes, appeared the most in the interviews, and were referred to in single interviews consistently: *information processing capacity* and *organizational change intensity*.

5.2. Interview results

In the first stage, 25 out of 27 of informants considered the capacity of information systems to collect data, analyze information and generate knowledge as one of the most prominent characteristics of IT systems when their roles in organizations are at stake. In the words of one CIO in a multinational chemical enterprise:

> *These days, information and analytics are the key to success. Organizations are bombarded with tremendous amount of information from different segments of the market, current and potential customers, their suppliers, research labs, scientific discoveries, university findings, new initiatives of their competitors, from the public, press, media, internet, seminars, conferences, and so many other sources. The challenge for organizations is how to deal with this amount of information….Successful organizations are those who know how to handle information properly and quickly turn it into advantage for themselves against the competition. Of course, they [organizations] need to be able to make sense of information and process it to their advantage. And here comes the role of IT and analytics as the most powerful enablers of what I call "information revolution".*

A senior IT manager reflected on his 14 years of experience:

I think the most important role of ICT is to process information and generate new knowledge out of it. Never before were we able to transform information so neatly and timely into intelligence for our businesses. This is now possible, thanks to marvelous job of computers!

An IT consultant involved in the design and implementation of IT-based enterprise systems in the past 8 years recalled:

Nowadays, you can see many companies computerize or automate different parts of their organization. They all have access to more or less the same systems, materials and blueprints in the market. What distinguishes them from each other, once these systems are installed in place, is how far they can go deep into data and extract the type of information they require for their daily operations. It's important to gather data from every corner of the company, even those corners where valuable info may be tapped into desperate minds and unnoticed systems. Then, it's up to the [IT] systems to process this data. And different systems, even when they might seem completely similar or substitutable, have totally different data mining and visualization capacities…. And our job is partly to guide companies to pick the right system with right capabilities.

According to a consulting partner involved in a telecom project at the time of the interview:

If you ask me about the most important characteristic of IT that shapes and changes the type and significance of the role it plays in companies, I would definitely point to its power to process information….You tell me! Can you compare a decision support system or a crisis control system with a simple spreadsheet software or a videoconferencing tool?...Upon successful implementations, they [the two groups of IT applications] lead to completely different effects....And that depends on how far they can process information, extract complex patterns out of data and support managers in making critical decisions.

The second dimension, greatly highlighted by the informants, was the scope and intensity of organizational changes initiated or provoked through implementing an IT system. Out of 27 respondents, 24 of them implicitly or explicitly referred to this attribute in their interviews. The following remarks from different individuals were typical:

….To assess the role of IT, you need to first observe how it is actually implemented in the organization and how much change it causes….you can then talk about a successful implementation.

> *For any [IT] system, it's important to know if the organization is ready to use it; if intended people are actually using it; if processes, routines and norms have been appropriately altered; if corporate culture has been adapted; and so many more [if conditions]….All these necessary changes make the implementation and management of IT projects a great hurdle but they also increase the strategic value of the system so as to obscure it….such that it [the IT implementation] cannot be anymore observed, copied or imitated by your competitors, at least not easily….you're safe then to enjoy its benefits for a long time.*
>
> *….IT changes the way people work and communicate. Different systems change the structure and policy of the firm to different degrees, some in a fundamental way while others in an incremental way…. and this is the most essential factor I can think of when you ask me to differentiate different types of [IT] systems from each other.*
>
> *Based on years of experience in IT and business services [sectors], I believe in IT-induced change. That's what I call it the "magic of IT" and that's what you're looking for or at least should look for to build your [classification] model.*

A VP (Vice President) innovation and technology development from a manufacturing company explained the importance of organizational change as:

> *Yeah, I would say change; that is indeed innovation in and of itself! Every ICT application brings with itself a degree of change to the company. Without those changes neither is the system fully utilized, nor are its potentials realized. Think of, for example, our new CAD/CAE [computer-aided design and engineering] systems. We installed them last year but we're still busy until now to train our employees, reconfigure our R&D methods, adjust our business model, optimize our ordering processes, etc….But we're sure that, at the end, these systems will streamline our operations and will give us a head start next year. We can already hear those rumors in the industry about our system and our future!...On the other hand, think of our new digital conference tool or collaboration software that we just purchased and introduced in the beginning of this year. They are already, after only five months, in full use, such that we've already thought about upgrading or replacing them with more powerful systems! Of course, these applications are great but didn't make our rivals envy or angry as we didn't hear any story about them [these IT applications]!*

Similarly, a senior IT consultant reflected on one of her recent projects in the energy sector and the many meetings she had with the board members:

….we discussed it in length, over and over, and we came to the conclusion that we need to go for the big change. This is because systems that change a significant part of the organization, in radical and even sometimes unplanned ways, are the only ones that can make a significant difference and provide the [client] company with an edge. Lower degrees of change means a rapid replication by others and therefore a waste of money. It's a simple rule; believe me! The bigger the change, the higher the value….They [the client company's board members]wanted the big change, and we helped them to make it happen….I can assure you that their ERP system is now one of the most sophisticated ones in the industry.

6. Theories Used to Conceptualize Typology Dimensions

We aimed to construct our typology based on management theories of the firm, so it can also be used by theoretical studies that seek for theory development. Hence, we reviewed the existing theories used in IS research to recognize theories that could best serve our purpose (of conceptualizing the typology's dimensions). Several theoretical perspectives have been used in the literature to examine the business value of IT. Examples include the microeconomic theory of production (Becchetti et al., 2003; Brynjolfsson and Hitt, 2003), transaction cost economics (Garicano and Kaplan, 2001; Zaheer and Venkatraman, 1994), resource-based view of the firm (Bharadwaj, 2000; Mata et al., 1995; Melville et al., 2004; Wade and Hulland, 2004), knowledge-based theory (Srivardhana and Pawlowski, 2007), dynamic capabilities (Sambamurthy et al., 2003), and organizational information processing theory (Gattiker and Goodhue, 2004; 2005).

For development of the IT typology, we draw on two theories: Organizational Information Processing Theory (OIPT) and Resource Based View (RBV). These theories provide guidelines for designing organizational structures in order to achieve superior performance. Both of these theories can be used to explain how companies yield performance improvements by using information technology. Yet, OIPT looks at this issue primarily from an operational perceptive while RBV takes a strategic view. The decision to adopt these two specific theories relies on the following reasons.[3] First,

[3] As indicated by previous seminal studies (e.g. Gattiker & Goodhue, 2005; Melville et al., 2004), both of these two theories have been proven to be useful in examining the IT resource of the firm.

these theories have the firm as their unit of analysis. Our typology is also meant to characterize IT roles at the level of the firm. Second, they analyze firm resources and their attributes from two distinct perspectives (i.e. operational and strategic). Our typology also intends to synthesize and integrate these two perspectives into one combinative model. Third, these theories explicate a clear link between resource attributes and performance of the firm. Our typology is intended to link IT assets to business capabilities and objectives as well. Fourth, in these theories, the two attributes that constitute the foundations of our typology are essential determinants (and predictors) of organizational performance. This is crucial for conceptualization of the attribute space.

6.1. Operational perspective: Organizational Information Processing Theory

The Organizational Information Processing Theory (OIPT) (Galbraith, 1974; Tushman and Nadler, 1978) conceives information as the most critical success factor for organizations to face contingencies and achieve performance. From an OIPT perspective, organizations are designed around information, information sources/flows, and information processing capabilities to reduce uncertainty. Uncertainty reflects the lack of (enough) information on the current or future status of the internal tasks or the environment surrounding the organization (Galbraith, 1977). Uncertainty arises from, among others, the organizational tasks contingency, instability of the external environment, fluctuation of service demand, and interdependencies and differentiations among internal and external subunits of the firm. In essence, OIPT considers the link between information as a key organizational resource and managing its usage as the most critical performance factor of the organization. OIPT argues that organizations must adopt at least one of the following four information processing designs to improve performance. Two of these information processing designs reduce the need for information processing: *managing the environment* and *creating self-contained tasks*. The other two information processing designs are meant to create mechanisms that increase the organization's capacity to process information: *investing in information systems* and *creating lateral relations*. OIPT posits that an organization is doomed to accept a lower performance, unless it adopts at least one of the above operational designs.

As one of the primary elements of organizational design, information technology enables or facilitates gathering, generation and storage of data, transformation of data into useful information, and communication and integration of organizational knowledge. From an OIPT perspective, information processing ability of IT plays the central role here; a higher degree of information processing means accessibility to information of a higher quality, richness and timeliness that can be translated to organizational intelligence and performance through better decisions and operations (Daft and Lengel, 1986; Fairbank et al., 2006; Huber, 1990). According to Davenport (2006: 9), "Every day, advances in [information] technology and [analytics] techniques give companies a better and better handle on the critical minutiae of their operations." We conclude from the premise of OIPT that the extent of information processing capacity that a certain IT system offers the firm can determine the extent that system supports the firm to reduce uncertainty and increase operational performance. In other words, *information processing capacity* can serve as a proper attribute to link IT capability to organizational performance. Different types of information technologies would have differential effects on firm performance depending on the degree of information processing they accommodate (and accordingly their position along the "information processing" dimension of our typology).

6.2. Strategic perspective: Resource-Based View

The Resource-Based View (RBV) of the firm argues that firms possess heterogeneous resources, a subset of which enables them to achieve superior performance (Barney, 1991; Grant, 1991; Wernerfelt, 1984). For firm resources to confer superior performance (and accordingly, competitive advantage), they should be (Barney, 1991):[4] (1) valuable, i.e. supporting the firm to achieve its (strategic) objectives, (2) rare, i.e. accessible to only a limited number of firms, (3) (imperfectly) inimitable, non-substitutable, and non-transferable, i.e. imposing substantial cost and/or time disadvantages for competitors to imitate, and (4) (structurally) well-organized and embedded into the organization for proper exploitation.

Appling RBV to the field of IT business value, the extent to which an IT system can be considered as a source of superior performance depends on the extent it possesses the above attributes (especially the third and the fourth one as sources of sustainability of competitive advantage). Earlier RBV studies tend to focus on the unique value of IT as a scarce resource, while more recent studies attribute IT payoff to co-presence or co-development of (IT and non-IT) organizational resources (Barua and Mukhopadhyay, 2000; Davern and Kaufman, 2000; Hitt and Brynjolfsson, 1997). For instance, Clemons

[4] Known as *VRIO Framework* in the literature.

and Row (1991) refer to an important characteristic of IT as its ability to change organizational resources and their value. IT does this through facilitating the appropriation and leverage of other resources, increasing their potential value, managing their interactions and integrations, and complementing diverse economic activities of the firm. Clemons and Row (1991) provide insights into linking this characteristic of IT to shifts in organizational performance. Other authors highlight the role of organizational complementarities, historical changes, casual ambiguity, supplementary resources, path dependency, socially complex links, organizational embeddedness, and time compression diseconomies as important drivers of inimitability and non-substitutability of IT capabilities (Bharadwaj, 2000; Dehning and Stratopoulos, 2003; Mata et al, 1995).

Central to RBV is the notion of resource heterogeneity and firm idiosyncrasy. Organizational change (whether or not IT-enabled) is one of the main reasons behind heterogeneity and idiosyncrasy of firm resources. According to Orlikowski and Iacono (2001), firms adopt information technologies that are not homogenous and undifferentiated entities, rather they are malleable and differ in their intrinsic characteristics, their ability to complement other organizational resources, and the degree of organizational change that needs to occur when they are implemented. Similarly, Fichman (2000) indicates that information technologies differ with respect to how difficult they are implemented, assimilated, and become available for effective utilization by the firm. O'Hara et al. (1999) also refer to a similar notion by differentiating IT systems with regard to the extent to which the firm's processes need to evolve in order to adapt to the requirements of the new technology and optimize its performance payoffs. The important role of organizational changes, complementarities and co-investments/innovations, such as business processes reengineering, workflow redesign, inter-organizational relationships, and cross-functional integration in creating and/or sustaining the performance effects of IT has been emphasized in a number of other studies as well (e.g. Brynjolfsson and Hitt, 2000; Devaraj and Kohli, 2000; Powell and Dent-Micallef, 1997; Ross et el., 1996).

As a common element in the RBV studies of IT business value, we conclude that *organizational change intensity* of an IT resource is a fundamental attribute to determine the extent of its performance and competitive implications. Those IT systems that entail fundamental organizational changes, require significant organizational complementarities, and/or result in substantial organizational embeddedness are more complicated, incur significantly more costs, require more time to be implemented, learned and adapted, and impose more critical risks to the organization. However, once implemented and deployed properly, these systems provide much stronger barriers to imitation and substitution, create more value, and infer much stronger performance and competitive advantages for the firm. In other words, IT-enabled organizational change generates response lags and barriers to erosion that impede or prevent dissipation of IT-induced business advantages (Piccoli and Ives, 2005). This means that different types of IT systems would have different performance effects (partly) depending on the level of organizational change they bring with themselves into the firm (and accordingly their position along the "organizational change" dimension of our typology).

7. Organizational Roles of Information Technology

We define the concept of "IT Roles" as the primary mechanisms and core functions through which information technology enhances and/or enables the capability of the firm to (1) execute its working operations, (2) introduce new operations, (3) achieve its strategic goals, and/or (4) formulate new strategies. IT roles disentangle the connection between IT resources and business processes of the firm, indicate the essential functionalities of IT, and explicate how IT investment contributes to firm performance. We distinguish six types of IT roles: 1) Information, 2) Communication, 3) Automation, 4) Coordination, 5) Integration, and 6) Transformation. In identifying and characterizing various roles of IT, special attention is given to the two basic criteria of information systems that are considered important based on our theoretical and empirical investigations. As noted earlier, these criteria are the extent of information processing an IT system performs (from an operational perspective) and the extent of organizational change it enacts (from a strategic perspective). Below different types of IT roles are defined, described and exemplified. A summary of the characteristics and examples of IT roles is given in Appendix A.

1. Information Role of IT

The information role of IT is defined as the ability of IT to generate, gather, and store data in a reusable, organized, and secure manner. The existing literature accounts for this role of IT and its performance effects (e.g. Davenport and Short, 1990; Laudon and Laudon, 2009; Mooney et al., 1996; Remenyi et al., 1994; Sambamurthy and Zmud, 2000; Weill, 1992).[5] An office scanner generates data by digitizing a paper document into a computer file. Point-of-Sale (POS) scanners are used to collect data in chain stores. Databases and data warehouses are then used to store and organize this data in a more meaningful, structured and accessible manner. The information role of IT is accomplished by simple operations such as sorting, categorizing and summarizing data and improves the search and retrieval processes. In addition to accessibility and reusability, security and reliability of data are also of great importance. Data needs to be protected from leakage, corruption and damage. Antivirus and encryption software and firewalls, for example, are used for this purpose to ensure the integrity of data. Overall, the information role of IT neither involves high levels of data processing nor fundamentally changes the way an organization is structured or operates.

2. Communication Role of IT

The communication role of IT is defined as the ability of IT to promptly transmit and disseminate data and information among distant individuals, teams and organizations. The literature points to this particular role of information technology in many aspects (e.g. Andersen, 2001; Bardhan et al., 2007; Bouwman et al., 2005; Lai, 2001; Sproull and Kiesler, 1991; Straub and Wetherbe, 1989). Email is used to exchange data. RFID tags are used to transmit data on the physical location (and other attributes) of the product, to which they are attached, to the interested parties (such as the courier service providers). Videoconferencing tools are used to share voice and image data among the group participants. Corporate intranet, simple groupware software, electronic boardroom, web-based call center, interactive whiteboard, and Group Support System (GSS) are other examples of digital tools that primarily focus on the communication role of IT. Similar to the information role, the communication role of IT by itself neither involves high levels of data processing nor fundamentally changes the way the organization functions.

3. Automation Role of IT

The automation role of IT is defined as the ability of IT to standardize, mechanize and computerize operational activities and decision making processes of the firm by

[5] A detailed review of IT roles, with a separate treatment of each particular literature source, is not presented in this paper due to space constraints. This background document is available upon request.

eliminating or minimizing manual interventions. In fact, automation reflects the use of technology to replace labor. Labor substitution then results in efficiency gains through productivity improvements and cost savings. The automation role of information technology and its impact on firm performance have been frequently highlighted in the literature (e.g. Davenport and Short, 1990; Fiedler et al., 1994; Laudon and Laudon, 2009; Mooney et al., 1996; Remenyi et al., 1994; Vonderembse et al., 1997). CAD systems automate the design processes and robots mechanize the manufacturing processes and assembly lines of the firm. Expert systems and Decision Support Systems (DSS) facilitate decision-making processes of the firm. Other examples include accounting software, office automation, and Transaction Processing Systems (TPS). The application of IT as an automating tool includes high levels of computation and information processing in the form of monitoring, programming, controlling, and commanding. Yet, it does not result in fundamental changes in the concept of organizational entities or the nature of business processes. Operational tasks, workflows and production processes, which mainly used to be handled manually by employees, are now operated and controlled by computers, but, in essence, they remain more or less the same.[6] In other words, automation systems do not typically change the manner in which tasks are accomplished from a logic of work perspective.

4. Coordination Role of IT

The coordination role of IT is defined as the ability of IT to organize, co-plan and synchronize activities and parties, in a synchronous or asynchronous fashion. Existing literature supports this particular role of information technology (e.g. Argyres, 1999; Bouwman et al., 2005; Bardhan et al., 2007; Mulligan, 2002; Nambisan, 2003; Sanders, 2008). Electronic inventory management systems of wholesalers coordinate their ordering processes with their sales. Participatory Project Management (PPM) tools coordinate different parties involved in a project. Electronic document review systems synchronize and coordinate editing and reviewing of corporate documents by different organizational units. Supply Chain Management (SCM) systems coordinate activities of different parties along the value chain in order to optimize supply chain

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[6] "IT was primarily used to automate existing operations and to increase the speed of communication. Automation within organizational functions meant that routine information collection and storage tasks were taken over by IT, replacing paper and people with electrons, without fundamentally changing the way work was done." (Zammuto et al., 2007).

performance. Coordination, like automation, entails high levels of information processing necessary to link diverse actors (and their varied objectives) to each other and to attain cooperative action. As to the degree of organizational change, this IT role enables different organizational entities to separately exist and function (as they are used to), while they just share the necessary information for the purpose of co-planning of decisions and actions in order to reach a common goal.

5. Integration Role of IT

The integration role of IT is defined as the ability of IT to combine, assimilate, and fundamentally reorganize the existing processes and domains of the firm into new, unified processes and domains. IT-enabled integration has been accredited in the scholarly literature from different perspectives (e.g. Alsene, 1999; Gunasekaran, 2004; Mulligan, 2002; Sambamurthy and Zmud, 2000; Song and Song, 2010; Vollmer and Peyret, 2006). As examples, Enterprise Resource Planning (ERP) integrates the procurement, production and sales functions of the company into a single, centrally-controlled system. Similarly, Knowledge Management Systems (KMS) integrate different knowledge sources within an organization to create a unified knowledge repository for employees. Integration occurs when information technology is used to couple multiple processes and/or domains in a tight and intertwined manner such that fundamental (structural) changes enact, new entities form, and old entities are not anymore (readily) recognizable. Needless to say, the process of integration involves high levels of data manipulation and information processing.

6. Transformation Role of IT

The transformation role of IT is defined as the ability of IT to develop completely new production strategies, sales and marketing methods/channels, organizational structures, and business models, which leads to reconfiguration and transition of the organization as a whole to new forms. IT-enabled organizational transformation has been the subject of a number of academic studies (e.g. Brynjolfsson and Hitt, 2000; Dutton et al., 2005; Hitt and Brynjolfsson, 1997; Mooney et al., 1996; Remenyi et al., 1994; Teo et al., 1997, Venkatraman, 1994). This IT role manifests itself in the form of among others, fundamentally restructuring/redesigning of the organization (e.g. flattening of hierarchies and delegation of management responsibilities in decentralized organizations), re-engineering business processes (e.g. introduction of lean manufacturing, build-to-order (BTO) production or just-in-time (JIT) strategy, implementation of Six Sigma, or engagement in e-commerce), and developing completely new products (e.g. software, digital media/content or online services). In the above examples, IT revolutionizes the way an organization is structured, operated and/or managed and, in fact, transforms it to a (totally) new form.

8. A Typology of IT Roles

Based on the theoretical arguments and external audits presented earlier, we now develop a typology of IT roles. We then explain the hierarchical relationship among IT roles, and finally incorporate and discuss the model in the context of IT value creation process of the firm.

8.1. Categorization of IT roles

The intensity of information processing an IT system carries out and organizational changes it causes provide a solid basis for mapping the capability of the system to its performance implications. Operationally, the processing intensity reflects the richness and significance of the accessible information and accordingly the potential value of this information to create business value for the organization. Strategically, the change intensity reveals the reach of the IT effects throughout the organization. The higher the intensity of organizational changes (resulting from an IT implementation), the more diffused and embedded the IT effects are in the organization, the more difficult it is to replicate them in another organization, and the stronger the response-lag driver[7] are (and therefore the more sustainable the strategic value of IT is). Figure 1 categorizes IT roles (introduced in the previous section) along these two theoretical criteria.

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[7] Response-lag drivers are structural determinants and characteristics of the firm and its technological endowment that contribute to raise and strengthen barriers to erosion and thus delay or deny imitation by competitors or new industry entrants (Piccoli & Ives, 2005).

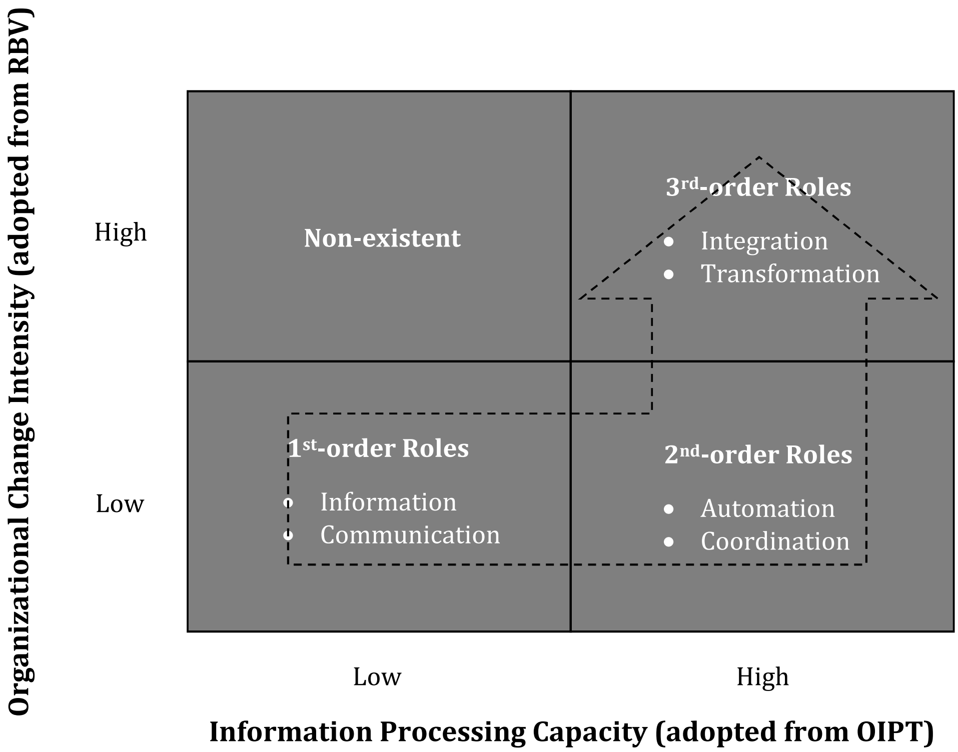

Figure 1: Typology of IT Roles

First-order roles reflect the very basic, still essential, capability of information technology. This class includes *information* and *communication* roles of IT.[8] First-order roles provide the necessary foundation for higher-order roles, by providing basic capabilities such as data generation/digitization, data storage/retrieval, data security/protection, and data transmission/dissemination. The level of processing of data and information through these roles is relatively low as they typically accommodate simple operations. Similarly, they neither require nor result in substantial changes in organizational processes and entities. Consequently, their

[8] Accordingly, ICT (Information and Communication Technology) might be a more illustrative term than IT to capture these two basic roles.

performance effects do not provide the organization with substantial advantage and significant leap against the competition. IT projects at this level are normally easy to understand and plan and rarely result in unanticipated or disruptive consequences. The very ubiquitous and easy-to-exploit nature of the first-order roles makes them almost commodity factors of production, which are essential for all businesses to survive but provide distinction to none (Carr, 2003; 2004). Electronic mail, databases and intranet, for example, are nowadays present in almost any corporation (of almost any size); doing business without them seems to be, if not impossible, unbelievably cumbersome. Yet, can an organization argue that it has achieved superior performance advantage over its rivals simply by using email or having databases or an intranet?

Second-order roles enhance the capability of IT provided by the first-order roles through providing high-level processing and management of information. This processing can take various, usually complex, computational forms such as control algorithms, numerical calculations, and data mining. This class of IT roles includes *automation* and *coordination* roles. Although the intensity of information processing is high, second-order roles do not result in fundamental structural changes of the organizational elements. Manually operated and/or coordinated tasks and processes are now computerized, while the involved organizational entities and processual workflows continue to exist. The performance effect and business value of second-order roles are greater than those of their first-order counterparts, due to availability of new, processed and rich data as well as resulting (operational) efficiency gains. In this regard, OIPT predicts that information about the current or future status of the internal tasks or the external environment significantly contributes to success and performance of the organization.

Second-order roles of IT, especially when they are combined with intangible, strategic resources (such as market power or brand recognition), historical events (such as first-mover advantages), or social processes (such as special relationships with customers/suppliers) can even push the firm significantly ahead of the competition (at least temporarily). To name a few instances, the automation of reservation processes of American Airlines and coordination of sales activities of American Hospital Supply with its buying hospitals through introducing new IT systems (i.e. SABRE and ASAP systems respectively), complemented by specific organizational practices/capabilities, provided the two companies with considerable revenue growth and competitive advantage for a long time.[9]

Finally, third-order roles provide the highest level of sophistication and reconfiguration to an organization. Including *integration* and *transformation* roles, this category creates/integrates knowledge, assimilates different departments of the firm, combines different units of the firm with those of its partners, creates new organizational entities and/or fundamentally alters the market relations, management structure, business model and/or strategic positioning of the firm. Third-order roles are the most difficult, costly and complex capabilities of IT to develop (or acquire). The social integration, organizational embeddedness and complex interrelation of IT systems, delivering third-order capabilities, with other organizational resources make their imitation or substitution extremely difficult and time-consuming, if not impossible. For exactly the same reasons, third-order IT applications are very risky with respect to their performance effects and require careful planning and management. IT projects associated with third-order roles are very difficult to manage as people are affected, tasks are modified and organizational policy, structure an culture are all transformed due to technology implementation. Not all organizations manage to exhibit third-order roles of IT as they do not dare to take the risk of adopting these IT systems and their resulting organizational changes or fail to implement and institutionalize these systems effectively; yet, those, which successfully do, can a priori be expected to achieve superior performance and competitive advantage.

As RBV predicts, IT resources that underpin more significant and intertwined changes in the organization are more likely to act as strong impediments against imitation and sustained sources of competitive advantage. For instance, IT has revolutionized the way Dell does business. Introduction of the JIT and BTO strategies, along with an extensive use of online services (to bypass sales intermediaries) and computer-aided manufacturing (CAM) systems has enabled the company to stand up the competition and boost its sales dramatically in the past years. Without a strategic and smart use of IT, this whole organizational transformation would be totally impossible. Wal-Mart is another example, where IT (such as sophisticated inventory and supply chain

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[9] For other examples, see Jackson (1985) and Smith & Fingar (2003).

management systems) has enabled the firm to bypass the rivals in the very competitive retail market of the US and achieve tremendous efficiency gains, by integrating and streamlining various departments and functions inside the company with each other as well as with those of the company's many suppliers. Without a revolutionary, still effective, use of IT, Wal-Mart would have never been a role model in the industry.

The classification scheme in Figure 1 includes four quadrants and a dashed arrow. The fourth quadrant does not exist. It is intuitively unlikely that an IT resource exists which creates fundamental changes in the status quo of the organization without performing high-level processing and computation. For significant IT-enabled organizational changes (leading to sustained competitive advantage) to happen, enormous quantity of information needs to be gathered and processed, different knowledge sources to be integrated, new knowledge to be created, and many decision making, planning, and control processes to be handled by IT. As to another element of the model, the dashed arrow denotes the evolutionary roadmap of value creation through IT. In other words, the arrow reflects the development path of an IT-implementing enterprise seeking for higher benefits and business value through more advanced IT investments. The path starts at the first-order roles and goes through the second-order roles until it reaches the third-order roles. If the first steps towards achieving radical performance improvements are to support the daily operations of the company as is, to enhance the essential information and communication capacities, and to automate the existing routines and processes, the ultimate step should be obliterating and abandoning old ways of working and creating and reengineering entirely new ones (Hammer, 1990). It is also necessary to note that the four-fold matrix in Figure 1 is a two-by-two representation where only "high" and "low" values are observable. In reality, though, both the horizontal and vertical axes are continuums of values ranging from very low to very high. For instance, in the current scheme, 2nd-order roles occupy similar position to 1st-order roles in terms of their organizational change intensity; they are both categorized as "low". However, 2nd-order roles actually possess higher change intensities than 1st-order roles on average (while both categories can be considered low with respect to 3rd-order roles).

8.2. Hierarchy of IT Roles

As shown in Figure 2, the roles of information technology create a hierarchy where each class of roles is built upon and includes the support of its preceding class. The hierarchy means that, for instance, automation is not feasible before relevant data about the task or process (to be automated) is generated (e.g. through measurement sensors) or gathered from relevant sources (e.g. through data transmitters). Likewise, coordination of groups, activities and domains is not achievable without communication of their conditions and objectives. Transformation of an organization through IT is also not viable without substantially automating relevant processes and coordinating different domains of the business.

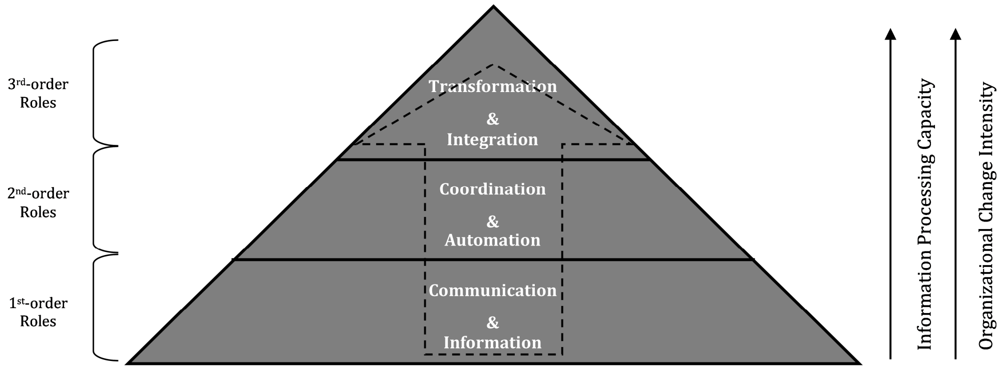

Figure 2: Hierarchy of IT Roles

IT systems of various kind focus on one or multiple roles, depending on the type of capability and contribution they deliver. An electronic mail system is primarily used for communication (and very simple coordination) purposes, while a CAD system automates design processes and an ERP system aims at integrating different departments of the firm. Accordingly, organizations can function at different layers of the pyramid, depending on how far they have climbed the hierarchy to exploit different capabilities of their information technology investments. As we climb the hierarchy, the level of system complexity and technical sophistication increases. As a result, the level of information processing that the system is capable of handling intensifies. In other words, systems (and accordingly, organizations) of higher orders in the hierarchy work with, process and produce a greater amount of information than their lower ranked counterparts. Due to increased complexity and sophistication, applications of higher ranks require more time and other organizational co-investments for full implementation. Put it differently, exploitation of these applications is harder and more costly and thus not all organizations can reach the top levels of the hierarchy (due to resource constraints and strategic choices).

As a simple comparison, suppose company A aims at installing a local intranet or internal LAN to increase connectivity and communication among its (groups of) employees. Company B aims at implementing a SCM system to coordinate (and ultimately integrate) its logistics and supply chain activities with those of its suppliers. The amount of time and money required for implementing and further adjusting/customizing a SCM system is far more than those required for installing and configuring an intranet or LAN. Besides, organization B needs to undergo much more complicated and extensive structural changes and process adaptations, compared to organization A, before the optimum value of its IT investment can be realized. However, upon full implementation of the system and acquiring competency to use it effectively, organization B can enjoy higher levels of benefits in terms of outperforming and distinction from its competitors, compared to company A. The dashed arrow in Figure 2 reflects this evolution path of IT-adopting organizations from basic uses of IT towards more sophistication and business value. Put it in a maturity context, an enterprise which, for example, transforms its business model with the use of online services is more mature in exploiting IT-based capabilities, compared to an enterprise that simply uses IT for basic information and communication purposes.

The content and nature of data is another important aspect that evolves along the hierarchy. Figure 3 shows this content evolution. In the lower levels of the hierarchy (i.e. first-order roles), raw data is generated/gathered, stored and communicated. The low level of information processing does not significantly change the nature of data, although plain processes such as (re)coding, indexing, sorting, and simple processing are applied, which give meaning to the raw data and transform it to useful information (ready for further processing). Upper roles involve high levels of information processing. Information is analyzed and combined to create new information and knowledge that is suitable for decision making, monitoring and planning purposes. Finally, in the highest levels of the hierarchy (i.e. 3rd-order roles), information and knowledge from various sources are gathered, integrated and further processed, leading to new (and more sophisticated) knowledge and eventually to business intelligence (BI).[10]

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[10] See Gilad & Gilad (1985) for examples on how a firm can convert raw data to business intelligence in real-life practice.

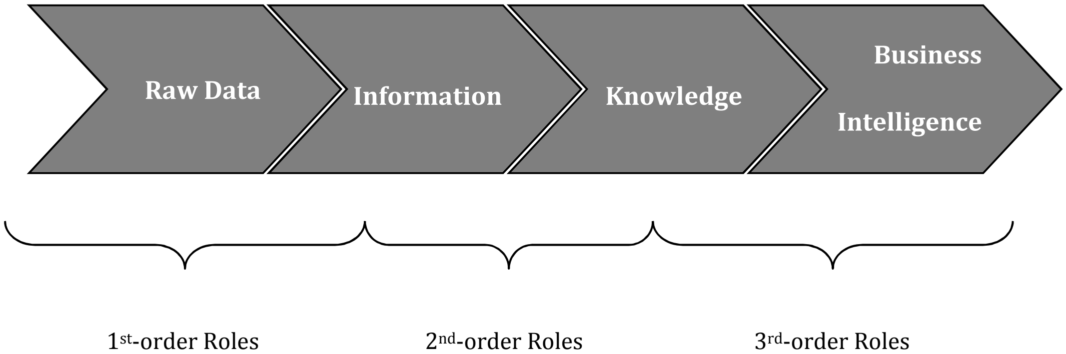

Figure 3: Content Evolution along the Hierarchy of IT Roles

8.3. The value creation process of IT roles

In section 8.1, a theoretical model was introduced to categorize various capabilities of IT while in section 8.2 a hierarchal setting for ordering these capabilities was proposed. The next phase for completing the intended framework is to explicate the position and relationship of the identified IT roles with respect to other elements of the IT business value process. Figure 4 shows a generic process of IT value creation incorporating IT roles.

Investments in information technology per se do not lead to organizational performance. To create value from an IT investment, like other investment types, intended users need to learn how to use the technology, get used to it, and receive the necessary supports and incentives before they can effectively adopt the technology and commit themselves to using it. In other words, the first phase after investing in information technology is to gain and/or enhance the competency to use the technology productively. In this respect, the literature highlights a number of important *facilitating conditions* or *competency factors* such as employee training (e.g. Gallivan et al., 2005; Marler et al., 2006) and management/technical support (e.g. Trauth and Cole, 1992; Venkatesh et al., 2003).

When the implemented IT system is accepted, used for its intended purposes and integrated into the adopting organization, the technology reveals diverse capabilities, depending on its primary function(s) and core task(s) in the enterprise. As discussed earlier, an IT system can exhibit (a combination of) six different roles. IT can change the way a company generates, gathers and stores information as well as the way it communicates information internally or externally. IT can further alter the way a company conducts business processes, makes decisions and coordinates internal and external activities/interactions. Finally, IT can be used to integrate separate domains and transform the whole organization into a new form. In this regard, IT roles are the manifestation of IT capabilities in practice and the link between IT investments and performance effects.

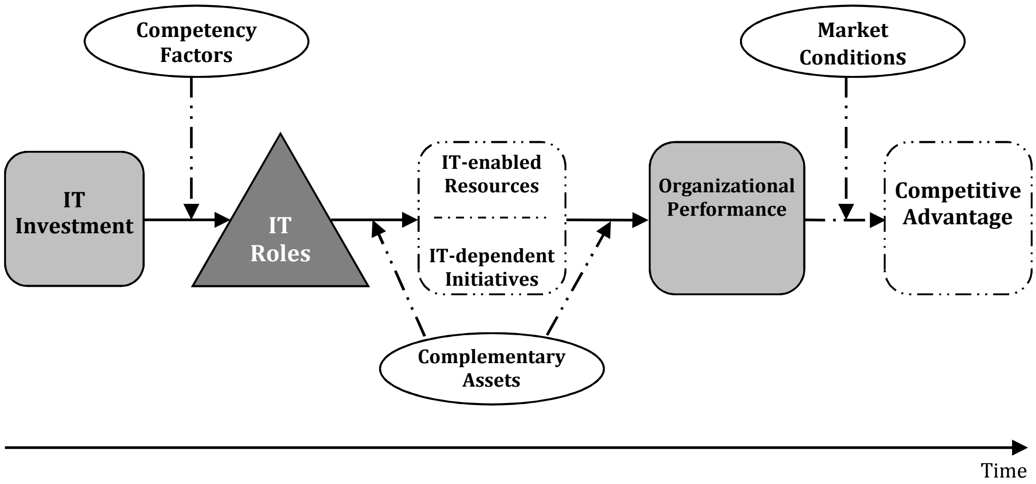

Figure 4: IT Value Creation Process and IT Roles

IT roles in combination with organizational complementary resources create value. The value is generally created and observed in the form of intermediate (or process-level) effects (Barua et al. 1995; Brynjolfsson and Hitt 2000; Melville et al. 2004; Tanriverdi, 2005). These intermediate effects are further translated to organization-wide effects. The literature suggests numerous intermediate organizational variables through which IT affects firm performance, such as organizational infrastructures (including quality leadership, employee empowerment, decentralization, team–based working, process management capabilities and business process reengineering) (Albadvi et al. 2007), intra- and inter-organizational collaboration (Bouwman et al., 2005; Venkatraman, 1994), operational efficiency (Becchetti et al., 2003; Thatcher and Oliver, 2001), and innovation (Adamides and Karacapilidis, 2006; Tarafdar and Gordon, 2007). To give an example, there are various mechanisms through which IT affects the innovative capacity of the enterprise. The information and integration roles of IT extend the knowledge base of the company by gathering, integrating and creating new knowledge. IT also reduces the cost of information search and knowledge sharing, which are influential for the problem solving and decision making processes of innovation. The communication and coordination roles of IT expand the reach of organizational knowledge, so that relevant information is accessible to all organizational members, in good quality, right time and desired form. They also facilitate collaborative work among internal teams or with external parties. Finally, IT applications such as CAD/CAM systems automate the design and prototyping phases of innovation processes.

The above intermediate effects of IT combined with other (non-IT) organizational capabilities manifest themselves in what Nevo and Wade (2010) express as IT-enabled resources or alternatively what Piccoli and Ives (2005) refer to as IT-dependent initiatives. An IT-enabled resource is a system yielded from a proper combination of an IT asset and an organizational resource in a synergistic and integrated fashion that leads to creation of new emergent capabilities (Nevo and Wade, 2010). Examples of such capabilities include tracking customer complaints, performing tele-robotic operations, improved time management and enhanced inventory control. IT-dependent initiatives consist of competitive moves that depend on the use of IT to be enacted and are designed to lead to improvements in a firm's position (Piccoli and Ives, 2005). They consist of a system of activities (dependent on IT at their core) that fosters the creation and appropriation of economic value. Examples include electronic commerce, business integration, business process reengineering, and customer relationship management. Pioneering historical examples of IT-dependent initiatives include: SABRE (the global reservation and distribution system of American Airlines), Dell Online (the direct sales portal linked to build-to-order platform of the company), the highly efficient supply chain management system of Wal-Mart interconnected through its many suppliers, the sophisticated data warehousing and data mining technology of Harrah's Entertainment linked to its state of the art customer relationship management system, and ASAP (the automated ordering and purchasing system of American Hospital Supply). In all the above cases, these initiatives (have) helped the implementing company to strengthen its competitive edge and maintain its leadership position in its respective industry for a long time.

The intermediate effects (of different type), being in the form of an IT-enabled resource or an IT-dependent initiative, can lead to higher-order benefits in the form of organizational performance and further competitive advantage. Although the performance effects of IT are wide-ranging, they can fall into two general categories: *efficiency* (underlining the internal processes and economic aspects of the firm) and *effectiveness* (underlining the market position and competitive advantage of the firm)

(Dewett and Jones, 2001). As the final phase of the IT value creation process, superior performance needs to be converted to competitive advantage, a process that is dependent on various conditions of the market (e.g. reaction of customers to the firm's offerings), competitive environment (e.g. strategic decisions of rivals), and regulatory framework (e.g. intellectual property rights of the country) in which the firm operates (see e.g. Melville et al., 2004; Sethi and King, 1994). The influence of the external environment is considerable as firms in different contexts will evolve and create value differently after investing in IT.

As indicated in Figure 4, for IT business value to be captured in intermediate and further high-level effects, certain complementary resources and co-investments are crucial (Milgrom and Roberts, 1990; 1995). The existing literature accounts for diverse complementarities, such as workplace organization, workflow redesign, business process reengineering, inter-firm relations, and workforce skills (Bresnahan et al., 2002; Brynjolfsson and Hitt, 2000), greater use of teams, broader distribution of certain decision rights, and increased worker training (Brynjolfsson et al., 2002), and workplace practices, change initiatives, and corporate culture (Melville et al., 2004). These organizational complementarities play a very important role in creating and sustaining competitive advantage from IT investments, because they are usually: (1) idiosyncratic (i.e. firm-specific) and tightly embedded in the organizational structures and routines of the firm, (2) not directly and easily observable and imitable by competitors, and (3) dependent on various social processes and complex historical events/decisions of the firm.[11]

Finally, the time dimension in Figure 4 deserves attention. Any phase of the generalized process explained above takes some time to complete. It takes time for IT users to learn/understand the technology and become accustomed to and competent in using the new system. It also takes time for IT roles to manifest themselves. Resulting IT-based capabilities are then combined with other organizational resources to create process- and firm-level effects. Last but not least, there is some lag or adjustment time required to match organizational factors and IT investments

[11] Supported by Brynjolfsson et al. (2002), the fact that productive use of IT requires complex systems or clusters of complementarities may explain why and how successful IT-implementing firms (such as Dell, Wal-Mart and BoA) have been reaping impressive productivity gains and ongoing competitive advantages through their IT initiatives.

(Brynjolfsson and Hitt, 1998). In this regard, complementarities are associated with different adjustment speeds; some like workplace reorganization is slowly changing, while others like training and hiring practices are fast changing.

9. Model Validation via Experts' Opinion

9.1. Evaluation criteria

The process of validation depends to a large extent on the nature of the research (Emory and Cooper, 1991). In the present research, the proposed framework is the product of literature review, external audit and conceptual theorizing. As such, theory is a profound element in designing and conceptualizing the model (Walshan, 1995). For the process of validation, we should then use empirical evidence to ensure reliability and confidence in using the model in practice (Walsham, 1993). We assess the adequacy and strength of the proposed typology against the criteria proposed by Hunt (1991). According to Hunt (1991), five criteria should be used to justify whether or not a typology is adequate: (A) Is the phenomenon to be classified adequately specified? (B) Is the classification characteristic adequately specified? (C) Are the categories mutually exclusive? (D) Is the typology collectively exhaustive? (E) Is the typology useful?

A. Is the Phenomenon to be Classified Adequately Specified?

We argue that the proposed definition of IT roles is persistent and inclusive, rather than temporary or limited. The definition includes both the enabling as well as facilitating effects of IT. It also encompasses IT functions at both the operational as well as strategic levels of the organization. Therefore, as long as the mechanisms and processes of business value creation through IT at the firm level are concerned, our definition seems to provide an adequate specification of the phenomenon. As a result, the typology is supposedly able to elucidate and classify organizational roles of IT in full.

B. Is the Classification Characteristic Adequately Specified?

Whether the typological characteristics used to construct the typology are specified adequately rests on two notions. First, are the variables used to classify the phenomenon under study appropriate? Second, is the typology inter-subjectively certifiable? We conducted an extensive review of the literature that deal with modeling IT use and/or impact in organizations. This review included both existing typologies as well as process-oriented models of ITBV. We further augmented theoretical knowledge with empirical investigation. Interviews with specialists helped us to come to our final decision and identify appropriate variables to construct the typology. The answer to the second question depends on the evaluations of the typology in future (empirical) studies and observations via surveys, case-studies and interviews. We try to partly substantiate this issue with our second-round expert interviews (reported in the next section).

C. Are the Categories Mutually Exclusive?

The assessment of whether or not the typological categories are mutually exclusive is based on whether categorization variables support sufficiently distinct types of IT roles. Information processing capacity and organizational change intensity of an IT system do not necessarily depend on each other. In general, IT roles can almost always be confidently assigned to a single class. This means that the categories of IT roles presented through the typology are mutually exclusive. However, if one concerns finding proxies (for roles) by mapping IT roles to IT applications, there are cases where an IT application may exhibit more than a single role. Then, it is more difficult to assign that IT application to an individual class of IT roles. For instance, a collaborative groupware system can take the form of a simple communication tool, but, when utilized to its full capacity, it can handle coordination tasks as well. We clarified this issue earlier when we introduced the hierarchy of IT roles: systems that expose more than one role belong to the class of their higher order (i.e. more dominant) role. Our interview results reported later in the next section indicate that the above issue is not in fact severe. The incidence that an IT system strongly exhibits roles of different classes such that it cannot be confidently assigned to a single class happens only occasionally. Nevertheless, the fact that a given typology does not fully meet the standard of mutual exclusivity is not a mortal blow, as not all typologies are strictly ideal (Hunt, 1991: 188).

D. Is the Typology Collectively Exhaustive?

To validate the condition of collective exhaustiveness, every organizational role of IT should have a home in the proposed typology (Hunt, 1991: 188). This indicates that we cannot find a role that is not covered or characterized by any of our typological classes. The literature review supports this argument. The evaluation interviews, reported below, also indicate this. None of the experts we interviewed could add a new class to the typology or name/exemplify a role that cannot be placed in one of the categories of the typology. Nonetheless, the ultimate test of whether the proposed typology is collectively exhaustive or not occurs over time, when future empirical evidence supports its exhaustiveness or alternatively suggests new categories of roles.

E. Is the typology useful?

This criterion suggests that the proposed typology should compare favorably with regard to competing typologies as to reconciling issues or resolving problems. Besides, the typology should serve its intended purpose. We intensively reviewed the existing typologies in order to make sure that we know what typologies are available and what they lack. Although the concept of IT roles as articulated in this paper has not been specified or conceptualized in any study before, there are still a number of typologies or models that can be considered competing with our typology. We identified the shortcomings of the available typologies and attempted to construct ours such that: (1) it synthesizes and reconciles the two dominant perspectives and levels of analysis (i.e. operational and strategic) into one model, (2) it has a wide scope to serve multiple purposes (e.g. ITBV assessment, portfolio management, system classification, etc.) and be used in multiple contexts, (3) it is nested in management theories and hence useful for theory development studies of ITBV, and (4) its level of abstraction allows for an explicit link between IT-enabled/dependent capabilities and business objectives of the firm.

As to the second question, whether or not the typology can serve its intended users, the main motive behind our empirical investigations was to develop a typological tool that is useful for both academicians and practitioners. We decided to observe whether or not IT managers can indeed communicate with our typology and put it in practical use. We could simply rely on pure theoretical studies to identify the categorization variables and to construct the typology. However, we confronted our theoretical knowledge with thoughts and opinions of specialists in two rounds: when we aimed to construct the attribute space and when we aimed to evaluate and improve the model.

9.2. Interview results

As discussed earlier, we randomly divided our initial sample of 54 eligible experts to two equal subsamples. We interviewed the first subsample to come to a definite decision regarding the categorization variables. In the second round of interviews, we aimed to evaluate the model. Same as the previous round, semi-structured problem-centered interviews were used, although this time the interviews were rather lengthier (as we needed more time for elaboration) and more structured. The length of interviews ranged between approximately 70 and 110 minutes. Based on the pre-programmed protocol, the main objectives were threefold: [12]

1. How does an expert evaluate the proposed classification framework (including the IT categorization matrix in Figure 1 and the IT roles pyramid in Figure 2) in terms of: (1) simplicity and understandability of the model, (2) logical structure of the model, (3) completeness of the model, and (4) usability of the model?
2. How does an expert evaluate the proposed classification framework in relation to other elements of the IT value creation process (as shown in Figure 4), especially with regard to: 1) the process leading to emergent capabilities from IT roles and 2) the relationship between IT roles and diverse measures of organizational performance?
3. How does an expert conceptualize the proposed role-based hierarchy (Figure 2) and validate its operationalization by assigning IT systems of various types (as proxies for IT roles) to different levels of the pyramid?

Initially, the experts were asked to give details about their specialties, responsibilities and experiences in their present as well as previous positions/organizations. The experts were then questioned whether or not they use or have used any sort of IT classification model, in order to assess their familiarity with such tools. In case of a positive response, they were further asked to explain those model(s) and how they have been used in practice. Afterwards, the interviewed professionals were presented with the proposed framework in the form of specifically-designed vignettes and concise, yet clear-cut, descriptions that could provide them with a clear picture of the particular issues of our interest in this research. The interviewees were requested to objectively assess the validity of the framework from multiple perspectives. Specifically, they were asked whether (1) they could fully understand, observe and conceptualize the model, (2) they found the model intuitively logical and rational, (3) they found the model applicable and useful in practical matters with respect to their overall expertise and experience, (4) they could properly communicate with the model and relate it to their current/past tasks and/or projects, (5) they could explain the main

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[12] The interview protocol is not presented in the paper due to space constraints but is available upon request.

features and strengths of the model and provide relevant examples, and (6) they could explain the main shortcomings and limitations of the model and give recommendations for improvement.

Almost all of the interviewees could understand and explain different aspects and dimensions of the framework in full details without any difficulty. In some cases, real-life examples of different IT roles seemed to enhance understanding. The following remarks were typical among the respondents:

> *….this process framework can add granularity to our understanding of the critical linkages between IT investments and organizational competencies.*

> *Yeah, it seems like a simple and pragmatic model for understanding [of] the process of IT use and impact generation….although the model seems [to be] commonsense somehow, honestly, I hadn't ever thought of presenting IT roles in such a beautiful way.*

> *….the structure of the model is understandable and easy to follow….you can easily see how roles are built on each other and support one another….it's a nice way to organize your thoughts around IT and what it does for you and your organization.*

> *If this instrument is meant to classify what you articulate as IT roles, based on what I understand from IT roles, it does a pretty good job; it's simple, easy to understand and grounded in practical notions….I love the way it portrays and simplifies the complex reality!*

As a very positive point about the model, almost all the experts observed the built-in hierarchical structure of the model by conceptualizing and relating different IT roles to their related work practices in real-life projects. An IT project manager reflected on his most recent project in logistics:

> *….the higher you get in the pyramid, the more complex the applications and the greater the organizational benefits [become];at the top of the pyramid, we can find very complex and compound roles of IT while at the bottom of it [the pyramid], simple and basic roles [reside]. I can't advise you a better and clearer model to assess the impact of IT on firm performance through the possible intermediate channels….these functions might seem obvious but the model does a good job to put them beside each other and group them in a reasonable, concrete and coherent way.*

Most of the experts found the way the roles are built on each other and the logic behind it very interesting and rational. Around 89% (i.e. 24 out of 27) of the respondents found the model quite complete as they could not think of any other major IT role that has not been incorporated in the model.[13] Some of the respondents found it more appealing to have the data flow and content evolution (as depicted in Figure 3) directly incorporated into the hierarchical model. Another suggestion made by two of the interviewees would exclude the ultimate transformation role. According to a VP technology development in a pharmaceutical company:

> *Transformation is not a role of IT per se, but a very ambitious goal and complex combination of organizational change, technology and people….to me, it [transformation] is a mix of all other roles.*

With respect to efficacy and utility of the framework, more than 96% (i.e. 26 out of 27) of the respondents declared the model to be useful for identifying and examining the organizational impacts of IT. In a consulting partner's words:

> *….as far as I can see, different layers [roles] of the model are quite useful to differentiate between diverse types of IT projects and implementations with respect to their characteristics, benefits and risks for the implementing organization. These layers remind me of different types of projects we deliver to our clients….We can say that a database management project is simply a project at the information level….while an ERP project seems to be at the level of integration of the company departments and business units.*

A CTO, with 6 years of experience in the management board, described the model as:

> *….the model is especially useful in clarifying how IT generates value. The impact is driven by the roles and the value is derived from the roles. I think we even might be able to extend this model to where IT is applied across firms, such as in networks and alliances….you shouldn't limit it [the model] to only internal operations and interactions inside a single firm.*

In relation to the above issue, a senior IT consultant found the classification beneficial as:

> *….[the classification] gives structure to the complex matter of business value assessment of IT and structuring something complex is always*

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[13] Two respondents recommended *collaboration*, *optimization*, and *reconfiguration* roles to be integrated in the model. Their recommendations led us to somehow broaden our initial definitions of the roles in order to capture these concepts by the primary six roles of IT we have identified. The present definitions of IT roles encompass these notions.

advantageous….Dividing the roles of IT into different classes can make it much easier to make relevant choices and come to optimal decisions, because it helps to structure your mind and your decisions in a systematic way….I like it! I like this model because despite its simplicity it's illustrative.

To further validate applicability of the model, most of the professionals managed to confidently map their own or their clients' organization(s) to one of the levels of the hierarchy and fit the IT evolution path of their (clients') organization into the model. This means that they managed to distinguish the different capability-based phases an IT-implementing organization (whether their own or their clients' organization) has gone through. The majority (24 out of 27, i.e. about 89% of respondents) also managed to establish clear links between different IT roles and specific (intermediate and high-level) performance measures in diverse industrial settings.[14] A general director with more than 11 years of prior experience as an IT project manager in different companies recalled:

> *That's very interesting! The three companies I've worked for in the past 10 years each resembles a specific level of the hierarchy; their expectations and achievements from their IT assets were totally different. For the first one, automation of processes and labor saving was the objective; the ultimate dream was to replace all our staff, even ourselves, with robots! The second one aimed higher goals with coordination and integration goals in mind. I can very well remember those days that we were revolutionizing our factories from desperate and isolated silos to connected and synchronized plants…. My current company's target is the most ambitious [one]. We say "the sky is the limit"….we want to transform our business model, service delivery model and supply chain model all with IT….And we're now busy doing it [the transformation] very well, I think; we're reaching the sky and climbing your pyramid to the top as I see brighter days one after the other!*

As to areas for further improvement, a few of the respondents expressed difficulty when differentiating between multiple roles of some particular IT applications (such as those of a decision support or e-learning system). A middle manager in a steel manufacturing reminded:

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[14] *Efficiency improvement* and *collaboration enhancement* were the two most cited intermediate effects in the course of interviews, while *productivity increase* and *cost reduction* were the two most referred high-level effects of IT.

….the model is in general very illuminating, but sometimes the boundary between adjutant roles in a single category is not very sharp and [that] is subject to the specific definition and interpretation that is applied to the IT system in question….For example, I can mention our computerized control systems that I have difficulty in categorizing them as having automation role [of production lines] or rather coordination role [of plant schedules]or even both….yet, they [these systems] are anyway in the category of 2nd-order roles based on your model. Aren't they?

9.3. IT applications as proxies for IT roles

At the final phase of interviews, the respondents were asked to assign a list of commonly-used IT systems to different categories of roles in order to find out how well IT applications can serve as an appropriate proxy for IT roles for use in future empirical studies. As a testbed, this is the first step towards operationalization and measurement of IT roles using secondary data sources. The central question here is: in your opinion, what is the primary role that a specific IT system/application fulfills in the organization?

The responses received from the panel of experts were then compared against our a priori expected roles in order to come to a qualitative judgment. Table 3 summarizes the results.

Table 3: Experts' Opinion on the Primary Role of Diverse IT Applications

IT Application as a Proxy for IT Roles	Role(s) Assigned by the Experts Panel	% (#) of Interviewed Experts, N=26*	Expected IT Role based on Literature
Computer Aided Design (CAD)	Automation Coordination	96% (25) 4% (1)	Automation
Computer Aided Manufacturing (CAM)	Automation Coordination	92% (24) 8% (2)	Automation
Customer Relationship Management (CRM)	Coordination Information	81% (21) 19% (5)	Coordination
Decision Support System (DSS)	Automation Coordination	88% (23) 12% (3)	Automation
E-commerce Systems	Automation Transformation	85% (22) 15% (4)	Automation

E-learning Systems	Information Automation	88% (23) 12% (3)	Information
Electronic Data Interchange (EDI)	Communication Automation	81% (21) 19% (5)	Communication
Electronic Mailing Systems	Communication Coordination	96% (25) 4% (1)	Communication
Enterprise Document Management (EDM)	Information Coordination	96% (25) 4% (1)	Information
Enterprise Resource Planning (ERP)	Integration Coordination	88% (23) 12% (3)	Integration
Knowledge Management System (KMS)	Integration Information	81% (21) 19% (5)	Integration
Supply Chain Management (SCM)	Coordination Integration	85% (22) 15% (4)	Coordination

* One corporate IT manager from the pool of the twenty-seven interviewed experts in the 3rd stage of the research was not really familiar with and interested in theoretical modeling of IT value creation process. Thereby, this single observation was excluded from the analysis, as it could not provide us with useful and reliable information.

As shown in Table 3, the experts are (almost) confidently unequivocal about some of the IT systems they were asked about. EDM was almost collectively recognized by the participants as a system for efficient storage, organization and retrieval of digital documents. CAD and CAM systems were mainly believed to be used to automate the design and manufacturing processes of the firm respectively. E-mail systems were also understood as communication enhancing tools among individuals and organizations. The primary role of these systems was evident in the words of respondents:

> *Yeah, I know these [EDM] systems very well and use them almost every day. They're simple applications for data gathering and document search….they have a simple structure for organizing data and an easy-to-understand and [easy-to-]use logic behind them….*

> *….it's obvious; we use CAD/CAM systems to automate the product design and engineering processes in our manufacturing plant….The process although not fully automated yet, [has]saved us a lot in terms of labor, energy and materials saving since two years ago that we first installed them [the CAD/CAM systems].*

It's simple! Don't you know what e-mail does?! It's is a simple, yet I have to admit, a very effective tool for communications among people, groups, teams, etc. What else can it be for?!

With regard to other applications, a few of the experts recognized a different primary role than what was expected based on theory. Yet, the expected role was always identified by at least four-fifths of the respondents. In case experts came up with another role than what expected, further questioning learned that this could be attributed to differences in their definition/perception of the (level of advancement of the) system in question.

As shown in Table 3, two roles, i.e. communication and automation, have been assigned to EDI. EDI is used for communication and information exchange among business partners. If further modules are installed on top of a basic EDI system, it can also automate the ordering, billing, and invoicing procedures of the firm. A senior IT manager explained the situation as:

….normally, orders used to come in by phone; someone needed to answer the phone and enter the order into the corporate system. Nowadays, with EDI, this middleman is taken away and the process is done automatically, and thereby quicker and more accurate.

DSS has been assigned two roles as well, i.e. automation and coordination. DSS is typically used to automate or facilitate (the more routine part of) the decision making processes of the firm. More advanced systems, though, can also be used to coordinate different tasks, especially under emergency and crisis conditions. A CIO noted this case during his interview:

….in urgent situations these [DSS] systems make it easier to make complex decisions, while [they] handle simple decisions themselves….

Notably, CRM and KMS systems are two very interesting cases with the least consensus over their primary roles in accordance with the theory .In its simplest form, a CRM system can be defined as a sole database where customer records and contact histories are kept, tracked and retrieved when needed. However, in a broader sense and with respect to the standard definition of CRM systems, when implemented to their full potential (as described by a consulting partner in an international consulting firm):

….[CRM] systems can work beyond a simple database and coordinate and optimize sales and marketing activities by coupling client information to billing and project information. As a result, more targeted and customized

service is delivered to clients, higher value is generated for them and they become more satisfied. This can lead to higher sales and market share in return.

KMS can also take a very basic form of a database of the (codified) knowledge of the employees, which is organized in the form of several documents. More complete and advanced implementations (up to a level that we normally expect from standard versions of KMS), though, can be used to link different domains to each other and integrate knowledge from different sources and actors to expand and enrich the exiting knowledge base of the firm as well as to create new knowledge. According to a number of our participants, the second scenario is not always the case in organizations in the current business environment. An IS director with more than 15 years of relevant experience in industry characterized the situation as:

In theory, [KMS systems are] very nice with great promises, but in practice often not more than those systems in which documents are stored….well, yes too bad!

An IT project leader put it differently:

I have never seen these [KMS] systems properly implemented anywhere. The main reason is that they take a lot of time and extra effort from people to codify their own tacit knowledge in a proper way and further keep track of and update it regularly in the system. I wouldn't map it [KMS] to any higher role than information, at least the way I've seen it implemented as just an information storage tool in organizations till now.

Table 3 shows that the majority of the interviewed practitioners believed that ERP systems deliver integration role as to integrate otherwise uncoupled and separate (primary and secondary) systems and processes of the firm. According to observations of an IT consultant involved in many ERP projects in the past:

….[by implementing ERP] you let your corporate systems work together, just in time, lean and mean.

Still, a number of participants were convinced that the advantages that ERP systems promise in theory are very hard to achieve in practice. The following comment reflects a CTO's experience in this respect:

….however, in reality these [ERP] systems are typically used to organize, harmonize, and optimize material and work streams and information flows within the organization, without really integrating and changing the company structure internally. In order for an ERP system to work ideally,

you have to change the ways you are used to do things, even if they might already work perfectly for you….After all, full integration by itself is a high aim.

The role of SCM was also identified as coordinating and optimizing different activities and domains along the (internal and external) value chain of the company and, in some cases, as integrating the company's departments with those of its downstream and upstream partners. A corporate IT manager in a chemical company explained this as:

SCM systems play a crucial role in our industry, if not for all industries these days. They connect your firm to its many upstream suppliers and sometimes downstream customers, coordinate and [they] streamline all the ordering, billing, inventory control, critical servicing processes in almost real-time….We are now even thinking of promoting our [SCM] systems to a lean manufacturing setup with JIT [just-in-time] and Six Sigma philosophies behind it. This will radically increase our capacity utilization, operational efficiency and customer satisfaction in the near future, we hope. I bet the next time you interview me or one of my colleagues, we'll tell you good stories about our victories!

E-learning software is another interesting category. Depending on what exactly e-learning software does and delivers (which implies its specific definition and perceived value in the mind of the interviewed expert), our panelists placed it in different levels of the hierarchy. In a simple form, an e-learning system provides employees with information about a topic. In a more complete and modern implementation, though, such a system can actually replace a tutor and automate teaching/training procedures (like the available step-by-step and interactive video-based tutoring software). One of the IT managers we interviewed had a fresh hands-on practice in implementing one of these systems in her organization:

We recently installed one of these systems in our company. We spent hundreds of thousands of dollars on it. It took us months to fully install the software and configure it, and then to train our employees and managers. We then had a hard time to convince them to really use it…. At first, they seemed like simple banks or catalogues of data, which made us suspicious about how much time and money we had spent on them. However, later on we realized their magical power….nowadays, our employees are very satisfied with the system….that [the system] has freed them [employees] from attending so many seminars, courses, workshops, etc. throughout the year. They can follow courses, attend in simulated workshops, solve their educational problems and

> *even contribute to seminars in accordance with their place and time of comfort; at home, in the evenings, in weekends, or even while on holiday. Overall, the system has automated so many tasks for us, has saved us some money and most importantly has increased the productivity of our employees….That's important!*

As to the last application type, almost all the interviewed professionals agreed on the automation role of e-commerce systems, as to automating (part of) the ordering, billing and servicing of the company. From another perspective, shared by a number of experts, e-commerce systems, especially highly-developed ones, create totally new procurement, marketing and/or sales channels, revolutionize the way the company is organized, and transform the organization into a new, online/internet-based entity. A senior consultant reflected on his experience in the banking and insurance industry:

> *Such a[n] [e-commerce] system really changes the organization, the way customers view and come in contact with your organization; it's a new way to reach a new market and I will put it in the transformation layer of the pyramid without any doubts.*

Another consultant made a similar note on the role of these systems:

> *I think, if not now, in the near future no business would be meaningful or at least profitable without getting enough support from e-commerce….many organizations have already thought of transforming their business models and corporate infrastructures to what I call [inter]net-enabled platforms…Just take a look at the current fast and widespread trend of cloud computing and crowd sourcing. Internet is rapidly propagating throughout all our businesses….many more companies will go almost completely online and that's why I believe the key to success is e-commerce and e-business. You'll see that!*

10. Managerial Relevance and Recommendations for Future Research

Information technology has long been argued and testified as one of the strategic resources that can leverage the performance and position of the firm. Still, IT investments can only be rewarding if they suit the needs and goals of the implementing company. In this respect, one of the biggest challenges facing the managers of today's corporations is to get a clear picture about their level of IT capability, to spot their IT needs and set their IT roadmap accordingly, and to make informed choices from the very wide range of available technologies in the marketplace. In order to come to a right investment decision, a sharp understanding of how different information technologies function and how they affect organizational performance is an important requisite. The typological framework proposed in this paper attempts to serve corporate and IT managers with some features to face this challenge. It is a step towards opening the black box of IT value creation process through demonstrating how and explaining why certain organizational outcomes happen following investments in certain IT applications.

The framework identifies IT roles as the essential intermediate mechanisms through which IT investments are transformed into organizational impacts, being business process or performance effects. In other words, the framework acknowledges IT roles as an important bridge between implementation efforts and organizational effects. By doing this, the framework offers managers a clearer picture of how IT actually creates value in their organization. We bring the idea one step ahead by classifying IT roles, such that roles with common characteristics and similar effects are bundled together. We identify six primary roles, classified into three general classes: information and communication (1^{st}-order roles), automation and coordination (2^{nd}-order roles), and integration and transformation (3^{rd}-order roles). This effort helps decision makers better structure their mind and understand different technological options in a systematic way when they tackle a complex IT investment problem and therefore it is useful for IT portfolio management. An important feature of the framework is its combinative nature. By integrating the two major levels of IT-based capability analysis (i.e. operational and strategic), the framework enables researchers to investigate and interpret the roles of IT in creating organizational capabilities from the perspectives of operational as well as strategic value of IT.

The categorization of IT roles in this paper, contrary to most of the existing typologies of IT, is based on theoretical foundations adopted from Organizational Information Processing Theory and Resource Based View of the firm. Based on these theories and follow-up interviews with 27 senior IT experts, the extent of information processing that a specific IT system handles (or is capable of handling) and the extent of organizational change it triggers (or complementarities it requires) were identified as the two important characteristics that determine the potential of the IT resource to improve organizational performance and create competitive value. The theoretical foundation makes the model also suitable for management scientists, who wish to theoretically analyze the IT resource or the IT value creation process of the firm. The external audits, accompanying our literature study, increase the relevance and applicability of the proposed model in practice. As to the next step towards completing the framework, we ranked the identified roles of IT in the form of a hierarchy with respect to their competitive performance potential. Higher roles in the hierarchy are more difficult, costly, riskier and slower to be developed/exploited and require much more complementarities aside. However, once in place properly, they make the firm reap substantial benefits and leap ahead of the competition far more than the roles of lower ranks. As such, the proposed hierarchy of IT roles has practical implications, relevant for management decisions. Managers can use the hierarchy to assess "where are we and where do we go from here?" in terms of the level of IT-based capability their organization has achieved or plans to achieve. As to the final stage of the model development, the relationship between IT roles and other basic components of the IT value creation process are systematically clarified. This way, the framework can serve as an analytical tool, helping managers think out of the box by understanding and assessing the consequence(s) of their investment choices more carefully. Moreover, practitioners can use the proposed typology to decompose the overall IT-based capacity of their organization, evaluate their strengths and weaknesses, and assess whether or not their current IT portfolio fits their business strategic directions.

Finally, for evaluation purposes, the framework and its applications were discussed and validated through semi-structured interviews with a representative panel of 27 senior IT managers and consultants. This step allowed us to find out to what extent practitioners comprehend the model and can further put it into use. It also helped us improve the model, when necessary. On the basis of the interview results, the framework can be considered to be simple, pragmatic, comprehensible, comprehensive and valuable in tackling IT portfolio management and IT business value problems by giving structure and guideline to the analysis and decision making phases of the process of problem solving. The simplicity and sensibility of the model was especially found to be appealing to senior managers and directors we interviewed. Furthermore, the results emphasize on the strengths of the framework in unraveling the intermediate mechanisms through which IT value is actually generated. This is useful for those seeking to develop an understanding or a new theory of the ITBV creation phenomenon. The interviewed experts supported the framework as a handful tool to track the IT evolution path of the firm and to assess its IT maturity as well.

As to a strong application of the proposed typology, we suggest its use in line with the [capabilities required (CR) → IT → business value (BV)] thematic progression proposed by Kohli and Grover (2008: 31). With this paradigm shift, they propose that firms must first uncover the specific digital capabilities required for their organization and then identify and analyze what it takes to build them and generate business value from them (Kohli and Grover, 2008: 30). Interestingly, our interview results reveals that the majority of senior IT experts interviewed still think and act according to the *old paradigm* with IT in the center (of any activity or impact) and everything else (such as organizational capabilities) surfacing it. Our proposed typology bridges the backward path from CR to IT and helps us exactly identify and analyze what it takes to build the required capabilities. Different capabilities or initiatives of the firm are dependent on or enabled by different types of IT roles, which themselves are provided by different types of IT systems or applications. The suggested framework can thus make it easier for corporate managers to inspect their required capabilities and cope with the abundance of information technologies available to them in the market. In this direction, we might even decide to extend the typology beyond the boundaries of a focal firm to incorporate cross-boundary settings and inter-organizational IT-based capabilities as well. This is a promising agenda for future research as IT-based value is nowadays increasingly co-created through relationships between companies (Kohli and Grover, 2008: 28).

There are a number of steps to be followed to make the typology even more appropriate for empirical (academic) studies. When the experts were asked to assign a unique primary role to a number of IT systems, they showed a small degree of discrepancy. The discrepancy was more considerable when the respondents did not share a common definition about the features and/or scope of the IT system in question. This makes IT systems a less favorable proxy to measure/track IT roles. To circumvent this operationalization issue, a first step is that researchers engage in collecting primary data. IT roles can then be directly defined and asked about in surveys. A second crucial step to enhance the model is to deeply examine the relationships among different roles and different classes of firm-level intermediate and output measures of performance, theoretically and/or empirically. This line of research can result in a new theory to explain the organizational impact and business value of information technology. It also leads to identification and characterization of influential complementarities in the process of IT value creation. As to a related recommendation to further improve and validate the framework, it shall be applied in case studies and field experiments where a deeper degree of details and interrelations are made known. As to a third step, the framework should be employed in longitudinal and historical studies of IT adoption to shed light on the characteristics of the evolution path and determinants of the maturity level of IT-adopting organizations over time. Last but not least, an important step is to measure various roles of IT and to link them to business performance through secondary sources of data, when collecting primary data is not an option of consideration. In this vein, it is important to choose strong proxies or construct new instruments that can distinguish and quantify various roles with good precision.

Despite the positive appraisal of the typology by the interviewed professionals, as with any typology, its true strength will be revealed over time. Inevitably, researchers will continue to debate and examine the relevancy and appropriateness of the proposed definition and typology of IT roles in future conceptual and empirical studies. We leave it to them to compare the usefulness of our typology against the competing models in specific contexts and for specific applications. We hope that the proposed typology in this paper inspires further theoretical and empirical studies that by themselves generate new knowledge and, in part, enrich the debate around how IT creates business value for the firm.

References

Adamides, E.D. & Karacapilidis, N. (2006) Information technology support for the knowledge and social processes of innovation management. *Technovation*, **26**, 50-59.

Agarwal, R. & Lucas, H.C. (2005) The Information Systems Identity Crisis: Focusing on High-Visibility and High-Impact Research. *MIS Quarterly,* **29**, 381-398.

Albadvi, A., Keramati, A. & Razmi, J. (2007) Assessing the impact of information technology on firm performance considering the role of intervening variables: organizational infrastructures and business processes reengineering. *International Journal of Production Research*, **45**, 2697–2734.

Alsene, E. (1999) The computer integration of the enterprise. *IEEE Transactions on Engineering Management*, **46**, 26-35.

Andersen, T.J. (2001) Information technology, strategic decision-making approaches and organizational performance in different industrial settings. *Journal of Strategic Information Systems*, **10,** 101-119.

Argyres, N.S. (1999) The Impact of Information Technology on Coordination: Evidence from the B-2 "Stealth" Bomber. *Organization Science*, **10**, 162-180.

Bailey, K. D. (1994) Typologies and Taxonomies: An Introduction to Classification Techniques. Sage, Thousand Oaks, CA.

Bardhan, I.R., Krishnan, V.V. & Lin, S. (2007) Project performance and the enabling role of information technology: An exploratory study on the role of alignment. *Manufacturing & Service Operations Management*, **9**, 579-595.

Barney, J.B. (1991) Firm Resources and Sustained Competitive Advantage. *Journal of Management*, **17**, 99-120.

Barua, A., Kriebel, C.H. & Mukhopadhyay, T. (1995) Information Technologies and Business Value – an Analytic and Empirical Investigation. *Information Systems Research*, **6**, 3-23.

Barua, A. & Mukhopadhyay, T. (2000) Information Technology and Business Performance: Past, Present, and Future. In: *Framing the Domains of IT Management: Projecting the Future through the Past,* Zmud, R.W. (ed.). Pinnaflex Press, Cincinnati, OH.

Becchetti, L., Bedoya, D.A.L. & Paganetto, L. (2003) ICT investment, productivity and efficiency: Evidence at firm level using a stochastic frontier approach. *Journal of Productivity Analysis*, **20**, 143-167.

Bharadwaj, A.S. (2000) A Resource-Based Perspective on Information Technology Capability and Firm Performance: An Empirical Examination. *MIS Quarterly*, **24**, 169-196.

Bhatt, G. & Grover, V. (2005) Types of Information Technology Capabilities and Their Role in Competitive Advantage: An Empirical Study. *Journal of Management Information Systems*, **22**, 253-277.

Bouwman, H., Van Den Hoof, B., Van De Wijngaert, L. & Van Dijk, J.A.G.M. (2005) *Information & Communication Technology in Organizations: Adoption, Implementation, Use and Effects*, 1st edn. SAGE Publications, London.

Bresnahan, T. F., Brynjolfsson, E. & Hitt, L.M. (2002) Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence. *The Quarterly Journal of Economics*, **117**, 339-376.

Brynjolfsson, E. & Hitt, L.M (1998) Beyond the Productivity Paradox- Computers are the catalyst for bigger changes. *Communications of the ACM*, **41**, 49-55.

Brynjolfsson, E. & Hitt, L.M. (2000) Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives*, **14**, 23-48.

Brynjolfsson, E. & Hitt, L.M. (2003) Computing productivity: Firm-level evidence. *Review of Economics and Statistics*, **85**, 793-808.

Brynjolfsson, E., Hitt, L.M. & Yang, S. (2002) Intangible Assets: Computers and Organizational Capital. *Brookings Papers on Economic Activity*, **1**, 137-198.

Cao, G. (2010) A Four-Dimensional View of IT Business Value. *Systems Research and Behavioral Science*, **27**, 267-284.

Carr, N.G. (2003) IT Doesn't Matter. *Harvard Business Review*, **81**, 5-12.

Carr, N.G. (2004) Does IT Matter? Information Technology and the Corrosion of Competitive Advantage. Harvard Business School Publishing, Boston, MA.

Clemons, E.K. & Row, M.C. (1991) Sustaining IT advantage: the role of structural differences. *MIS Quarterly*, **15**, 275-292.

Czaja, R. & Blair, J. (2005) *Designing surveys: A guide to decisions and procedures*, 2nd edn. Sage Publications, Thousand Oaks, CA.

Daft, R.L. & Lengel, R.H. (1986) Organizational information requirements, media richness and structural design. *Management Science*, **32**, 554–571.

Davenport, T.H. (1998) Putting the enterprise into the enterprise system. *Harvard Business Review*, **76**, 121–131.

Davenport, T.H. (2006) Competing on Analytics. *Harvard Business Review*, **Jan.**, 1-9.

Davenport, T.H., & Short, J.E. (1990) The New Industrial Engineering: Information Technology and Business Process Redesign. *Sloan Management Review*, **31**, 11-27.

Davern, M.J. & Kauffman, R.J. (2000) Discovering Potential and Realizing Value from Information Technology Investments. *Journal of Management Information Systems*, **16**, 121-143.

Dehning, B. & Stratopoulos, T. (2003) Determinants of a Sustainable Competitive Advantage Due to an IT–Enabled Strategy. *Journal of Strategic Information Systems*, **12**, 7–28.

Devaraj S. & Kohli R. (2000) Information technology payoff in the health-care industry: A longitudinal study. *Journal of Management Information* Systems, **16**, 41-67.

Dewett, T. & Jones, G.R. (2001) The role of information technology in the organization: a review, model, and assessment. *Journal of Management,* **27**, 313–346.

Dutton, W.H., Kahin, B., O'Callaghan, R. & Wyckoff, A.W. (2005) *Transforming Enterprise: The Economic and Social Implications of Information Technology*. MIT Press, Boston, MA.

Emory, C.W. & Cooper, D.R. (1991) *Business Research Methods*. Irwin, Boston, MA.

Fairbank, J.F., Labianca, G., Steensma, H.K. & Metters, R.D. (2006) Information Processing Design Choices, Strategy and Risk Management Performance. *Journal of Management Information Systems*, **23**, 293-319.

Fichman, R.G. (2000) The Diffusion and Assimilation of Information Technology Innovations. In: *Framing the Domains of IT Management: Projecting the Future through the Past*, Zmud, R. (ed.), pp. 105-127. Pinnaflex Publishing, Cincinnati, OH.

Fiedler, K.D., Grover, V. & Teng, J.T.C. (1994) Information technology-enabled change: the risks and rewards of business process redesign and automation. *Journal of Information Technology*, **9**, 267-275.

Fry, L.W. (1982) Technology-Structure Research: Three Critical Issues. *The Academy of Management Journal*, **25**, 532-552.

Galbraith, J.R. (1974) Organization design: An information processing view, *Interfaces*, **4**, 28-36.

Galbraith, J.R. (1977). *Organization Design*, Addison-Wesley, Reading, MA.

Gallivan, M., Spitler, V. & Koufaris, M. (2005) Does Information Technology Training Really Matter? A Social Information Processing Analysis of Coworkers' Influence on IT Usage in the Workplace. *Journal of Management Information Systems*, **22**, 153–192.

Garicano, L. & Kaplan, S.N. (2001) The effects of business-to-business E-commerce on transaction costs. *Journal of Industrial Economics*, **49**, 463-485.

Gattiker, T.F. & Goodhue, D.L. (2004) Understanding the local-level costs and benefits of ERP through organizational information processing theory. *Information & Management*, **41**, 431-443.

Gattiker, T.F. & Goodhue, D.L. (2005) What happens after ERP implementation: understanding the impact of interdependence and differentiation on plant-level outcomes? *MIS Quarterly*, **29**, 559-585.

Gilad, B. & Gilad, T. (1985) A Systems Approach to Business Intelligence, *Business Horizons*, **28**, 65-70.

Grant, R.M. (1991) The Resource-Based Theory of Competitive Advantage. *California Management Review*, **33**, 114-135.

Gunasekaran, A. & Ngai, E.W.T. (2004) Information systems in supply chain integration and management. *European Journal of Operational Research*, **159**, 269-295.

Hammer, M. (1990) Reengineering work: don't automatic, obliterate. *Harvard Business Review*, **68**, 104-112.

Hitt, L.M. & Brynjolfsson, E. (1997) Information Technology and Internal Firm Organization: An Exploratory Analysis. *Journal of Management Information Systems*, **14**, 81-101.

Hofstede, G.H. (2001) Culture's consequences: comparing values, behaviors, institutions and organizations across nations. 2nd edn. SAGE, London.

Huber, G.P. (1990) A Theory of the Effects of Advanced Information Technologies on Organizational Design, Intelligence, and Decision-Making. *Academy of Management Review*, **15**, 47-71.

Hunt, S.D. (1991) Modern marketing theory: Critical issues in the philosophy of marketing science, South-Western Publishing Co., Cincinnati, OH.

Jackson, B. (1985) *Winning and Keeping Industrial Customers*. Lexington Books, Lexington, MA.

Keen, P.G.W. (1991) *Shaping the future: Business Design through Information Technology*, 1st edn. Harvard Business School Press, Boston.

Keil, M. (1995) Pulling the plug: Software project management and the problem of project escalation. *MIS Quarterly*, **19**, 421-450.

Ko, M. & Osei-Bryson, K-M. (2004) Using regression splines to assess the impact of information technology investments on productivity in the health care industry. *Information Systems Journal*, **14**, 43-63.

Kohli, R. & Grover, V. (2008) Business value of IT: an essay on expanding research directions to keep up with the times. *Journal of the Association for Information Systems*, **9**, 23-39.

Lai, V. (2001) Intra-organizational Communication with Intranets. *Communications of the ACM*. **44**, 95-100.

Laudon, K.C. & Laudon, J.P.(2009) *Management Information Systems: Managing The Digital Firm*, 11th edn. Pearson Education, Upper Saddle River, NJ.

Lindlof, T.R. & Taylor, B.C. (2002) *Qualitative Communication Research Methods*, 2nd edn. Sage Publications, Thousand Oaks, CA.

Malone, T.W. & Crowston, K. (1994) Toward an interdisciplinary theory of coordination. *ACM Computing Surveys*, **26**, 87-119.

Marler, J.H., Liang, X. & Dulebohn, J.H. (2006) Training and Effective Employee Information Technology Use. *Journal of Management*, **32**, 721-743.

Marradi, A. (1990) Classification, Typology, Taxonomy. *Quality and Quantity*, **24**, 129-157.

Martin, R. (2007) The CIO Dilemma. *Information Week*, **131**, 38-44.

Mata, F.J., Fuerst, W.L. & Barney, J.B. (1995) Information technology and sustained competitive advantage: a resource-based analysis. *MIS Quarterly*, **19**, 487-505.

McAfee, A. (2006) Mastering the three worlds of information technology. *Harvard Business Review*, **84**, 141-149.

Melville, N., Kraemer, K. & Gurbaxani, V. (2004) Review: Information technology and organizational performance: An integrative model of IT business value. *MIS Quarterly*, **28**, 283- 322.

Miles, M.B. & Huberman, A.M. (1994) *Qualitative data analysis: An expanded sourcebook*, 2nd edn. Sage, Newbury Park, CA.

Milgrom, P. & Roberts, J. (1990) The economics of modern manufacturing: Technology, strategy, and organization. *American Economic Review*, **80,** 511-528.

Milgrom, P. & Roberts, J. (1995) Complementarities and fit: Strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics*, **19**, 179-208.

Mooney, J.G., Gurbaxani, V. & Kraemer, K.L. (1996) A Process Oriented Framework for Assessing the Business Value of Information Technology. *The DATA BASE for Advances in Information Systems*, **27**, 68-81.

Mukhopadhyay, T. & Cooper, R.B. (1993) A Microeconomic Production Assessment of The Business Value of Management Information Systems: The Case of Inventory Control. *Journal of Management Information Systems*, **10**, 33-55.

Mulligan, P. (2002) Specification of a capability-based IT classification framework. *Information & Management*, **39**, 647-658.

Myers, M.D. (2009) Qualitative Research in Business & Management. Sage, London.

Myers, M.D. & Avison, D.E. (2002) *Qualitative Research in Information Systems: A Reader*, Sage Publications, London.

Myers, M.D. & Newman, M. (2007) The qualitative interview in IS research: Examining the craft. *Information and Organization*, **17**, 2-26.

Nambisan, S. (2003) Information Systems as a Reference Discipline for New Product Development. *MIS Quarterly*, **27**, 1-18.

Nevo, S. & Wade, M.R. (2010) The Formation and Value of IT-Enabled Resources: Antecedents and Consequences. *MIS Quarterly*, **34**, 163-183.

O'Hara, M., Watson, R. & Kavan, C. (1999) Managing the three levels of change, *Information Systems Management*, **16**, 63-70.

Orlikowski, W.J. & Iacono, C.Z. (2001) Research Commentary: Desperately Seeking the "IT" in IT Research-A Call to Theorizing the IT Artifact, *Information Systems Research*, **12**, 121-134.

Piccoli, G. & Ives, B. (2005) Review: IT-Dependent Strategic Initiatives and Sustained Competitive Advantage: A Review and Synthesis of the Literature. *MIS Quarterly*, **29**, 747-776.

Powell, T.C. & Dent-Micallef, A. (1997) Information technology as competitive advantage: The role of human, business, and technology resources. *Strategic Management Journal*, **18**, 375-405.

Radhakrishnan, A., Zu, X. & Grover, V. (2008) A process-oriented perspective on differential business value creation by information technology: An empirical investigation. *Omega*, **36**, 1105-1125.

Ravichandran, T. & Lertwongsatien, C. (2005) Effect of Information Systems Resources and Capabilities on Firm Performance: A Resource-Based Perspective. *Journal of Management Information Systems*, **21**, 237-276.

Remenyi, D., Money, A. & Twite, A. (1994) *A guide to measuring and managing IT benefits*, 2nd edn. NCC Blackwell Limited, Oxford.

Ross, J.W., Beath, C.M. & Goodhue, D.L. (1996) Develop long-term competitiveness through IT assets. *Sloan Management Review*, **38**, 31-42.

Sabherwal, R., & Chan, Y.E. (2001) Alignment Between Business and IS Strategies: A Study of Prospectors, Analyzers, and Defenders. *Information Systems Research*, **12**, 11-33.

Sambamurthy, V., Bharadwaj, A. & Grover, V. (2003) Shaping agility through digital options: reconceptualizing the role of information technology in contemporary firms, *MIS Quarterly*, **27**, 237–263.

Sambamurthy, V., & Zmud, R.W. (2000) Research Commentary: The Organizing Logic for an Enterprise's IT Activities in the Digital Era - A Prognosis of Practice and a Call for Research. *Information Systems Research*, **11**, 105-114.

Sanders, N.R. (2008) Pattern of information technology use: The impact on buyer–suppler coordination and performance, *Journal of Operations* Management, **26**, 349-367.

Sethi, V. & King, W.R. (1994) Development of Measures to Assess the Extent to Which an Information Technology Application Provides Competitive Advantage. *Management Science*, **40**, 1601-1627.

Silverman, D. (1997) Qualitative Research: Theory, Method and Practice. Sage, London.

Silverman, D. (1998) Qualitative Research: meanings or practices? *Information Systems Journal*, **8**, 3-20.

Silverman, D. (2000) Doing qualitative research: A practical handbook. Sage, London.

Sircar, S. & Choi, J. (2009) A study of the impact of information technology on firm performance: a flexible production function approach. *Information Systems Journal*, **19**, 313-339.

Sircar, S., Turnbow, J.L. & Bordoloi, B. (2000) A Framework for Assessing the Relationship Between Information Technology Investments and Firm Performance. *Journal of Management Information Systems*, **16**, 69-97.

Smith, H. & Fingar, P. (2003), *IT Doesn't Matter- Business Processes Do*. Meghan-Kiffer Press, Tampa, FL.

Song, L.Z. & Song, M. (2010) The Role of Information Technologies in Enhancing R&D–Marketing Integration: An Empirical Investigation, *Journal of Product Innovation Management*, **27**, 382–401.

Sproull, L. & Kiesler, S.B. (1991) *Connections: New ways of working in the networked organization*, MIT Press, Cambridge, MA.

Srivardhana, T. & Pawlowski, S.D. (2007) ERP systems as an enabler of sustained business process innovation: A knowledge-based view. *Journal of Strategic Information Systems*, **16**, 51–69.

Straub, D.W. & Wetherbe, J.C. (1989) Information Technologies for the 1990s: An Organizational Impact Perspective. *Communications of the ACM*, **32**, 1328-1339.

Strauss, A. (1987) *Qualitative Analysis for Social Scientists*. Cambridge University Press, Cambridge.

Tallon, P.P., Kraemer, K.L., & Gurbaxani, V. (2000) Executives' Perceptions of the Business Value of Information Technology: A Process-Oriented Approach. *Journal of Management Information Systems*, **16**, 145-173.

Tanriverdi, H. (2005) Information Technology Relatedness, Knowledge Management Capability, and Performance of Multi-business Firms. *MIS Quarterly*, **29**, 311-334.

Tarafdar, M. & Gordon S.R. (2007) Understanding the influence of information systems competencies on process innovation: A resource-based view. *Journal of Strategic Information Systems*, **16**, 353-392.

Teo, H.-H., Tan, B.C.Y. & Wei, K.K. (1997) Organizational Transformation Using Electronic Data Interchange: The Case of TradeNet in Singapore. *Journal of Management Information Systems*, **13**, 139-165.

Thatcher, M.E. & Oliver, J.R. (2001) The impact of technology investments on a firm's production efficiency, product quality, and productivity. *Journal of Management Information Systems*, **18**, 17-45.

Trauth, E.M. & Cole, E. (1992) The organizational interface: A method for supporting end users of packaged software. *MIS Quarterly*, **16**, 35–53.

Turban, E., Leidner, D., McLean, E. & Wetherbe, J. (2009) *Information Technology for Management: Transforming Organizations in the Digital Economy*, 7th edn. Wiley International, New York, NY.

Turban, E., Rainer, R.K. & Potter, R.E. (2004) *Introduction to Information Technology*, 2nd edn. John Wiley & Sons, New York, NY.

Tushman, M.L. & Nadler, D.A. (1978) Information processing as an integrating concept in organizational design. *Academy of Management Review*, **3**, 613–624.

Venkatesh, V., Morris, M.G., Davis, G.B. & Davis, F.D. (2003) User acceptance of information technology: Toward a unified view. *MIS Quarterly*, **27**, 425-478.

Venkatraman, N. (1994) IT-Enabled Business Transformation - from Automation to Business Scope Redefinition. *Sloan Management Review*, **35**, 73-87.

Vonderembse, M.A., Raghunathan, T.S. & Rao, S. (1997) A post-industrial paradigm: to integrate and automate manufacturing. *International Journal of Production Research*, **35**, 2579–2599.

Walsham, G. (1993) *Interpreting Information Systems in Organizations*. John Wiley & Sons, Chichester, UK.

Walsham, G. (1995) Interpretive Case Studies in IS Research: Nature and Method. *European Journal of Information Systems*, **4**, 74-81.

Wade, M. & Hulland, J. (2004) The Resource-Based View and information Systems Research: Review, Extension, and Suggestions for Future Research. *MIS Quarterly*, **28**, 107-142.

Ward, J., Griffiths, P. & Whitmore, P. (2002) *Strategic Planning for Information Systems*, 3rd edn. John Wiley and Sons, New York, NY.

Weill, P. (1992) The relationship between investment in information technology and firm performance: A study of the valve manufacturing sector. *Information Systems Research*, **3**, 307-333.

Wernerfelt, B. (1984) A resource-based view of the firm. *Strategic Management Journal*, **5**, 171-180.

Zaheer, A. & Venkatraman, N. (1994) Determinants of electronic integration in the insurance industry: An empirical test. *Management Science*, **40**, 549-566.

Zammuto, R.F., Griffith, T.L., Majchrzak, A., Dougherty, D.J. & Faraj, S. (2007) Information technology and the changing fabric of organization. *Organization Science*, **18**, 749–762.

Zand, F. & Van Beers, C. (2009) Performance Effects of Enterprise Application Software: New Insights into the Mediating Role of Innovation. *Proceedings of the 13th International Business Information Management Association (IBIMA) Conference on Knowledge Management and Innovation in Advancing Economies*.

Appendix A: IT Roles

IT Role	Definition	Information Processing	Organizational Change	Exemplar IT Applications	Exemplar Literature References
Information	The ability of IT to generate, gather, and store data in a reusable, organized, and secure manner	Low	Low	Point-of-Sale (POS) Systems, Databases, Data Warehouse Systems (DWS), File Server Systems, Firewalls, Encryption Software	Davenport & Short (1990), Laudon & Laudon (2009), Mooney et al. (1996), Remenyi et al. (1994), Sambamurthy & Zmud (2000), Weill (1992)
Communication	The ability of IT to promptly transmit and disseminate data and information among distant individuals, teams and organizations	Low	Low	Video Conferencing, Radio Frequency Identification (RFID), Group Support Systems (GSS), Interactive Whiteboard, Email, Intranet	Andersen (2001), Bardhan et al. (2007), Bouwman et al. (2005), Lai (2001), Sproull & Kiesler (1991), Straub & Wetherbe (1989)
Automation	The ability of IT to standardize, mechanize and computerize operational activities and decision making processes by eliminating or minimizing manual interventions	High	Low	Computer Aided Design/ Manufacturing (CAD/CAM), Expert Systems, Decision Support Systems (DSS), Accounting Software, Transaction Processing Systems (TPS), Computer Numerically Controlled (CNC) Machines	Davenport & Short (1990), Fiedler et al. (1994), Laudon & Laudon (2009), Mooney et al. (1996), Remenyi et al. (1994), Scheer et al. (2004), Vonderembse et al. (1997),
Coordination	The ability of IT to organize, co-plan	High	Low	Workflow & Scheduling Systems, Participatory	Argyres (1999), Bouwman et al.

	and synchronize activities and parties, in a synchronous or asynchronous fashion			Project Management (PPM), Supply Chain Management (SCM), Electronic Document Review Systems, Inventory Management Systems	(2005), Bardhan et al. (2007), Mulligan (2002), Nambisan (2003), Sanders (2008)
Integration	The ability of IT to combine, assimilate, and fundamentally reorganize the existing processes and domains into new, unified processes and domains	High	High	Enterprise Resource Planning (ERP), Knowledge Management System (KMS), Material Requirements Planning (MRP) Systems, Inter-company Integration Systems, Computer Integrated Manufacturing (CIM)	Alsene (1999), Gunasekaran (2004), Mulligan (2002), Sambamurthy & Zmud (2000), Song & Song (2010), Vollmer & Peyret (2006)
Transformation	The ability of IT to develop completely new production strategies, sales/marketing methods, organizational structures, and business models, leading to transition and reconfiguration of the firm as a whole to new forms	High	High	Just-in-Time (JIT) Inventory Management, Built-to-Order (BTO) Production, Lean Manufacturing, E-commerce, Networked & Virtual Organizations, Business Process Reengineering (BPR), Flexible Manufacturing Systems (FMS)	Brynjolfsson & Hitt (2000), Hitt & Brynjolfsson (1997), Dutton et al. (2005), Mooney et al. (1996), Remenyi et al. (1994), Teo et al. (1997), Venkatraman (1994)

A wise man will make more opportunities than he finds. -- *Francis Bacon*

R&D COOPERATION, PARTNER DIVERSITY AND INNOVATION PERFORMANCE: AN EMPIRICAL ANALYSIS*

Abstract. The existing literature on R&D alliances mainly focuses on the motives, forms or impacts of inter-organizational collaboration schemes. This paper focuses on the issue of partner diversity. Two central issues are investigated: (1) the impact of stakeholder and geographic diversity of R&D partners on the radical and imitative innovation performance of innovating firms, and (2) the organizational determinants of partner diversity. The theoretical background is that cooperation with a diverse set of partners leads to two types of learning opportunities with regard to cooperation as well as innovation skills. These learning mechanisms are expected to enhance the firm's innovation performance. The empirical data for this research is based on the Dutch Community Innovation Survey extended with the R&D and ICT Surveys and the Production Statistics. Regression analysis is performed on a representative sample of 12,811 innovating firms in the Netherlands over the period 1994-2006. The results

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indicate that partner diversity is an important variable in explaining a firm's innovation performance. In line with previous studies, external R&D collaboration affects innovation performance positively. However, stakeholder and geographic diversity are found to act through different channels. Stakeholder diversity influences the sales of novel products per employee significantly positively while no similar effect could be observed in case of geographic diversity. Cooperation with different partner categories like customers, suppliers, competitors and universities leads to a variety of knowledge intake and synergetic effects that are necessary to develop and commercialize novel products. When innovation performance is defined as the sales of marginally changed products per employee, the observed phenomenon is the other way around. Geographic diversity affects the performance of incremental innovations significantly positively while no similar effect could be found for stakeholder diversity. Cooperation with partners in diverse geographical locations seems to result in successful adaption of existing products to different local requirements such as technical standards, market regulations and customer preferences. Further investigation into non-linearities between partner diversity and innovation performance revealed a sigmoid relationship. Innovation performance improves with partner diversity at moderate levels of diversity. At (very) low levels of diversity, performance declines as diversity grows because the knowledge pool of the network is not yet sufficient or effective enough. At (very) high levels of diversity, performance diminishes again due to inefficiencies and congruencies present in expansive networks. Furthermore, we found that the existence of prior experience exerts a positive moderating impact on this sigmoid pattern. The paper also makes the first step towards identifying the determinants of partner diversity, which seem to be the same for both kinds of diversity. Prior experience, patenting and information technology backbone of the firm are the main organizational determinants of R&D partner diversity.

Keywords: R&D Cooperation, Partner Diversity, Innovation Performance, Determinants of Diversity, Community Innovation Survey

1. Introduction

In the last ten years quite a number of studies have been published on the success or failure of inter-firm cooperation schemes with respect to firm performance. The general framework consists of exploring the conditions under which firms create value through inter-organizational collaboration (Annand and Khanna, 2000; Gulati *et.al*, 2009; Merchant and Schendel, 2000). The contribution of inter-firm alliances to value creation depends on (1) the purpose and the form of the alliance like joint ventures for production, joint marketing efforts, or research and development (R&D) consortia, and (2) the characteristics of the partners such as their geographical location or their position in the value chain (Lavie and Miller, 2008; Stuart, 2000).

Annand and Khanna (2000) show that inter-firm alliances do not lead to significant effects on value creation except when R&D alliances are concerned. Merchant and Schendel (2000) report that the pursuit of R&D-oriented activities exerts a positive effect on the value created by joint ventures. Particularly in innovative firms, cooperation with other firms on R&D aimed at developing innovative products or production processes are likely, ceteris paribus, to affect the firms' performance more than joint marketing efforts. In firms that are active in mature industries, though, marketing alliances might pay off more than R&D collaboration schemes (Hagedoorn, 1993; Merchant and Schendel, 2000).

A crucial issue in R&D collaboration is the selection of relevant partners (Howells *et.al*, 2004; Nieto and Santamaria, 2007). Many firms are involved in multiple collaboration schemes, i.e. they cooperate with for example foreign suppliers but at the same time also with domestic customers and universities. Multiple cooperation schemes with partners in different partner groups can be expected to increase the impact of alliances on firm innovation performance due to complementary information and synergetic effects resulting from organizational learning (Belderbos *et.al*, 2004a; Lavie, 2009; Lavie and Miller, 2008). Moreover, firms build partnering capability and collaborative know-how through multiple partnerships over time (Heimeriks and Duysters, 2007; Zollo and Winter, 2002).

This paper examines whether or not diversity of partners in R&D collaborations leads to better innovation performance of the innovating firm. Competitive pressure forces innovative firms to come up with radically changed or completely new products in order to achieve and sustain competitive advantage (Nieto and Santamaria, 2007). The current globalization wave also forces firms to introduce products that are new in foreign markets to stay competitive. Therefore, a distinction is necessary between imitative and radical innovation performance. Imitative innovation relates to the marginal or piecemeal changes leading to products that are new to the firm but not new to the market or other firms in the industry. Radical innovation pertains to the introduction of novel products that are completely new to the market and not previously introduced by other firms in the industry.

The central idea is that cooperation with a diverse set of partners (of different types) leads to 1) learning cooperation skills, making the firm more efficient in managing and coordinating cooperative efforts and 2) learning innovation skills, making the firm more productive in innovation processes. As to the first type of learning process, firms learn from their past/current collaboration activities which helps them refine their partnering routines and enhances their capacity to form and manage future collaborative efforts (Das and Teng, 2002; Simonin, 1997). Ties with multiple partner types lead to accumulation of specific knowledge, which facilitates the post-formation adaptation and alteration of future alliances with different types of actors (Reuer *et.al*, 2002). A more diverse portfolio of partners increases the efficiency of partnering strategies as well (Faems *et.al*, 2005). Learning takes place even from failures (Reuer and Zollo, 2005). Prior alliance terminations enable a firm to design better alliances and adopt more suitable strategies to avoid future terminations (Pangarkar, 2009). Learning cooperation skills is also expected to lead to more familiarity and trust between partners, resulting in reduced coordination and transaction costs and hence a positive effect on both imitative and radical innovation performance (Dodgson, 1993; Nooteboom, 1999).

With regard to the second kind of learning process, it can be expected that collaboration with a broader range of external partners enables innovating firms to acquire required information from a variety of sources and leads to more synergies and intake of complementary knowledge, which contributes to (specifically, radical) innovation performance (Belderbos, *et.al*, 2006; Laursen and Salter, 2006; Lavie, 2009; Nieto and Santamaria, 2007). Complementarity arises as different types of partners provide different types of knowledge and technological opportunities from different domains of expertise, which collectively enhance the probability to come up with an innovative product. For example, suppliers can provide technological knowledge on the production processes of the firm while customers and universities are sources of market-related and basic knowledge respectively (Belderbos *et.al*, 2004b). The domestic or foreign location of the cooperation partners is also influential to (imitative and radical) innovation of the firm as it relates to the issue that partners abroad are embedded in separate national innovation systems than partners in the domestic market and therefore have access to nation-specific resources (Lavie and Miller, 2008; Miotti and Sachwald, 2003). These unique resources produce knowledge that can be in short supply in the firm's home country. Geographic diversity can also lead to better adaption of existing products to customer preferences in foreign markets (Lavie and Miller, 2008).

The empirical literature on R&D alliances can roughly be divided into three groups. First, several studies investigate the determinants and motives of inter-organizational R&D cooperation (e.g. Belderbos *et.al*, 2004a; Cassiman and Veugelers, 2002; Hagedoorn, 1993; Kleinknecht and van Reijnen, 1992; Kleinknecht and Mohnen, 2002; Narula and Santangelo, 2009). Second, a number of studies focus on the impact of inter-organizational R&D collaboration on the innovation performance of the firm (e.g. Faems *et.al*, 2005; Tether, 2002). Third, a small number of studies pay attention to partner types (e.g. Alcácer, 2006; Alcácer and Chung, 2007; Belderbos *et.al*, 2004a; Knudsen, 2007; Miotti and Sachwald, 2003). The present study contributes to this latter strand of literature by focusing on two research themes, namely 1) the impact of partner diversity on the innovation performance of the firm, and 2) the organizational determinants of partner diversity. Two types of diversity are considered important, namely stakeholder and geographic diversity, which relate to partnering with actors in different partner groups and geographical locations respectively. The main contribution of this paper is that it distinguishes between different kinds of partner diversity and whether or not these differ in their impact on innovating firms' innovation performance.

The empirical analysis uses four waves of the Dutch Community Innovation Survey (CIS) extended with the R&D and ICT Surveys and Production Statistics data of 12,811 Dutch and multinational enterprises for the period 1994-2006. Several models are estimated using panel Tobit techniques after correcting for sample selection bias through a two-stage Heckman procedure. The results demonstrate that stakeholder diversity of partners affects the average innovating firm's radical innovation performance positively, which suggests that using information from different external partner groups increases the variety of knowledge intake and enhances the production and sales of novel products. Geographic diversity of partners is found to be important to imitative innovation performance of the firm. This implies the role of partners in different geographic locations in adapting and customizing existing products to local technical standards, market regulations and customer preferences. Moreover, the findings predict a sigmoid impact of partner diversity on innovation performance, suggesting that low or very high levels of diversity impose adverse effects on innovation performance. Furthermore, as a first attempt to detect the determinants of partner diversity, the analysis highlights the effectiveness of past organizational learning, applying appropriability mechanisms, and using (modern) information technologies for engagement in diverse business networks.

The next section establishes the theoretical and empirical background of the two research questions. In section 3, we formulate the empirical models and also present the operationalization of variables. Section 4 describes the data in details and in section 5 the empirical results are discussed. Conclusions, limitations and recommendations for future research are reported in the last section.

2. Theoretical and Empirical Background

2.1. R&D cooperation and different partner groups

In the last twenty years, inter-firm cooperation on R&D or innovation activities have increased due to a number of structural changes in the external environment of the innovative firm. First, greater product and technology complexity have increased costs and risks for innovators such that these can hardly be dealt with by only relying on a firm's own limited resources and capabilities. Consequently, networking or cooperating on innovation activities with different partners has become a relevant business activity as witnessed by a spectacular growth in strategic alliances with R&D partners (Hagedoorn, 2002; Wassmer, 2010). Second, the globalization wave of the last two decades has opened up more possibilities for cross-national alliances that contribute to creating competitive advantage in foreign markets (Lavie and Miller, 2008). Third, shorter products' lifecycle and time-to-market encourages firms to rely more on inter-firm cooperative strategies to develop and introduce new products (Tether, 2002).

The decision whether or not to engage in R&D cooperation and with what type of partner depends on the net gains from cooperation. In the framework of the transaction cost economics trade-offs exist between developing innovations in-house versus through arms-length trade. Collaboration with external partners is a between-in option aimed at combining the advantages of both in-house and arms-length trade ways of developing innovations. Cooperating firms have more control over and hence less uncertainty about the (complex) technology and input quality as compared with transactions at arms-length trade. Compared with in-house innovations, transaction costs like searching, negotiation, contracting and enforcement costs arise. Cooperating firms might also experience opportunistic behavior of the partners leading to more risks, resulting in leakage of sensitive knowledge and erosion of competitive advantage and thus necessitating trust-building and appropriability mechanisms (Gulati, 1995).

From the perspective of the resource-based theory, R&D cooperation is a valuable resource that helps the innovating firm to increase value and to gain competitiveness by pooling, integrating and combining its resources with those of other firms (Barney *et.al*, 2001; Das and Teng, 2000, Miotti and Sachwald, 2003). Mowery *et.al* (1998) emphasize the role of the resource-based view in explaining the influence of a firm's technological capabilities and resources on its choice of partners in technological alliances.[15] The knowledge-based perspective also recognizes networking and partnership as a vital mechanism for firms to acquire knowledge and fill their knowledge gaps (Spender, 2007). Similarly, from a cognitive perspective, inter-firm linkages are important for innovation as people and firms need outside sources of cognition and competence to complement their own (Nooteboom, 1999).

The motives behind forming or extending an R&D alliance have been a central theme of inquiry in several past studies. Innovating firms require inter-organizational R&D cooperation with different partners for different purposes (see Pittaway *et.al*, 2004 for a review). For instance, the need for basic research requires cooperation with public science institutions like universities (Tether, 2002; Van Beers *et.al*, 2008). Firms seek for cooperation with suppliers in order to improve input quality and reduce production costs through process innovations (Chung and Kim, 2003). Von Hippel (1988, 2005) emphasizes the importance of cooperation with customers and lead-users as a source of new ideas for product innovation. Sharing R&D costs, benefiting from resource pooling and getting assistance in quick market penetration are important motives to cooperate with competitors (Miotti and Sachwald, 2003). A substantial number of other studies focus on the impact of participating in R&D alliances on the innovation performance. Although some studies do not find evidence for a positive impact of

[15] Lavie (2006: 640) provides an extended version of the resource-based view by incorporating rents that arise from cooperation with external partners.

cooperation on innovation performance (e.g. Freel, 2003), the general finding is that in most cases cooperation facilitates innovation (Ahuja, 2000b; Faems *et.al*, 2005, Phelps, 2005; Stuart, 2000).

As far as internationalization of R&D alliances is concerned, cooperation activities with foreign partners offer new opportunities that domestic partners might be unable to deliver. For example, collaboration with foreign customers is expected to lead to new product innovations due to adaptation of products to foreign customers' preferences (Lavie and Miller, 2008). Collaboration with foreign suppliers can improve access to new technologies and resources that can stimulate innovation (Eisenhardt and Schoonhoven, 1996; Gulati, 1999). Narula (2003: 144) argues that R&D collaboration with a foreign partner can be explained by demand and supply issues. Demand deals with customers and is related to adaptive research in response to specific market conditions due to differences in customers' tastes or legal constraints. Supply issues are related to firms seeking to utilize immobile assets that are either firm- or location–specific. Firm-specific supply factors are addressed by the industrial cluster literature (Feldman and Florida, 1994; Krugman, 1991; Marshall, 1920; Saxenian, 1994; Van der Panne and Van Beers, 2006). Partner firms can be part of specific domestic or foreign clusters where they benefit from three main benefits as put forward by Marshall (1920), i.e. the supply of specialized suppliers, the availability of specialized workforce and the benefits of net incoming knowledge spillovers. Country-specific characteristics of foreign partners are part of location-specific supply factors. R&D cooperation with foreign partners provides the advantage of getting access to country-specific resources, including access to knowledge of a specialized workforce or institutional community in a certain high technological field (Miotti and Sachwald, 2003). For instance, the fact that the United States is considered to be closer to the technological frontier in biotechnology and micro-electronics than the average European Union (EU) country implies that innovating firms in these sectors, based in EU region, are more inclined to choose US rather than EU partners. Another reason in favor of engaging in foreign partnerships is that R&D alliances with foreign partners can be more beneficial than locating/establishing a research-oriented affiliate abroad, which has high start-up and time costs, especially when prior experience is limited in the destination country.

2.2. R&D partner diversity and innovation performance

As to the first research question of this paper, when an innovative firm involved in R&D cooperation (with one or more partner types) starts a new R&D partnership, it can expect increased effectiveness of the existing alliances due to accumulated learning and prior experience. Two kinds of learning benefits can be distinguished: 1) learning cooperation skills and 2) learning innovation skills. Learning cooperation skills is expected to lead to more trust between partners resulting in reduced coordination/transaction costs and hence a positive effect on (both imitative and radical) innovation performance (Dodgson, 1993; Gulati, 1995). Furthermore, due to learning-by-doing, firms become more efficient in managing cooperation, the more they cooperate (Nieto and Santamaria, 2007; Powell *et.al*, 1996). Firms' experience with multiple partnerships and collaboration with different types of partners helps them avoid pitfalls in new partnerships, develop effective partnering routines (Simonin, 1997) and mitigate local search constraints (Rosenkopf and Nerker, 2001) and thus improves the overall impact of their partnership portfolio (Lhuillery and Pfister, 2009).

The second kind of learning process, i.e. learning innovation skills, is based on the expectation that collaboration with more partners in different stakeholder groups leads to more synergies and intake of complementary, multidisciplinary knowledge, which contributes to the production and sales of novel innovative products (Belderbos *et.al*, 2006). A wider range of knowledge intake from different knowledge sources is a stimulus for radical innovation performance (Chesbrough, 2003; Laursen and Salter, 2006). Diverse knowledge sources allow individuals in innovative firms to make novel associations and linkages (Cohen and Levinthal, 1990) which increases their innovativeness. Firms working with a diverse set of partners are more likely to be exposed to new ideas, novel perspectives and tacit/combinative skills in different technological fields (Kogut and Zander, 1992; Lim, 2004) and to a larger extent develop specific competencies useful to manage innovation projects and absorb relevant information from outside sources (Spender, 2007; Zahra and George, 2002). Firms relying on a large variety of external cooperative partners and sources of information are also exposed to a wider "R&D horizon" (Scott, 1996) and, as a result, are more likely to develop more novel products (Amara and Landry, 2005).

Learning innovation skills is also relevant in case of R&D collaboration with partners abroad as access to unique resources of foreign partners can produce complementary knowledge (necessary for radically new products) that is in short supply in the firm's home country; this is because partners abroad are embedded in separate national innovation systems than partners in the domestic market and therefore have access to nation-specific resources (Lavie and Miller, 2008; Miotti and Sachwald, 2003). It is also possible that geographic diversity leads to better adaption of existing products to customer preferences in foreign markets (Lavie and Miller, 2008) and thus improves the imitative innovation performance of the firm overseas. Operation in a context of international partners increases the likelihood of exposure to valuable knowledge of a specialized workforce or institutional community in a certain high technological field as well (Miotti and Sachwald, 2003).

While we expect to observe a significantly positive contribution from partner diversity to innovation performance, the effects are expected to be stronger for radical compared to imitative innovations. A diverse portfolio of R&D partners gives the firm access to a broader range of technological knowledge, market information and complementarity skills that the firm lacks (Chesbrough, 2003; Laursen and Salter, 2006). However, firms are more in need of these external resources when it comes to developing or introducing radically new products/services that is accompanied with greater degrees of technological complexity, market uncertainty and financial risk (Belderbos *et.al*, 2006). In case of imitative innovations, changes to the product portfolio of the firm are incremental and consists of minor modifications and replications of the existing products of a competitor. In general, much of the required knowledge and capacity for developing and introducing such innovations is internally available which reduces the necessity of external knowledge flows and dependency on different types of partners.

2.3. Organizational determinants of partner diversity

The second question we explore concerns particular organizational factors that affect the ability of the firm to have a more diverse portfolio of R&D partners: "what are the organizational determinants of R&D partner diversity?" Three main organizational determinants of partner diversity can be distinguished, 1) prior collaboration experience, 2) appropriability mechanisms, and 3) information technology infrastructure.

The first determinant, prior collaboration experience, teaches firms how to select, attract and deal with different partner groups effectively, how to nurture proper partnering routines and conflict resolution mechanisms, and how to adjust objectives and expectations in a better way (Das and Teng, 1998a, 1998b; Heimeriks, 2008; Heimeriks and Duysters, 2007; Simonin, 1997; Zollo and Winter, 2002). Accumulation of past experience also assists firms to reduce probability of opportunistic behavior in their future cooperative endeavors (e.g. Gulati, 1995) and thereby alleviates barriers to cooperate and increases firms' comfort to engage in more diverse networks. Prior partnering experience with international partners makes firms familiar with crucial steps they require to take before they can adopt foreign partners and increases their tendency to establish more diverse alliances; these steps might relate to legal constraints, cultural differences, and standard requirements, among others (Lavie and Miller, 2008). Previous experience in networking with a pool of nationally-distant partners reinforces the firm capacity to discern its partners' national environments and to develop unique means for exploring external opportunities with distinctive partners (Barkema *et.*al, 1996; Barkema *et.al*, 1997; Lavie and Rosenkopf 2006).

Leakage of sensitive knowledge, unwanted resource spillover, and misappropriation of value created through partnering are among considerable barriers discouraging firms from establishing R&D partnerships (e.g. Gulati and Singh, 1998; Hamel, 1991). When the level of mutual trust among partners is limited, appropriability mechanisms such as patenting are especially important to protect intellectual property and competitive advantage of the firm (Cohen *et.al*, 2000; Geroski 1995; Harabi, 1994). In particular, availability and quality of protective means is a determinant of the firm's decision to engage in external cooperative agreements (Ahuja, 2000a; Cassiman and Veugelers, 2002) and in that way is expected to be a determinant of the firm's partner diversity as well.

Finally, the technological infrastructure of the firm is expected to be important to the firm's decision to cooperate with more partners (of different types) and therefore influential to partner diversity. Firms with diverse partnership portfolios are expected to have strong coordination capabilities in order to be able to manage such portfolios (Lavie and Miller, 2008). Similarly, high levels of coordination and communication between partners are an important part of an alliance's management capability, which is expected to affect a firm's capability to attract and collate a more diverse portfolio of partners (Littler *et.al*, 1995; Schreiner *et.al*, 2009). Advanced information technologies (IT) such as participatory project management (PPM) tools, inter-organizational systems (IOS), and groupware and collaboration technologies (GCT) facilitate collaboration and integration, coordination of tasks, and reuse of product and design information among the agents involved in a joint project (Aral *et.al*, 2007). Such systems mitigate uncertainty by enabling diverse project teams to communicate changes in real time (Carte and Chidambaram 2004), help firms spot low-cost and high-quality global partners (Bardhan *et.al*, 2007; Thomke, 2006), and support distributed innovation environments and dispersed/virtual new product development (NPD) teams (Boutellier *et.al*, 1998; Nambisan 2003). As a consequence, we expect that firms with higher levels of IT endowments exhibit higher propensities towards diverse networks of innovation partners.

3. Model and Model Operationalization

3.1. Empirical models

Three general models are investigated. In all models, subscripts *i* and *t* relate to individual firms and survey periods respectively. Model (1) relates innovation performance to external R&D cooperation and a number of observable control variables.

$$Innovation\_performance_{i,t} = \alpha_0 + \alpha_1 External\_cooperation_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 RD\_intensity_{i,t} + \alpha_4 RD\_permanence_{i,t} + \alpha_5 Training_{i,t} + \alpha_6 Process\_innovation_{i,t} + \alpha_7 Organizational\_innovation_{i,t} + \alpha_8 Group_{i,t} + \alpha_s Sector + \alpha_y Year + u_i + \varepsilon_{i,t} \quad (1)$$

Model (2) relates innovation performance to two measures of partner diversity and a number of control variables. To handle potential self-selection bias in firms' decision to cooperate with external R&D partners, a two-stage analysis is used. If the same firm attributes and industry conditions that derive firms' decision to engage in R&D cooperation with external partners also influence their tendency to cooperate with a more diverse set of partners, then failing to account for this self-selection bias may lead to misleading results. Following the Heckman (1979) procedure, we will estimate the second model in two stages. In the first stage, we predict whether or not the firm collaborates with any type of external partner.

$$External\_cooperation_{i,t} = \beta_0 + \beta_1 Internal\_cooperation_{i,t} + \beta_2 Size_{i,t} + \beta_3 RD\_intensity_{i,t} + \beta_4 Multinational_{i,t} + \beta_5 Extramural\_RD + \beta_s Sector + \beta_y Year + u_i + \varepsilon_{i,t} \quad (2a)$$

In the second stage, we investigate the impact of partner diversity on innovation performance of the firm, while controlling for the inverse Mills ratio in order to estimate the impact of self-selection based on the predicted values of *Lambda* obtained from the first stage.

$$Innovation\_performance_{i,t} = \delta_0 + \delta_1 Stakeholder\_diversity_{i,t} + \delta_2 Geographic\_diversity_{i,t} + \delta_3 Size_{i,t} + \delta_4 RD\_intensity_{i,t} + \delta_5 RD\_permanence_{i,t} + \delta_6 Training_{i,t} + \delta_7 Process\_innovation_{i,t} + \delta_8 Organizational\_innovation_{i,t} + \delta_9 Group_{i,t} + \delta_{10} IMR_{i,t} + \delta_s Sector + \delta_y Year + u_i + \varepsilon_{i,t} \quad (2b)$$

The third model investigates the organizational determinants of partner diversity.

$$Partner\_diversity_{i,t} = \varphi_0 + \varphi_1 Prior\_experience_{i,t} + \varphi_2 Patenting_{i,t} + \varphi_3 IT\_intensity_{i,t}$$
$$+ \varphi_4 Size_{i,t} + \varphi_5 Multinational_{i,t} + \varphi_6 Subsidy_{i,t} + \varphi_s Sector + \varphi_y Year + u_i + \varepsilon_{i,t} \quad (3)$$

The dependent variable in model (1) measures innovation performance. With regard to the variable of main interest in model (1), i.e. *External_cooperation*, a positive effect on *Innovation_ performance* is expected. The rest of the variables in model (1) are control variables. *Size* is expected to influence the dependent variable of model (1) positively as larger firms are supposed to innovate more often than smaller firms due to availability of more domestic financial resources and in-house multidisciplinary expertise. The three variables *RD_intensity*, *RD_permanence*, and *Training* correspond to absorptive capacity of the firm and are assumed to influence the firm's commercial success through learning mechanisms such as "learning by doing". A firm with a high absorptive capacity is better able to transform information and resources from diverse knowledge sources into innovations. A positive impact of these variables on the dependent variable is therefore expected. *RD_intensity* is the most common proxy for absorptive capacity in the literature. This variable measures how much of the firm's revenues are spent on internal learning processes through designing and developing new artifacts and know-how. *RD_permanence* and *Training* capture certain qualitative aspects of absorptive capacity.

Process_innovation indicates if the firm is involved in process innovations. Process innovations can lead to more innovative output as they are often a complementary part of product innovations. The same argument is valid for whether or not the firm is involved in organizational and/or marketing innovations, denoted by *Organizational_innovation*. Both variables are expected to have a positive impact on *Innovation_performance*. *Group* shows whether or not the firm belongs to a holding/group. A positive sign is expected as being a member of a holding can lead to pooled resources and knowledge and increased intra-group synergies and hence to higher innovation output. *Sector* and *Year* are vectors of industry and time dummies (preceded by vectors of parameters, for instance α_s and α_y, to be estimated).[16] Finally, u_i and $\varepsilon_{i,t}$ are the model's error components. The term u_i refers to firm-specific

[16] Sector dummies are based on 3-digit NACE codes (rev. 1.1) and allow for the possibility of firms moving between different sectors over time.

unobserved heterogeneity and $\varepsilon_{i,t}$ to idiosyncratic disturbance that is assumed to be i.i.d. normally distributed.

In model (2a) *External_cooperation* is regressed on a set of five explanatory variables in addition to sector and time dummies. The model is used to predict a firm's decision to engage in partnerships with external actors. *Internal_cooperation* tracks cooperation between members of an enterprise group. Firms having the experience of cooperating with their sister companies are more prepared to collaborate with external partners and hence a positive effect is expected. *Size* and *RD_intensity* are included as larger firms and those more intensively engaging in intramural R&D are expected to be more inclined towards external collaboration. *Multinational* tracks if the firm belongs to a multinational enterprise group. These types of firms, with international affiliates, are expected to be more likely to partner with external parties. Firms engaging in extramural R&D (*Extramural_RD*) have experience with opening up their innovation activities to third parties and thus are more likely to participate in collaborative agreements with any of them. Hence, we expect that *Extramural_RD* affects *External_cooperation* positively.

Model (2b) is similar to model (1) with two differences. Instead of *External_cooperation* two diversity measures are included in the model. *Stakeholder_diversity* and *Geographic_diversity* measure how diverse the portfolio of a firm's R&D partners is in terms of the partner's activity type and geographical location respectively. Moreover, model (2b) includes an additional explanatory variable. *IMR* (the inverse Mills ratio) is yielded from estimating model (2a) and added to capture the potential sample-selection bias.

The dependent variable in the two versions of model (3) is either *Stakeholder_diversity* or *Geographic_diversity*. *Prior_experience* is expected to affect *Partner_diversity* positively. Firms learn from their past experiences and are therefore more likely to broaden their alliance portfolio providing such experience exists (Das and Kumar, 2007).[17] When stakeholder diversity is concerned, any instance of external R&D

[17] Still, the capability of the firm to benefit from its prior experience may also depend on its absorptive capacity. According to Hoang and Rothaermel (2005: 342), "It appears that to reap benefits from prior alliance experience, a firm needs to possess absorptive capacity, the potential capacity to acquire and assimilate new knowledge and the realized capacity to transform and exploit the new knowledge."

cooperation is considered as prior experience. In case of geographic diversity, tough, only previous cooperation with foreign partners is considered to be prior experience. *Patenting* specifies whether or not the firm relies on patenting as a mechanism to protect its innovations/inventions against others. Firms using patents are expected to be more willing to engage in collaboration with third parties. *IT_intensity* is a regulated measure of the firm's IT endowments and expected to facilitate the diversification of its alliance portfolio. Multinational firms are indicated by the variable *Multinational*. These firms, due to their nature, are expected to have more experience and inclination to work with partners of diverse types or in diverse locations. Finally, *Subsidy* is a control variable indicating if the firm has participated in any subsidy program such as EU-Framework Programmes.[18] One of the primary eligibility requirements of such programs is to have innovation partners. Furthermore, research shows that companies receiving public financial support/grant are more likely to cooperate with others, which increases the likelihood of a more diverse portfolio of partners as well (Dekker and Kleinknecht, *forthcoming*).

3.2. Operationalization of variables

Innovation_performance, defined as the log of the share of innovative sales per full-time employee, is observed at the end of the period *t*. Two types of performance measures are distinguished. Radical innovations relate to sales of the firm new to the market/sector. Imitative innovations represent products already introduced to the market by competitors but new to the firm.[19,20] The variables of main interest, i.e. *External_cooperation*, *Stakeholder_diversity* and *Geographic_diversity* relate to the duration of the period *t*. *External_cooperation* takes a value of 1 if firm *i* collaborates with any type of external partner during the time period *t* and a value of 0 otherwise. The firm was asked if it had cooperation on any of its innovation activities with external

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[18] This includes benefits such as tax credits/reductions, governmental grants, subsidized loans and loan guarantees. Ordinary payments for research conducted entirely for the public sector under contract are excluded.

[19] The definition of "product" in the surveys includes both *physical goods* and *intangible services*.

[20] According to the surveys, newness is defined with respect to fundamental capabilities and characteristics of the firms' products as a whole and/or their subsystems including technical specifications, incorporated software or other immaterial components such as intended uses and user friendliness.

enterprises or institutions during the period *t*.[21] Therefore, it is a valid assumption that, on average, a time-lag of 18 months exists between when a firm engages in external cooperation and when its innovation output is measured in the survey. This built-in time-lag is of proper magnitude as innovation partnerships and R&D projects last on average one to two years (e.g. Lavie and Miller, 2008; Pakes and Schankerman, 1984). Other variables in the models, except for those explained below, are directly extracted from the CIS survey and belong to the general characteristics of the firm or indicate the state of the firm during the period. *Size* measures the natural logarithm of the firm size (in full-time equivalent number of employees). *Process_ innovation* includes new or significantly improved production/manufacturing technologies, distribution/delivery methods, supply chain/logistics processes, and support activities (such as maintenance or computing systems). The outcome of the process should have significant impact on the level of output, quality of products or costs of production/distribution. Pure organizational or managerial changes are excluded. The variable takes the value 1 if a firm is involved in process innovations and 0 otherwise. *Organizational_innovation* is defined as implementation of new or significantly changed corporate strategies, management methods, organizational structures, marketing concepts and sales channels. The variable takes the value 1 if an organizational innovation occurs during the period *t* and 0 otherwise. *Group* shows a value of 1 if the firm belongs to a holding/group (of sister companies) and 0 otherwise (i.e. independent).

RD_intensity is defined as the log of the average of intramural R&D expenditures of the company divided by the average of its total turnover. Since investments and sales are prone to high fluctuations and vulnerable to several types of economic shocks, we opted to use average figures over the 3-year period *t* (prior to measuring output at the end of the period *t*) to correct for these unwanted, incidental turbulences and attain a less noisy measure. *RD_permanence* and *Training* are dummies with value 1 if the firm conducts intramural R&D on a permanent/continuous basis and training activities related to development and/or commercialization of innovations respectively and 0 otherwise. *Internal_cooperation* is a dummy with value 1 if a firm, which is part of an enterprise group, internally cooperates on innovation activities with other firms in the

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[21] Cooperation is defined as active participation on innovation activities such as joint R&D and exploratory projects. Pure contracting out of work and outsourcing are excluded.

group and 0 otherwise. *Multinational* is a dummy similar to *Group* with the difference that it takes a value of 1 only if the firm is part of a multinational enterprise group (with headquarters both inside and outside the Netherlands) and 0 otherwise. *Extramural_RD* is 1 when a firm engages in extramural R&D activities performed by third parties (including other enterprises and public/private research organizations) and purchased by the firm and 0 otherwise.

With regard to model (3), the first determinant, *Prior_experience*, has a value of 1 if the firm has had experience with external R&D partners in the past and 0 otherwise. *Prior_experience* indicates whether or not the firm had experience with (foreign) external partners prior to period t. For example, for $t = 4$ (i.e. the fourth wave of CIS: 2004-2006), *Prior_experience* is equal to 1 for all those firms which had at least an external partner during the time period 1994-2004. For the first period (i.e. 1994-1996) this variable is set to missing. *Patenting* is a dummy variable with value 1 if the firm patents its innovations and 0 otherwise. *IT_intensity* is defined as the average IT capital stock (including both hardware and software) as a share of the average total capital of the company over the period t.[22] *Subsidy* is a variable with value 1 if the firm has participated in a public subsidy program and 0 otherwise.

The diversity variables are constructed through the Herfindahl index, also known as the Simpson's diversity index.[23] It is among the most accepted measures of diversity in the economic literature (Patil and Taillie, 1982; McDonald and Dimmick, 2003).[24]

$$H = \sum_{j=1}^{N} \left(\frac{P_j}{P_T} \right)^2 \tag{4}$$

[22] Detailed R&D expenditure and capital stock data for the three years covered by each wave of the CIS survey are supplemented through specialized R&D and ICT surveys supplied by the Statistics Netherlands.

[23] We distinguish between stakeholder diversity and geographic diversity as these two variables measure different dimensions of partner diversity with diverging effects on innovation and different implications for practice. In contrast to most of existing studies, we do not merge these multiple dimensions in a single indicator (e.g. Blau index).

[24] For the sake of increased measurement accuracy, we chose to adopt a diversity index rather than to simply add up the different partner categories as being used in some studies (see e.g. Laursen and Salter, 2006).

with P_j representing the number of partners of category j, P_T the total number of partners and N the number of different partner categories. It is possible to utilize dummies in the arithmetic operation of this index, where only positive cases are counted and not the number of partnerships of each category. As a result, the total number of partners of different categories can never exceed the total number of categories. The Herfindahl index was originally developed to measure the degree of market concentration. As this study is interested in diversity (and not concentration) of the innovating firms' partners, the complement of the Herfindahl index is relevant.

$$Diversity = 1 - \sum_{j=1}^{N} \left(\frac{P_j}{P_T} \right)^2 \qquad (5)$$

If *Diversity* approaches 0 all the partners of the firm would belong to a single category. It approaches 1 if partners are more equally distributed over a large number of categories.[25] We use two diversity measures in this study. For stakeholder diversity, we have 6 categories: competitors (or other enterprises in the same sector of the firm), customers (or clients), suppliers (of equipment, materials, services, components, and software), universities (and other higher education institutions), private science institutes (and consultants and commercial R&D labs), and public science institutions (and government/non-profit research institutes).[26] For geographic diversity, there are 4 categories: the Netherlands, (rest of the) Europe, USA, and others (all other countries).[27]

[25] In theory, we have diversity equal to 1 when we are dealing with a set of infinitely large number of partner categories.

[26] 2002-2004 and 2004-2006 surveys include exactly the same set of partner categories. In 1994-1996 and 1998-2000 surveys, the categories of consultants and private science institutes were originally separate from each other but were later merged for calculation of the diversity index.

[27] 2002-2004 and 2004-2006 surveys include exactly the same set of partner locations. In 1994-1996 and 1998-2000 surveys, Japan was distinguished from the category of others. In 1998-2000 survey, European countries were divided into European Union or Free Trade Association countries (EU/EFTA) and EU Candidate Countries (EU-CC). In both cases, the subcategories were merged before the diversity index was calculated.

4. Data and Descriptives

Models (1), (2a), (2b) and (3) will be estimated with a panel of firms reporting product innovation(s) during the period 1994-2006. The panel is constructed from four waves of the Dutch Community Innovation Survey (CIS). The CIS is a very rich source of innovation data at the micro level. It has a rigorous sampling/data collection protocol in the Netherlands. The surveys belong to the periods 1994-1996, 1998-2000, 2002-2004, and 2004-2006. Subscript t in the empirical models refers to one of the above 3-year time periods. However, as explained earlier, different variables are observed at different points across the period which introduces relevant time-lags in measuring the variables. These time-lags are of interest when one concerns potential dynamics and endogeneity in the models. The CIS data is complemented with data from the R&D Survey (1995, 1997, 1999, 2001, 2003, and 2005), ICT Survey (period 1993-2005) and annual Production Statistics (period 1994-2006). The final panel includes information about 12,811 Dutch and foreign innovating firms in the Netherlands. In Table 1 the descriptives for the relevant variables are reported.

Table 1: Descriptives of relevant variables

	Type	Mean	Std. Dev.	Observations
Dependent variables				
Innovation performance	Continuous			
• *Radical*	(log scale)	5.235	4.813	10,799
• *Imitative*		7.772	4.152	10,786
External Collaboration	Dichotomous	0.363	0.481	12,811
Partner Diversity	Continuous			
• *Stakeholder*	$\in [0, 1]$	0.169	0.293	12,811
• *Geographic*		0.094	0.215	12,811
Independent variables				
Size	Continuous (log scale)	4.329	1.394	12,811
R&D Intensity	Continuous (log scale)	0.038	0.079	11,717
Process Innovation	Dichotomous	0.687	0.464	12,811
Organizational Innovation	Dichotomous	0.736	0.441	12,659
Group	Dichotomous	0.597	0.491	12,811
Multinational	Dichotomous	0.195	0.396	12,606
R&D Permanence	Dichotomous	0.475	0.499	12,811
Training	Dichotomous	0.494	0.500	12,811
Internal Collaboration	Dichotomous	0.202	0.401	12,277
Extramural R&D	Dichotomous	0.735	0.442	12,811
Prior Experience	Dichotomous			

• *Prior Cooperation*		0.472	0.499	2,864
• *Prior Foreign Cooperation*		0.289	0.454	2,864
Patenting	Dichotomous	0.190	0.392	12,811
IT Intensity	Continuous ∈ [0, 1]	0.163	0.261	4,024
Subsidy	Dichotomous	0.389	0.488	12,690
Cooperation with				
Any external partner	Dichotomous	0.363	0.481	12,811
Competitors	Dichotomous	0.139	0.346	12,811
Customers	Dichotomous	0.216	0.411	12,811
Suppliers	Dichotomous	0.253	0.437	12,811
Universities	Dichotomous	0.123	0.329	12,811
Private Science institutes	Dichotomous	0.136	0.343	12,811
Public science institutes	Dichotomous	0.109	0.311	12,811
Dutch partners	Dichotomous	0.327	0.469	12,811
European partners	Dichotomous	0.173	0.378	12,811
American partners	Dichotomous	0.058	0.234	12,811
Other partners	Dichotomous	0.050	0.219	12,811
Additional descriptives				
Turnover (1000 €)	Continuous	75,100	653,000	12,606
Employees (fte)	Continuous	294.7	1767.0	12,811
R&D Employees (fte)	Continuous	11.4	140.5	11,635
R&D Expenditure (1000 €)	Continuous	1,110	18000	12,811
Innovation Expenditure (1000 €)	Continuous	2,004	25200	12,811
Share in Total Sales of	Continuous			
• *Radical Innovations*	∈ [0, 1]	0.081	0.154	10,814
• *Imitative Innovations*		0.246	0.248	10,814
Innovation performance	Continuous			
• *Radical*		21,052	96,022	10,799
• *Imitative*		37,420	146,344	10,786
R&D Intensity	Continuous	0.043	0.099	11,717

The dichotomous variables are rather complete for the whole sample. In case of continuous variables, some data is missing due to invalid/non-response. *Prior_experience* is only available for 2,864 firms as it is defined for only those firms that are present in more than one CIS survey. For all firms in the first survey (1994-1996) this variable is missing too. Availability of *IT_intensity* also drops to 4,024 firms due to linking the CIS and ICT surveys.

The average firm in our sample has 295 employees (11 of which directly engaged in R&D activities), generates on average € 75.1 million in annual sales (over the period 1994-2006), and spends € 2 million on innovation activities (of which €1.1 million on intramural R&D) for 3-year or shorter innovation projects.[28] On average, 8.1% and 24.6% of our sampled firms' sales can be considered radical (new to the market) and imitative (only new to the firm) respectively. Translating these figures to performance measures, the average firm in the sample produced €21,052 and €37,420 radical and imitative sales per employee respectively.[29] The average R&D intensity in our sample of innovating firms amounts to 4.3%. About three-fifth of firms in the sample belong to a bigger enterprise group while around one-fifth of them are multinational. Firms in our sample are product innovators. Around one-third (36.4%) of them formally cooperate with external R&D partners on innovation activities, two-third (68.7%) report process and 73.6% organizational innovation alongside their product innovations. Nearly half of the firms in the sample conduct in-house R&D on a regular basis. Half of the sample provides special innovation-related training for their employee, about one-fifth patent their innovations and two-fifth has received subsidies from public/governmental organizations during the period 1994-2006. On average, the share of IT capital in total capital stock of our firms amounts to 16.3%.

Looking at the pattern of cooperation with different types of partners reveals interesting results. As expected, vertical cooperation with the value chain partners (i.e. suppliers and customers) are the most common type of partnership. Horizontal cooperation with competitors and partnership with science institutes due to their specific risk concerns (e.g. the threat of leakage of sensitive information) or high barriers (e.g. requirements for conducting basic research) are less common forms of collaboration. As to the location of partners, expectedly, cooperation takes place substantially more with domestic than foreign partners. By far, Dutch partners are the most common choice for firms in the Netherlands. Among partners outside the national borders, European enterprises are, on average, the first choice, followed by partners in the US or other countries. Observing the diversity measures suggests that the sampled firms' partner portfolios are on average rather concentrated. In other words, most firms in the sample either do not cooperate at all or cooperate with partners in only one or a limited number of categories. The concentration is stronger in case of geographic than stakeholder diversity.

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[28] CIS Survey asks about innovation/R&D expenditures over a 3-year period.

[29] To conform to normality conditions, we use these measures in the logarithmic scale as our dependent variables.

Table 2 shows the sectoral distribution of the sample based on 2-digit NACE codes.[30]

Table 2: Sectoral distribution of the sample

Sector	# of firms	% of sample
Manufacturing	**5,671**	**44.27**
• **High Technology**	**2,378**	**18.56**
Pharmaceuticals, Chemicals and Related Products	586	4.57
Electrical Machinery and Apparatus Manufacturing	907	7.08
Electronics, Computers and Office Equipment	325	2.54
Medical, Optical and Scientific Instruments	235	1.83
Aerospace and Transportation Equipment	325	2.54
• **Low Technology**	**3,293**	**25.71**
Food, Beverage and Tobacco	699	5.46
Textile, Clothing and Leather	218	1.70
Paper and Related Materials	335	2.61
Printing and Publishing	346	2.70
Rubber, Plastics and Synthetic Materials	370	2.89
Glass, Pottery and Related Products	202	1.58
Base Metals and Fabricated Metal Products	762	5.95
Furniture and Wood Products	361	2.82
Services	**6,083**	**47.48**
• **Knowledge Intensive**	**3,519**	**27.47**
Air/Water Transportation	630	4.92
Post and Telecommunications	74	0.58
Finance: Banks/Insurances and Pension Funds	397	3.10
Real Estate Trade and Rental	266	2.08
Multimedia/Entertainment and Computer Services	547	4.27
Health, R&D and Education	58	0.45
Professional and Commercial/Business Services	1547	12.07
• **Knowledge Non-intensive**	**2,564**	**20.01**
Auto Trade and Repair of Motor Vehicles	230	1.79
Wholesale and Commission Trade	1,483	11.58
Retail Trade	326	2.54
Catering Services	184	1.44
Environmental and Community/Cultural Services	341	2.66
Others	**1,057**	**8.25**
Agriculture/Forestry, Fishery and Mining	294	2.29
Public Utilities: Electricity, Gas and Water Supply	64	0.50
Construction and Related Activities	699	5.46
Total	**12,811**	**100**

[30] The sample size and composition allowed us to control for the sector dummies in the regressions based on 3-digit NACE. This leads to capture more of firm idiosyncrasies and sector heterogeneities.

The sample covers all major manufacturing and services sectors of the economy. More than 44% of the sample belongs to manufacturing, nearly 48% to services and the rest to firms in other sectors. A careful comparison with the National Accounts (NA) data reveals that the sample overrepresents most of the manufacturing industries while underrepresents some services such as the *Telecommunications*, *Health* and *Education* sectors. This can be explained by the fact that the sample only includes firms with sales of new products. Our definition of production innovation, though capturing both goods and services, is more applicable to the manufacturing sectors due to the more measurable/tangible nature of output in these sectors.[31] In Table 2, the manufacturing and services sectors have also been divided respectively into high vs. low technology and knowledge intensive vs. non-intensive, based on the general classification of OECD.[32] In manufacturing, low technology industries constitute a larger portion of the sample while in services the majority belongs to the knowledge intensive sectors.

5. Econometric Results and Discussion

5.1. Innovation performance as a function of external collaboration

Model (1) is estimated for both radical and imitative innovation performance. By definition, both of these measures of innovation are characterized by a lower bound of 0 as no negative value for company sales is conceivable. Besides, the number of firms that report a value of 0 is substantial. These are firms with product innovation projects that were not completed by the end of the 3-year period about which they were

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[31] Apart from the sectoral distribution, the size and revenue distributions in our sample resemble those in the NA data to a very good extent and thus our sample can be considered as a good representation of the Dutch economy as a whole. Supplementary data in this regard is available upon request.

[32] See the Eurostat portal: http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/hrst_st_esms_an9.pdf for an introduction. In this study, high-technology and medium-high-technology firms are classified as high tech manufacturing while medium-low-technology and low-technology firms are classified as low tech. Knowledge intensive services includes several groupings such as knowledge-intensive high-technology, market and financial services while knowledge non-intensive includes less-knowledge-intensive services sectors. In accordance with the OECD classification, we define different subclasses in our analysis based on 3-digit NACE; however, for the sake of presentation in table 2, the groups are merged and shown on 2-digit level.

questioned, for one of the following reasons: (1) the project was completely abandoned or seriously hampered in the concept stage or after it was begun, (2) the project was seriously delayed with respect to its initial planning, (3) the project required more than 3 years to complete and therefore it was still ongoing by the end of the period when the firm was surveyed. This means that we deal with censored dependent variables in model (1) and thus use maximum likelihood estimation of a type I Tobit model. [33] In all the Tobit regressions performed, the standard likelihood-ratio test indicates that the panel version of the estimator is favorable over its cross-section (or pooled) version. The likelihood function in panel Tobit is calculated by Gauss-Hermite quadrature. As to a robustness check, the reported results were found significantly insensitive to the quadrature parameters and the number of integration points.

To observe inter-sectoral differences, estimations are reported for 5 different samples. In addition to the complete sample, estimation results are presented for the manufacturing, services, high-tech, and low-tech subsamples separately.[34] Standard one-tailed z-test is used to compare regression coefficients between the groups. Drawing on the work of Clogg *et.al* (1995), the relevant z-statistic is calculated as (Paternoster *et.al*, 1998):

$$Z = \frac{|b_1 - b_2|}{\sqrt{\sigma_{b_1}{}^2 + \sigma_{b_2}{}^2}} \qquad (6)$$

b_1 and b_2 are the estimated coefficients associated with the two subsamples and σ_{b1} and σ_{b2} are the coefficient standard errors.

[33] From Madalla (1984) and Wooldridge (2002: 524) we know that a *Tobit* estimator would be necessary to regress censored dependent variables on a set of explanatory variables, as GLS (and particularly OLS) would result in biased (asymptotically inconsistent) estimations. We also conducted a bootstrapped version of Tobit, which led to exactly identical results in terms of the sign and significance of almost all the coefficients; size of the estimates was also highly comparable between the two methods. The results of the bootstrap procedure are available on request.

[34] Refer to the data section for applicable definitions. Manufacturing and services exclude Construction, Energy, Agriculture, and Mining sectors. High-tech includes high-technology manufacturing and knowledge-intensive services. Low-tech includes low-technology manufacturing and knowledge-non-intensive services.

Table 3: Impact of external R&D collaboration on radical and imitative innovation performance: Panel Tobit estimates for 1994-2006 with robust standard errors

Radical Innovation Performance	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
External Collaboration	0.960***	0.953***	0.845***	0.108	1.107***	0.845***	0.262
	(0.130)	(0.171)	(0.187)	(0.253)	(0.181)	(0.186)	(0.260)
Size	0.111**	0.207***	-0.085	0.292***	0.001	0.248***	0.247***
	(0.048)	(0.067)	(0.062)	(0.091)	(0.062)	(0.074)	(0.097)
R&D Intensity	6.868***	7.215***	5.862***	1.353	6.202***	8.242***	2.040
	(0.784)	(1.160)	(0.962)	(1.507)	(0.899)	(1.483)	(1.734)
Process Innovation	0.711***	0.662***	0.835***	0.173	0.873***	0.588***	0.285
	(0.130)	(0.176)	(0.182)	(0.253)	(0.177)	(0.191)	(0.260)
Organizational Innovation	0.920***	0.926***	0.744***	0.182	0.849***	0.982***	0.133
	(0.143)	(0.186)	(0.207)	(0.278)	(0.198)	(0.205)	(0.285)
Group	0.096	-0.036	0.229	0.265	-0.252	0.422**	0.674***
	(0.132)	(0.174)	(0.189)	(0.257)	(0.185)	(0.189)	(0.264)
R&D Permanence	1.410***	1.367***	1.068***	0.299	1.339***	1.362***	0.023
	(0.136)	(0.181)	(0.193)	(0.265)	(0.196)	(0.192)	(0.274)
Training	0.761***	0.646***	0.989***	0.343*	0.917***	0.659***	0.258
	(0.124)	(0.161)	(0.180)	(0.241)	(0.175)	(0.175)	(0.247)
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	
Model Diagnostics							
Observations	9626	5401	3280		4147	5479	
Log likelihood	-25614	-14646	-8850		-11363	-14208	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	

Imitative Innovation Performance	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
External Collaboration	0.193**	0.228**	0.161	0.067	0.100	0.264**	0.164
	(.091)	(0.117)	(0.143)	(0.185)	(0.139)	(0.117)	(0.182)
Size	-0.087***	0.036	-0.162***	0.198***	0.027	-0.219***	0.246***
	(0.033)	(0.046)	(0.048)	(0.066)	(0.048)	(0.046)	(0.066)
R&D Intensity	0.564	2.110***	-1.010	3.120***	1.421**	-0.977	2.398**
	(0.566)	(0.815)	(0.763)	(1.116)	(0.701)	(0,985)	(1.209)
Process	0.603***	0.605***	0.382***	0.223	0.503***	0.685***	0.182

Innovation	(0.090)	(0.118)	(0.137)	(0.181)	(0.134)	(0.117)	(0.178)
Organizational Innovation	0.546***	0.248**	0.968***	0.720***	0.717***	0.408***	0.309*
	(0.098)	(0.125)	(0.155)	(0.199)	(0.150)	(0.125)	(0.195)
Group	0.176*	0.177	-0.053	0.230	0.077	0.214*	0.137
	(0.091)	(0.118)	(0.143)	(0.185)	(0.141)	(0.116)	(0.183)
R&D Permanence	0.478***	0.535***	0.269*	0.266*	0.272*	0.670***	0.398**
	(0.094)	(0.121)	(0.148)	(0.191)	(0.148)	(0.120)	(0.191)
Training	0.312***	0.448***	0.243*	0.205	0.365***	0.280***	0.085
	(0.085)	(0.109)	(0.136)	(0.174)	(0.133)	(0.108)	(0.171)
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	
Model Diagnostics							
Observations	9,612	5,400	3,278		4,145	5,467	
Log likelihood	-27,080	-14,882	-9,589		-11,807	-15,281	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	

All: Complete sample; Mfg: Manufacturing sector; Svc: Services sector; H Tech: High-technology and/or knowledge-intensive sectors; L Tech: Low-technology and/or knowledge non-intensive sectors. Z-test: One-tailed Z-test results of the difference between the two subsamples' regression coefficients. *, **, *** indicate that estimates are significant at 10%, 5% and 1%. Robust standard errors are reported in parentheses.

Table 3 reports the results of estimating model (1).[35] R&D cooperation with external parties, as expected, is found to have mostly a significant positive effect on both radical and imitative innovation performance of the firm. In other words, firms produce more innovative output per employee if they cooperate on their innovation activities with external firms. Expectedly, the effects are stronger in case of radical than imitative products. Radical innovations are fundamentally riskier and require

[35] As noted earlier, the CIS survey design is such that the independent variables of our models are by definition have an average time-lag of about 1.5 years with respect to the dependent variables. To further investigate the effect of larger time-lags on our results, we also tested similar models where dependent variables belong to period *t* and independent variables to period *t*-1. Concerning the fact that dependent variables are defined at the end of each period and independent variables over the 3-year duration of each period, this resulted in an average time-lag of 4.5 years. To avoid any concerns about potential endogeneity, we also replicated the analysis based on the GMM method (Arellano and Bond, 1991). In both cases, the obtained results are highly comparable to those reported in this paper in terms of the sign and significance of the variables of interest, although the magnitude of some of the effects is greater with larger time-lags or based on the GMM method. We decided to report the present results due to significantly greater sample sizes and statistical fit of the models. The other versions of the results are accessible on request.

more finance and knowledge that might be only available beyond the internal resource pool of the firm. This increases the importance of relying on external sources of financial and knowledge resources for successfully conducting and introducing radical innovations. As to specific sectoral characteristics, manufacturing firms benefit more from inter-firm collaboration compared to services firms, although the difference in results is not significant. This can be due to the definition of innovation applied in this research that is more suitable/traceable in manufacturing than in services sector. Comparing the high- and low-technology sectors reveals an interesting finding. External collaboration is more effective for radical innovations in high-tech sectors and for imitative innovations in low-tech sectors. This can be attributed to the higher level of product complexity and market volatility and shorter product life cycle (due to higher rates of obsolescence) in high-tech markets. This makes inter-firm alliances more essential to radical innovations in these markets as firms need to rely on external resources to be able to cope with these uncertainties and discontinuities.

As to the control variables, the effect of firm size is mixed. Larger firms are found to have a higher radical innovation performance in manufacturing and low-tech industries and lower imitative innovation performance in services and low-tech industries. Overall, significant differences in size effects between the subsamples are observed. R&D intensity and R&D permanence, as expected, positively contribute to (especially radical) innovation performance of the firm. The effect of R&D intensity and R&D permanence are greater in manufacturing firms as developing new products is more dependent on continuous R&D activities than introducing new services (which is highly dependent on marketing activities instead). R&D permanence is found to be more essential in low- rather than high-tech industries. At the first sight, this finding might appear surprising. However, the rate of internal R&D activities is lower in low-tech industries which makes their continuity more important for explaining performance and differentiating firms in these sectors. As to another learning element, training of employees is found to be significant to innovation performance, particularly in case of radical innovations. Training seems to be more important for firms in the services sector as well as high-tech firms that work with a greater deal of complicated and diverse knowledge/artifacts. Furthermore, the results show that process and organizational innovation complement product innovation in all the sectors studied. Finally, membership in an enterprise group seems to be non-influential to innovation performance. It is likely that the main part of group-membership potential effects is captured through the external collaboration and size variables and this renders the effect of group variable insignificant.

5.2. *Innovation performance as a function of partner diversity*

In order to examine the impact of partner diversity on the performance of innovation activities of the firm a two-stage model with self-selection bias correction is used.[36] Some of the firm's attributes favoring its decision to engage in external partnership might positively affect its preference or ability to diversify its portfolio of partners as well. In other words, firms might self-select whether or not and at the same time to what extent open up their innovation activities. In that case, possible self-selection bias leads to inconsistent results. Following the Heckman procedure, the first stage models the influential factors that determine the firm's decision to engage in partnerships. Results of estimating model (2a) are presented in Table 4.

Table 4: Firms' decision to engage in collaboration with external partners: Panel Probit estimates for period 1994-2006 with robust standard errors

External Collaboration	
Internal Collaboration	2.256***
	(0.072)
Size	0.178***
	(0.014)
R&D Intensity	1.850***
	(0.248)
Multinational	-0.321***
	(0.047)
Extramural R&D	0.424***
	(0.043)
Sector Dummies (3-digit NACE)	Yes
Time Dummies (1994-2006)	Yes
Model Diagnostics	
Observations	11,054
Log likelihood	-4,560
Prob > Chi^2	0.000

*, **, and *** indicate significance at 10%, 5% and 1% respectively. Robust standard errors are reported in parentheses.

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[36] A simple Type I Tobit also corrects for the selection bias. However, the proposed approach we employ here is similar to a Type II Tobit with the difference that it also corrects for the possible endogeneity of external R&D collaboration (see Lavie and Miller (2008) for an application of a similar approach).

As expected, firms are more prepared and likely to engage in external collaboration if they already have the experience of (1) partnering with other firms inside their enterprise group (providing they are a member of a holding) and/or (2) subcontracting/outsourcing part of their innovation activities to third parties. Larger firms are more likely to participate in R&D alliances due to availability of (non-)financial resources and possessing a better reputation and power position. Intramural R&D intensity of the firm increases its absorptive capacity and prepares the firm to collaborate and better benefit from external knowledge sources and spillovers. Surprisingly, multinational firms are less likely to engage in collaboration with external firms. Two explanations seem to be relevant here. First, multinational firms are typically very large enterprises with departments/plants and/or headquarters in different locations around the globe. This way, a firm part of a multinational enterprise might feel less need for cooperation with external parties as it is already nested in a large network and has access to a vast array of (diverse) resources internally. Second, multinational firms show relatively higher levels on the other independent variables in the model and the fact that they are multinational adds nothing on top of the contribution of these factors to probability of external collaboration.[37] In the second stage, model (2b) is estimated.

Table 5: Impact of geographic and stakeholder diversity on radical and imitative innovation performance: Panel Tobit for 1994-2006 with robust standard errors

Radical Innovation Performance	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
Geographic Diversity	0.054	-0.329	0.827	1.156*	0.153	0.086	0.067
	(0.390)	(0.509)	(0.575)	(0.768)	(0.528)	(0.574)	(0.780)
Stakeholder Diversity	1.184***	1.477***	0.851*	0.626	1.436***	0.909**	0.527
	(0.320)	(0.423)	(0.465)	(0.629)	(0.442)	(0.460)	(0.638)
Size	0.024	0.112	-0.140*	0.252***	-0.094	0.162*	0.256***
	(0.054)	(0.076)	(0.072)	(0.105)	(0.072)	(0.083)	(0.110)
R&D Intensity	6.234***	6.751***	5.358***	1.393	5.480***	7.917***	2.437
	(0.872)	(1.243)	(1.100)	(1.626)	(1.014)	(1.624)	(1.915)

[37] This is indeed the case as the ANOVA tests reveal that multinational firms are comparatively larger, spend more in R&D, and engage more frequently in internal cooperative schemes. The test results can be provided upon request.

Process Innovation	0.641***	0.555***	0.757***	0.202	0.833***	0.486**	0.347
	(0.137)	(0.182)	(0.195)	(0.267)	(0.187)	(0.200)	(0.274)
Organizational Innovation	0.908***	0.954***	0.725***	0.229	0.827***	0.962***	0.135
	(0.149)	(0.193)	(0.219)	(0.292)	(0.208)	(0.214)	(0.298)
Group	0.095	-0.022	0.257	0.279	-0.245	0.377*	0.622**
	(0.145)	(0.186)	(0.215)	(0.284)	(0.204)	(0.206)	(0.290)
R&D Permanence	1.412***	1.386***	1.044***	0.342	1.258***	1.430***	0.172
	(0.143)	(0.187)	(0.208)	(0.280)	(0.207)	(0.200)	(0.289)
Training	0.716***	0.599***	0.966***	0.367*	0.883***	0.593***	0.290
	(0.131)	(0.169)	(0.195)	(0.258)	(0.187)	(0.184)	(0.262)
Inverse Mills Ratio (IMR)	-0.333**	-0.371*	-0.061		-0.346	-0.361*	
	(0.153)	(0.202)	(0.215)		(0.215)	(0.217)	
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	
Model Diagnostics							
Observations	8970	5132	2959		3813	5157	
Log likelihood	-23842	-13900	-7990		-10444	-13358	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	
Imitative Innovation Performance	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
Geographic Diversity	0.805***	0.564	1.280***	0.716*	1.167***	0.432	0.735*
	(0.277)	(0.352)	(0.433)	(0.558)	(0.408)	(0.370)	(0.551)
Stakeholder Diversity	-0.098	-0.060	-0.111	0.051	0.007	-0.200	0.207
	(0.225)	(0.291)	(0.346)	(0.452)	(0.340)	(0.294)	(0.449)
Size	-0.122***	0.012	-0.235***	0.247***	-0.003	-0.258***	0.255***
	(0.038)	(0.052)	(0.053)	(0.074)	(0.054)	(0.052)	(0.075)
R&D Intensity	-0.162	1.750**	-2.419***	4.169***	0.0809	-1.774	0.965
	(0.626)	(0.872)	(0.836)	(1.208)	(0.782)	(1.085)	(1.337)
Process Innovation	0.611***	0.606***	0.351**	0.255*	0.456***	0.731***	0.275*
	(0.094)	(0.122)	(0.141)	(0.186)	(0.141)	(0.123)	(0.187)
Organizational Innovation	0.511***	0.248*	0.891***	0.643***	0.654***	0.399***	0.255
	(0.101)	(0.129)	(0.158)	(0.204)	(0.156)	(0.130)	(0.203)
Group	0.182*	0.158	-0.096	0.254	0.081	0.228*	0.147
	(0.099)	(0.125)	(0.155)	(0.199)	(0.153)	(0.127)	(0.199)
R&D Permanence	0.500***	0.547***	0.317**	0.230	0.346**	0.649***	0.303*
	(0.098)	(0.125)	(0.152)	(0.197)	(0.155)	(0.125)	(0.199)
Training	0.301***	0.422***	0.203	0.219	0.359**	0.255**	0.104

	(0.090)	(0.114)	(0.141)	(0.181)	(0.141)	(0.114)	(0.181)
Inverse Mills Ratio (IMR)	-0.048	-0.146	-0.071		0.191	-0.261*	
	(0.106)	(0.137)	(0.156)		(0.163)	(0.136)	
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	
Model Diagnostics							
Observations	8,956	5,131	2,957		3,811	5,145	
Log likelihood	-25,239	-14,146	-8,653		-10,851	-14,396	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	

All: Complete sample; Mfg: Manufacturing sector; Svc: Services sector; H Tech: High-technology and/or knowledge-intensive sectors; L Tech: Low-technology and/or knowledge non-intensive sectors. Z-test: One-tailed Z-test results of the difference between the two subsamples' regression coefficients. *, **, *** indicate that estimates are significant at 10%, 5% and 1% respectively. Robust standard errors are reported in parentheses. IMR, from estimating the first-stage model, corrects for the sample selection bias.

The results in Table 5 highlight a very interesting finding. In case of radical innovation, stakeholder diversity is highly influential while geographic diversity does not exert a significant effect. This means that firms require a diverse set of partners from different categories in order to develop and introduce novel products. This underlines the complementarity between knowledge and resources from multiple areas of expertise and application domains that is necessary for successful introduction of radical innovations. For instance, in a radical innovation project, suppliers might provide applied technical knowledge, customers offer marketing information and promotional insights, universities and public research institutes contribute with fundamental research, consultants facilitate management and coordination of the project, and competitors assist with establishing standards and give access to valuable financial resources. However, as the results suggest, on top of a diverse network of different types of partners, the location of these partners is less important. In line with the above line of reasoning, the observed effects are more profound in case of manufacturing and high-technology firms which are in need of a more complex and divergent set of skills and knowledge to develop innovative products. Ceteris paribus, a one-tenth point upsurge in stakeholder diversity (in a scale of 0-1) increases radical innovative sales of the firm per employee by nearly 14.8% and 14.4% in the manufacturing and high-technology sectors of the Dutch economy respectively.

In contrast to the above phenomenon, imitative innovation performance is significantly positively influenced by geographic diversity (but not stakeholder diversity) of the firm's R&D partners. This suggests that for introducing imitative products (goods or services), it is important to have partners from diverse geographical locations not necessarily from different partner groups. Introducing imitative products does not typically impose high barriers on the firm in terms of lack of fundamentally new knowledge or expertise. The product (or a simpler version of it) has already been introduced (by the firm or one of its rivals) into the market and much is known about its basic technical features and functional principles as well as market reactions and legal impediments facing it. Therefore, companies require external partners for imitative innovations less for acquiring diverse knowledge they lack but more for adapting and customizing their offerings to specific, local preferences of different markets or for adhering to national regulations, standards and restrictions in different countries. This justifies the significant effect of geographic diversity of a firm's partners on its imitative innovation performance. The effect is greater in services than manufacturing firms as product descriptions/specifications are more standardized and less customizable in case of physical goods rather than intangible services. Moreover, offering highly custom-made services (tailored to specific demands of different market segments) is more common than introducing multiple versions of a single product, as service customization is easier than product adaptation. Again, products in high-technology markets feature more customizable elements which strengthens the impact of geographic diversity of partners on innovation performance. Ceteris paribus, a one-tenth point rise in geographic diversity (in a scale of 0-1) increases imitative innovative sales of the firm per employee by nearly 12.8% and 11.7% in the services and high-technology sectors of the Dutch economy respectively.

Some observations are in order with regard to the control variables in Table 5. Similar to the empirical model presented in the previous section, the size effects are mixed (and dependent on the sector under study). The impact of R&D intensity is always significantly positive for radical innovations. With respect to imitative innovations, which are less dependent on in-house R&D activities, the effect can be positive or negative (for manufacturing and services firms respectively). The group variable again shows insignificant or weakly significant effects. Other controls exhibit predicted directions. The impact of process and organizational innovation, R&D permanence and employee training are significantly positive and, at the same time, generally greater for radical than for imitative innovations. The significant effect of the inverse Mills ratio reveals that correction for the selection bias is necessary.

5.3. Partner diversity as a function of organizational determinants

Table 6 reports the estimation results of model (3).[38] The dependent variable is the diversity index, which by construction has a lower bound of 0. In particular, a considerable number of firms in our sample cooperate with only one partner type (i.e. a diversity of 0). This results in a relatively high density of observations around the lower bound of diversity and obliges the use of a regression method for censored dependent variables.

Table 6: Organizational determinants of geographic and stakeholder diversity: Panel Tobit estimates for period 1994-2006 with robust standard errors

Geographic Diversity	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
Prior Foreign Experience	0.232***	0.218***	0.292**	0.074	0.370***	0.156**	0.214***
	(0.048)	(0.051)	(0.118)	(0.129)	(0.064)	(0.064)	(0.091)
Patenting	0.208***	0.153***	0.488***	0.335***	0.202***	0.197***	0.005
	(0.044)	(0.046)	(0.136)	(0.144)	(0.062)	(0.061)	(0.087)
IT Intensity	2.095***	0.911***	2.568***	1.657***	2.264***	1.008***	1.256***
	(0.302)	(0.190)	(0.324)	(0.376)	(0.251)	(0.193)	(0.317)
Size	0.108***	0.141***	0.002	0.139***	0.106***	0.102***	0.004
	(0.022)	(0.024)	(0.059)	(0.064)	(0.028)	(0.033)	(0.043)
Multinational	0.025	0.058	-0.189	0.247**	0.019	0.037	0.018
	(0.045)	(0.047)	(0.131)	(0.139)	(0.062)	(0.063)	(0.088)
Subsidy	0.242***	0.223***	0.124	0.099	0.277***	0.238***	0.039
	(0.048)	(0.051)	(0.124)	(0.134)	(0.076)	(0.061)	(0.097)
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	

[38] The number of observations in table 6 in comparison with those in table 3 and 4 drops considerably. Introducing *Prior_experience* in the model is partly responsible as this variable is only available for firms reporting in at least two waves of the CIS survey. Observations of the first wave (i.e. 1994-1994) are nevertheless dropped from the analysis as prior experience for these firms is not observable. Another reason lies on the integration of CIS and ICT surveys which results in a large number of dropouts, especially small and medium-sized enterprises that are less frequently covered by the ICT survey.

Model Diagnostics							
Observations	1533	1148	320		606	927	
Log likelihood	-885	-691	-149		-542	-531	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	

Stakeholder Diversity	**All**	**Mfg.**	**Svc.**	**Z-test**	**H. Tech**	**L. Tech**	**Z-test**
Prior Experience	0.205***	0.195***	0.167*	0.028	0.279***	0.157***	0.122*
	(0.043)	(0.050)	(0.089)	(0.102)	(0.066)	(0.057)	(0.087)
Patenting	0.203***	0.212***	0.178	0.034	0.193***	0.210***	0.017
	(.044)	(0.049)	(0.111)	(0.121)	(0.065)	(0.060)	(0.088)
IT Intensity	2.486***	2.320***	3.193***	0.873***	4.181***	0.850***	3.331***
	(0.152)	(0.195)	(0.262)	(0.327)	(0.238)	(0.194)	(0.307)
Size	0.097***	0.114***	0.007	0.107**	0.081***	0.109***	0.028
	(.022)	(0.027)	(0.048)	(0.055)	(0.031)	(0.032)	(0.045)
Multinational	0.024	0.032	-0.011	0.043	0.048	0.013	0.035
	(0.046)	(0.051)	(0.103)	(0.115)	(0.066)	(0.063)	(0.091)
Subsidy	0.270***	0.264***	0.226**	0.038	0.235***	0.293***	0.058
	(0.046)	(0.054)	(0.096)	(0.110)	(0.075)	(0.059)	(0.095)
Sector Dummies (3-digit NACE)	Yes	Yes	Yes		Yes	Yes	
Time Dummies (1994-2006)	Yes	Yes	Yes		Yes	Yes	
Model Diagnostics							
Observations	1,533	1,148	320		606	927	
Log likelihood	-1,065	-810	-212		-416	-643	
Prob > Chi²	0.000	0.000	0.000		0.000	0.000	

All: Complete sample; Mfg: Manufacturing sector; Svc: Services sector; H Tech: High-technology and/or knowledge-intensive sectors; L Tech: Low-technology and/or knowledge non-intensive sectors. Z-test: One-tailed Z-test results of the difference between the two subsamples' regression coefficients. *, **, *** indicate that estimates are significant at 10%, 5% and 1%. Robust standard errors are reported in parentheses.

Table 6 shows that the prior experience of firms with foreign partners has a positive impact on their partners' geographic diversity. The impact is significantly larger in high-technology than in low-technology industries. Patenting exerts a positive effect on geographic diversity as well. Surprisingly, the effect is significantly larger for services in comparison with manufacturing firms. This can be explained by the fact that patenting is a more routine practice among product manufactures while it is less common among service providers. Therefore, the effect of patenting is more unique and hence better observable among services industries. IT intensity shows a considerable impact on geographic diversity of the firm's partners. The effect is more profound in services and high-tech industries with general higher levels of IT adoption. Ceteris paribus, a one-tenth point growth in a scale of 0-1 (equal to 0.4 standard deviation units) in the share of IT capital in total capital of the firm escalates geographic diversity of partners by about 28.5% and 22.6% in the services and hi-tech sectors of the Dutch economy respectively. IT intensity is a general measure of the firm's level of dependency on IT. Providing that we had access to a more detailed and classified measure of the firm's IT endowments such as specialized groupware applications used for facilitating collaborations, managing projects, and coordinating tasks/teams, we expected to observe a greater effect of IT intensity on partner diversity. As to the control variables, the partner portfolio of larger firms and those receiving public subsidies for innovation activities are found to be more diverse. Being multinational seems to have no additional effect on diversity over its indirect effects through other variables in the model.

The bottom part of Table 6 examines the organizational determinants of stakeholder diversity of partners. The size, sign and significance of the determinants of stakeholder diversity are comparable to those of geographic diversity. The only noticeable difference is the impact of IT intensity on diversity which seems to be stronger in case of stakeholder diversity; the effect is still larger for services and hi-tech firms. Ceteris paribus, a one-tenth point growth (in a scale of 0-1) in the share of IT capital in total capital of the firm intensifies stakeholder diversity of partners by around 31.1% and 40.4% in the services and hi-tech sectors respectively.

5.4. Nonlinearity of the relationship between partner diversity and innovation performance

In contrast to our a priori expectations, geographic diversity did not reveal a significant positive effect on radical innovation performance. Stakeholder diversity did not affect imitative innovation performance significantly positively as well (see Table 5). Especially, in case of imitative innovations, the effect of stakeholder diversity, although statistically insignificant, turned out to be negative. This observation encouraged us to conjecture about some sort of complex nonlinearity in the relationship between partner diversity and innovation performance (that cannot be fully captured through linear models).

The benefits that stem from higher diversity of partners come at certain costs, risks and concerns. Nooteboom (2004) introduces the term cognitive distance, which exists between actors or firms with different experiences, and cognitive proximity between actors with similar or shared experiences. Learning takes place when an actor or firm interacts with other actors or firms that do things differently. Therefore, cognitive distance is necessary to learn new solutions. However, the cognitive distance cannot be too large as actors or firms might not then properly understand each other. A trade-off arises between cognitive distance and proximity. The optimum depends on, among others, the firm's absorptive capacity (Cohen and Levinthal, 1990). A firm with a larger absorptive capacity understands knowledge from a larger cognitive distance and has a higher optimal cognitive distance, a higher learning capability and accordingly higher learning performance. Yet, absorptive capacity is not an absolute concept that only depends on the firm's own knowledgebase and prior experience, but a relative one that is highly dependent on the context of the firm and compatibility between partners (Lane *et.al*, 2001). The unique resources and novel knowledge of the network is highly relevant and accessible to the firm when sufficient overlap between the knowledgebase and cultural background of peripheral partners exists such that dissimilarities can be handled effectively (Cohen and Levinthal, 1990; Phene *et.al*, 2006).

Higher diversity means networks of different partners with different interests, objectives, and characters. This implies extra coordination and organization costs due to efforts of the firm to get these different parties and objectives all in line with each other in order to jointly contribute to the ultimate goal of developing and selling innovative product(s). Diverse networks might be dominated by irresolvable and unbridgeable conflicts and resistances as well as lack of commitment, trust and positive interactions (e.g. Lane and Beamish, 1990). Focusing on the costs associated with greater stakeholder diversity, partners in diverse positions of the value chain share different technological languages and require specific (prerequisite) knowledgebase before they can be approached and further communicated and worked with effectively. Customers use market-oriented knowledge and functional language. Cooperation with universities requires investments in special channels and facilities that help the firm understand and translate the rather basic/fundamental research findings of universities to more applied, corporate knowledge. Horizontal cooperation with competitors relates to issues such as intellectual property rights, secrecy and appropriability concerns that might hinder effective partnering. Research shows that the more similar partners' technological portfolios are with one another, the easier it is to absorb each other's capabilities (Santangelo, 2000). From a geographical diversity perspective, partners of the firm might reside in multiple countries each of which may impose new, totally different legal, cultural, economic and political constraints hampering a fruitful collaboration (Lavie and Miller, 2008).

To explore the potential nonlinearities between partner diversity and innovation performance, we developed a model similar to model (2):

$$Innovation\_performance_{i,t} = \lambda_0 + \lambda_1 Diversity_{i,t} + \lambda_2 Diversity^2_{i,t} + \lambda_3 Diversity^3_{i,t} + \lambda_4 Size_{i,t} + \lambda_5 RD\_intensity_{i,t} + \lambda_6 Process\_innovation_{i,t} + \lambda_7 Organizational\_innovation_{i,t} + \lambda_8 Group_{i,t} + \lambda_9 RD\_permanence_{i,t} + \lambda_{10} Training_{i,t} + \lambda_{11} IMR_{i,t} + \lambda_s Sector + \lambda_y Year + u_i + \varepsilon_{i,t} \quad (7)$$

In this model, innovation performance can refer to either radical or imitative innovations and diversity can either mean stakeholder or geographic diversity. The rest of the control variables are similar to those in model (2). Table 7 (columns 1 and 2) reports the results for imitative innovation and stakeholder diversity for the full sample and its non-services subsample.[39]

Table 7: Non-linear relationship between partner diversity and innovation performance: Panel Tobit estimates for 1994-2006 with robust standard errors

Imitative Innovation Performance (SD units)				
	All sampled firms	*Non-services firms*	*Prior Experience = 1*	*Prior Experience = 0*
Stakeholder Diversity	-0.689*	-1.171***	-0.585*	-0.754*
(SD units)	(0.392)	(0.433)	(0.449)	(0.504)
Stakeholder Diversity²	0.618*	1.054***	0.473	0.643*
(SD units)	(0.354)	(0.391)	(0.399)	(0.447)
Stakeholder Diversity³	-0.130*	-0.228***	-0.091	-0.129*
(SD units)	(0.078)	(0.086)	(0.088)	(0.98)
Size	-0.036***	-0.019	-0.036*	-0.042**
(Mean centered)	(.011)	(0.013)	(0.019)	(0.021)
R&D Intensity	-0.091	0.448**	0.436*	0.137
(Mean centered)	(0.182)	(0.226)	(0.258)	(0.323)
Process Innovation	0.163***	0.178***	0.202***	0.138***
(Mean centered)	(0.027)	(0.031)	(0.044)	(0.040)

[39] The non-services subsample was selected as product innovation is more tangible for these sectors and this might help us better reveal nonlinear dynamics we aimed to investigate.

Organizational Innovation	0.141***	0.074**	0.051	0.212***
(Mean centered)	(0.029)	(0.033)	(0.046)	(0.042)
Group	0.038	0.067**	0.182***	0.011
(Mean centered)	(0.029)	(0.032)	(0.057)	(0.046)
R&D Permanence	0.113***	0.116***	0.120**	0.068
(Mean centered)	(0.029)	(0.032)	(0.047)	(0.042)
Training	0.083***	0.096***	0.039	0.100**
(Mean centered)	(0.026)	(0.029)	(0.041)	(0.040)
Inverse Mills Ratio	-0.019	-0.035	-0.114**	0.082*
(Mean centered)	(0.031)	(0.035)	(0.045)	(0.045)
Constant	1.871***	1.891***	2.092***	1.920***
	(0.094)	(0.087)	(0.252)	(0.175)
Sector Dummies (3-digit NACE)	Yes	Yes	Yes	Yes
Time Dummies (1994-2006)	Yes	Yes	Yes	Yes
Model Diagnostics				
Observations	8,956	5,998	1,161	1,284
Log likelihood	-13,227	-8,554	-1,743	-1,940
Prob > Chi²	0.000	0.000	0.000	0.000

*, **, and *** indicate significance at 10%, 5% and 1% respectively. Robust standard errors are reported in parentheses. Non-services includes the Manufacturing and Others sectors. Prior experience is equal to 1 if the firm has partnering experience in the past and 0 otherwise. Diversity index and its second and third powers as well as the innovation performance measure are in standard deviation units while all other independent variables are mean centered.

As shown in Table 7, the estimated parameters of the linear, squared and cubic terms of diversity are significantly negative, positive and negative respectively. In line with the previous findings in Table 5, process and organizational innovation, R&D permanence and employee training show significantly positive effects. The influence of firm size, R&D intensity and group membership turn to be dependent on the sample under analysis, as in Table 5. As reflected by the coefficient of IMR, we do not observe any significant sample-selection bias. Figure 1 illustrates our findings. It depicts the predicted imitative innovation performance as a function of partner stakeholder diversity based on model (7).

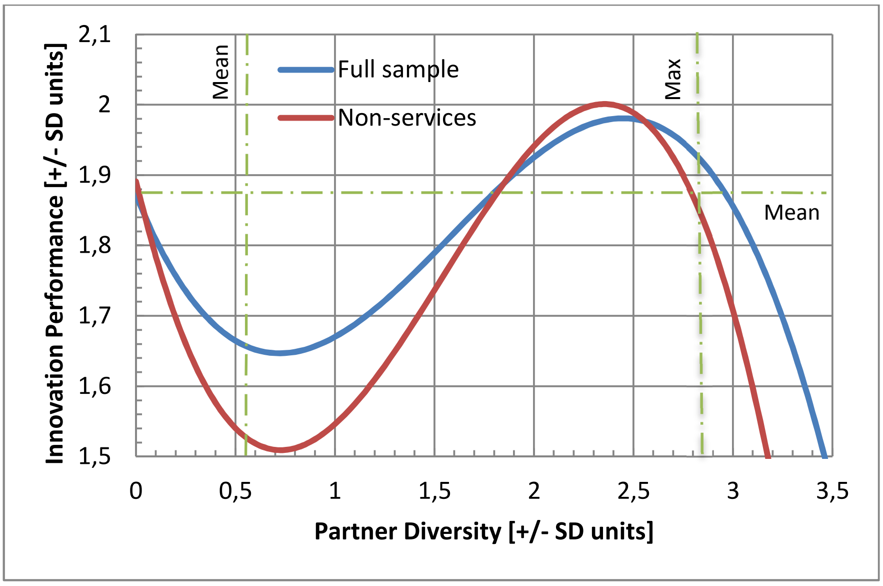

Figure 1: Predicted innovation performance as a function of partner diversity: Sigmoid pattern for the full sample and non-services firms

The variables of interest (i.e. the performance and diversity measures) are represented in units of standard deviation (SD), while all remaining variables are held at their mean levels. These modifications allow us to plot innovation performance against partner diversity in relative scales and at the average level of other explanatory variables. The figure captures a 3-stage sigmoid pattern characterizing the innovation performance implications of partner diversity. The observed trajectory reveals that performance initially declines up to around 0.4 standard deviation units below the mean as diversity rises up to nearly 0.2 standard deviation units above the mean. Then, it increases to more than 0.1 standard deviations above the mean until diversity reaches 1.9 standard deviations above the mean.[40] Subsequently, performance again declines as diversity further expands. Performance is about the mean when diversity reaches the maximum. The overall pattern of the observed sigmoid curve is the same

[40] At diversity values of about 1.2 SD units above the mean, innovation performance is again at the mean level.

for both the full sample and subsample of non-services firms. [41] However, the initial decline, subsequent upsurge and final drop of the curve are sharper in case of the sample of only non-services firms. [42]

There exists a trade-off between costs and benefits of cooperation. At low levels of partner diversity, the firm has already incurred the initial (quasi-fixed) costs[43] of establishing or joining collaborative partnerships with external parties but has not yet reached a point where it can benefit from the variety of knowledge and resources it may require. At this stage, the supply of the network is still incomplete and breadth of knowledge is limited; the partial knowledge the firm gains through the network is not that productive due to the high degree of complexities and uncertainties in innovation processes. Costs of cooperation outweigh the benefits from incomplete resource exchanges (Hitt *et.al*, 1997). After a threshold (0.2 SD units above the mean in our sample), at moderate-to-high levels of diversity benefits arises. Every single actor provides a relatively small piece of knowledge to the network but all the partners together provide a more complete set of resources that can be used in the firm's innovation processes. Firms gradually learn how to efficiently cooperate with a more diverse set of partners through developing idiosyncratic procedures for working with a pool of distant partners (Gulati and Singh, 1998; Lavie and Miller, 2008). They also learn how to leverage complementary knowledge by combining resources from diverse areas, how to benefit from inherent synergies between different types of

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[41] Lavie and Miller (2008) predict a similar sigmoid pattern when analyzing the relationship between the degree of foreignness of the firm's partner portfolio and its ROA performance. Yang *et.al* (2010) propose a similar pattern as well when investigating the relationship between the degree of R&D investments and firm profitability.

[42] Similar analysis was performed for both measures of innovation as well as both measures of diversity in different subsamples. In all instances a similar sigmoid pattern is observed although in some cases the effects of diversity (and its powers) are rendered insignificant due to multicollinearity. The results of other cases rather than those shown in this paper have not been presented due to space constraints but are available on request.

[43] The firm needs to incur additional costs to search for and attract appropriate partners. Then it should come to an agreement with them and cope with various contracting, monitoring and enforcing issues. It should also adapt/reorganize its own organization and activate/institutionalize proper IPR protection mechanisms. These costs are to some extent fixed. Later on, in order to create high novelty and added value through utilizing the complementary competencies of the partners, firms need to make relation-specific investments which creates risks of 'holdup' and 'spillover' (Nooteboom, 1999a).

partnerships and how to capitalize on valuable network resources (Gulati, 1999; Lavie, 2006). At these moderate levels of diversity, communalities between partners also materialize. At the same time, the portfolio of partners is still well-manageable at acceptable costs as institutional, cognitive and normative gaps that can hinder purposeful communication and engagement can be effectively identified and bridged (Gulati, 1999; Kostova and Zaheer, 1999).

As diversity further increases, the marginal return to the value of the network from adding new types of partners diminishes. That is because new partners are less likely to supply valuable, new or rare knowledge, resources or perspectives that have not already been brought to the network by other actors. At the same time, at (very) high levels of diversity (1.9 SD units above the mean in our sample), significant (partly new) costs and risks arise. At these levels, the network of partners becomes less effective and manageable as unnecessary dissimilarities and congruencies are starting to diverge from or oppose each other. The range of varied objectives, interests, requirements and constraints of partners (that should be dealt with) grows (Kostova and Zaheer, 1999). As a result, the firm needs to incur substantial coordination costs for developing collaborative routines to be able to manage the network of its partners, resolve conflicts and assimilate the external knowledge it acquires through this network (Hitt *et.al*, 1997; Nooteboom, 1999a, 1999b).

Following the above line of reasoning, we expect that firms' prior partnering experience moderates the adverse effects of very low and high values of partner diversity on innovation performance. This means that firms should learn from their past partnering efforts (no matter being successful or futile) to be more efficient in selecting their partners and managing their networks. Firms with prior experience possess valuable knowledge on how to approach actors and design the initial composition of the network they form/join in order to maximize the value of the imperfect knowledge of the network to their best of interest. They also know better how to manage a network and handle conflicts of interest when the network reaches tremendous expansion. Although a full account of moderating effects is beyond the scope of this paper, we decided to open up the venue for future research through a brief analysis. Results of regressing model (7) for two subsamples are presented in

Table 7 (columns 3 and 4). [44] The subsamples belong to firms for which we certainly know that they have or have not had past partnering experience in the period 1994-2006 (unless a firm with such an experience has not declared it in the survey). Figure 2 illustrates interesting findings.

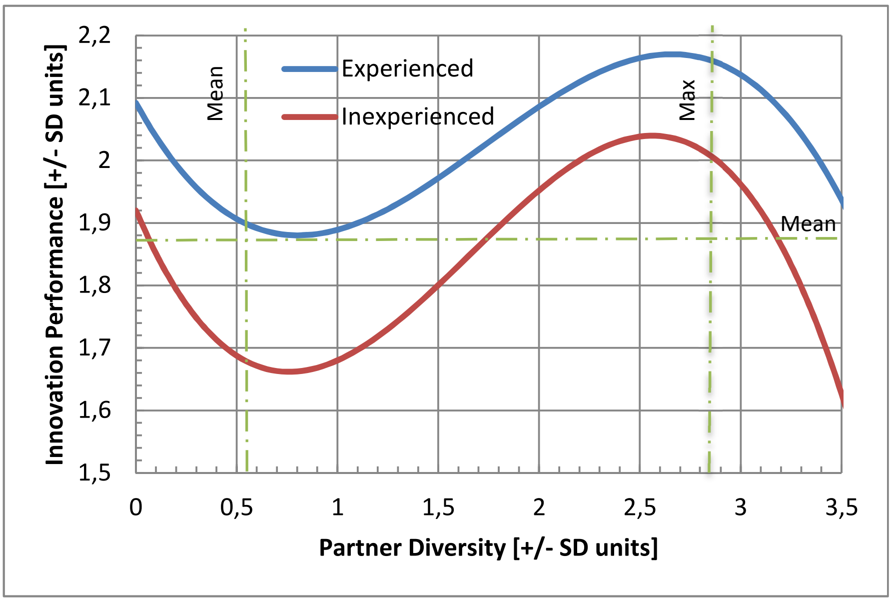

Figure 2: Predicted innovation performance as a function of partner diversity: Sigmoid pattern for firms with and without prior partnering experience

At any level of diversity, innovation performance of the experienced sample is higher than that of the inexperienced one. Moreover, performance of firms with prior experience, even at its lowest point, is always above the mean while performance of firms lacking such experience is below average at low-to-moderate or very high values of diversity.[45] Moreover, experience of firms with partner selection and/or management enables them to alleviate the adverse effects of increasing diversity on innovation performance. This is evident as the declines in performance are smoother

[44] Due to relatively smaller size of the subsamples and some multicollinearity among the diversity variables, we were unable to attain more precise estimates, especially with respect to diversity measures.

[45] Notice that the other (control) variables influencing innovation performance are kept at their mean in the graphs.

in case of experienced firms. In the first and third stages of the sigmoid trajectories in Figure 2, experienced firms observe a decline of 10% (i.e. 2.09 →1.88 SD units) and 8% (i.e. 2.17→1.99 SD units) in their performance respectively. However, the same figures for firms in the other group amounts to 14% (i.e. 1.92→1.66 SD unites) and 20% (i.e. 2.04→1.63 SD units) respectively.

6. Conclusions, Limitations and Recommendations

6.1. Conclusions

This paper addresses the impact of diversity of different kinds of partners in R&D cooperation schemes on the innovation performance of innovating firms. It also attempts to identify the organizational determinants of partner diversity. Two kinds of diversity are valid. First, stakeholder diversity relates to cooperation with partners from multiple categories and, second, geographic diversity to collaboration with partners in different countries. Two types of innovation are considered as well: radical innovations (new to the market) and imitative innovations (only new to the firm). The econometric analysis based on the Heckman two-stage estimation procedure to correct for self-selection bias and the Community Innovation Survey data of the Netherlands for 12,811 firms reporting product and/or service innovations in the period 1994-2006 produced the following results.

First, collaboration on innovation activities with external partners increases the performance of these activities, ceteris paribus. The effect is stronger in case of radical than imitative innovations due to the broad and complex range of resources required for developing and commercializing radical innovations. The effect is also stronger for manufacturing than for services firms, which are traditionally more R&D-oriented.

Diversity of partners has different effects on the two types of innovation studied. In case of radical innovations, stakeholder diversity significantly increases the sales of radically new products per employee while geographic diversity of partners does not affect this measure of innovation performance significantly. Actors from different stakeholder groups each partly contribute to the extensive set of knowledge and tacit skills that are necessary to develop completely new products. Networks that consist of partners from multiple stakeholder categories are valuable for the radical innovation performance of the firm as complementary and synergetic effects only occur at relatively high levels of stakeholder diversity. At low levels of stakeholder diversity, the partial, limited knowledge supplied by the network is less practical and effective for development and commercialization of radically new products. On the opposite, geographic diversity is influential to the sales of imitative products per employee while stakeholder diversity affects this measure of innovation performance insignificantly. Imitative innovations imply incremental changes to existing products in the market with the aim of better adjusting them to customers' wishes in local markets and/or better adhering to (inter)national standards. Cooperation with partners in different countries supports the firm to better achieve these objectives. As to another finding of the research, the observed effects of partner diversity on innovation performance are more profound in high-technology and knowledge-intensive industries due to higher degrees of product complexity, market volatility and riskiness/uncertainty of innovation projects in these sectors.

Further investigation detected a pattern of non-linearities between partner diversity and innovation performance. The impact of partner diversity on innovation performance develops through a sigmoid pattern, with performance first declining, then improving and finally declining again when diversity of the firm's innovation partners increases. The main rationale is that at low levels of diversity the knowledge base and hence the value of the network is limited. While incomplete learning occurs, the firm incurs certain costs that are necessary to formally establish or join a network of external partners. At medium to high levels of diversity, performance rises with diversity. On the one hand, the knowledge reservoir of the network becomes wide enough to provide the firm with many resources it needs during an innovation process. On the other hand, the network of partners is not that diverse to be unmanageable. Conflicts and congruencies can be resolved at reasonable costs and efforts and within acceptable time frames. Finally, at very high levels of diversity, an adverse effect on performance is observed. At these levels, costs outweigh the benefits as the added value of an additional partner (even from a new category) to the collective knowledge of the network is marginal. At the same time, management costs rise substantially due to extra coordination and transaction costs needed for governing an expansive network. In relation to the above phenomenon, prior partnering experience of firms contributes to their ability to select proper (combination of) partners and work with them more effectively. According to our findings, this results in experienced firms facing less adverse effects on their innovation performance in the formation and expansion phases of their R&D partnerships when the level of diversity is low or very high.

As to the factors explaining partner diversity, prior partnering experience of the firm is found to be an important determinant due to learning effects. Firms that patent are more prepared to protect their intellectual properties and thus more likely to have more diverse portfolio of partners. Public innovation subsidies promote partnering with more diverse actors as well. Information technologies offer vast communication, coordination and integration capabilities to the firm. Managing complex and diverse networks, spread over distant locations, is very difficult (if not impossible) without adopting appropriate information technology applications. Hence, as the analysis shows, IT intensity is another important determinant of partner diversity. IT effects are stronger in sectors that are historically dominant users of IT like services and high-tech industries.

Finally, we learn that absorptive capacity and learning mechanisms exert a significant impact on innovation performance of the firm. Investing in internal R&D activities and training employees both add to the absorptive capacity of the firm and increase its ability to understand and assimilate knowledge from (diverse) external sources and flows. Continuing R&D activities on a permanent basis is also helpful to build up a strong and enduring knowledge base that is advantageous in innovation processes. Process and organizational innovations were also found to be important complements to product innovation.

6.2. Limitations and recommendations for future research

As to any scientific research, the present one was also restricted by limitations. Deeper understanding of the impacts of partner diversity on innovation performance could have been gained if the number of different partners and their relative importance would have been incorporated rather than using the dummy indicators. However, the data at our disposal did not provide us with more details on different types of partnerships. To our best of knowledge, though, no representative dataset with this level of details on business partners exists for such a huge number of firms and long period of time. Surveying firms on their exact number of different partners and their relative importance is quite cumbersome and subjective.

We primarily emphasized on different kinds of partner diversity. An analysis of other specific characteristics of partners such as their innovative status, resource endowment or power position might lead to additional insights. With respect to geographic diversity, differentiation between domestic, European, American and other partners were made. This is a rough distinction and it seems worthwhile to investigate our research issues with a more detailed geographical distinction.

Our research suggests that the relationship between innovation performance and partner diversity is likely to follow a sigmoid functional form. A proper investigation of the features of this function such as the position of local extrema is beyond the scope of this paper and is left for future research. A comparative analysis of the shape and characteristics of the observed sigmoid pattern and the effect of moderating variables (such as corporate strategy or organizational structure) in different sectors of the economy offers valuable insights too and is another interesting avenue for further research. Future work should also shed more light on sector-specific innovation processes and the supportive role of external collaborations therein. In fact, we consider this last point as an opportunity that opens up new frontiers for future research in different directions.

References

Ahuja, G., 2000a, The duality of collaboration: inducements and opportunities in the formation of inter-firm linkages, *Strategic Management Journal*, 21, 317-343.

Ahuja, G., 2000b, Collaboration networks, structural holes, and innovation: A longitudinal study, *Administrative Science Quarterly*, 45, 3, 425-455.

Alcácer, J., 2006, Location Choices Across the Value Chain: How Activity and Capability Influence Collocation, *Management Science*, 52, 10, 1457-1471.

Alcácer, J. and W. Chung, 2007, Location Strategies and Knowledge Spillovers, *Management Science*, 53, 5, 760-776.

Amara, N. and R.J. Landry, 2005, Sources of information as determinants of novelty of innovation in manufacturing firms: evidence from the 1999 statistics Canada innovation survey, *Technovation*, 25, 3, 245-259.

Annand, B.N. and T. Khanna, 2000, Do firms learn to create value? The case of alliances, *Strategic Management Journal*, March Special Issue, 21, 295-317.

Aral, S., E. Brynjolfsson and M. Van Alstyne, 2007, Information, Technology and Information Worker Productivity: Task Level Evidence, *National Bureau of Economic Research Working Paper 13172*.

Arellano, M. and S. Bond, 1991, Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations, *The Review of Economic Studies*, 58, 277-297.

Bardhan, I.R., V.V. Krishnan, and S. Lin, 2007, Project performance and the enabling role of information technology: An exploratory study on the role of alignment, *Manufacturing & Service Operations Management*, 9, 579-595.

Barkema, H., J. Bell and J. Pennings, 1996, Foreign entry, cultural barriers, and learning, *Strategic Management Journal*, 17, 151-166.

Barkema, H., O. Shenkar, F. Vermeulen and J. Bell, 1997, Working abroad, working with others: How firms learn to operate international joint ventures, *Academy of Management Journal*, 40, 426-442.

Barney, J.M. Wright and D.J. Ketchen, 2001, The resource-based view of the firm: ten years after 1991, *Journal of Management*, 27, 6, 625-641.

Belderbos, R., M. Carree and B. Lokshin, 2006, Complementarity in R&D cooperation strategies, *Review of Industrial Organization*, 28, 4, 401-426.

Belderbos, R., M. Carree, B. Diederen, B. Lokshin and R. Veugelers, 2004a, Heterogeneity in R&D cooperation strategies, *International Journal of Industrial Organization*, 22, 1237-1263.

Belderbos, R., M. Carree and B. Lokshin, 2004b, Cooperative R&D and firm performance, *Research Policy*, 33, 1477-1492.

Boutellier, R., O. Gassmann, H. Macho and M. Roux, 1998, Management of dispersed product development teams: the role of information technologies, *R&D Management*, 28, 1, 13-25.

Carte, T. and L. Chidambaram, 2004, A capabilities-based theory of technology deployment in diverse teams: Leapfrogging the pitfalls of diversity and leveraging its potential with collaborative technology, *Journal of the Association for Information Systems*, 5 ,11-12, 448-471.

Cassiman, B. and R. Veugelers, 2002, R&D cooperation and spillovers: some empirical evidence for Belgium, *American Economic Review*, 92, 4, 1169-1184.

Chesbrough, H., 2003, Open Innovation: The New Imperative for Creating and Profiting from Technology, Harvard University Press, Cambridge, MA.

Chung, S., G.M. Kim, 2003, Performance effects of partnership between manufacturers and suppliers for new product development: the supplier's standpoint, *Research Policy*, 32, 587–603.

Clogg, C.C., E. Petkova and A. Haritou, 1995, Statistical methods for comparing regression coefficients between models, *American Journal of Sociology*, 100, 1261-1293.

Cohen, W.M. and D.A. Levinthal, 1990, Absorptive capacity: a new perspective of learning and innovation, *Administrative Science Quarterly*, 35, 1, 128–152.

Cohen, W.M., R. Nelson, J. Walsh, 2000, Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent (or not), *National Bureau of Economic Research Working Paper 7552*.

Das, T.K. and R. Kumar, 2007, Learning dynamics in the alliance development process, *Management Decision*, 45, 4, 684-707.

Das, T.K. and B.S. Teng, 1998a, Resource and risk management in the strategic alliance making process, *Journal of Management*, 24, 1, 21-42.

Das, T.K. and B.S. Teng, 1998b, .Between trust and control: Developing confidence in partner cooperation in alliances, *Academy of Management Review*, 23, 3, 491–512.

Das, T.K. and B.S. Teng, 2000, A resource-based view of strategic alliances, *Journal of Management*, 26, 1, 31-61.

Das, T.K. and B.S. Teng, 2002, The dynamics of alliance conditions in the alliance development process, *Journal of Management Studies*, 39, 725-746.

Dekker, R. and A. Kleinknecht, Picking winners and adding value? The impact of EU Framework Programs among German and Dutch innovators, *Science and Public Policy* (forthcoming).

Dodgson, M., 1993, Learning, Trust and Technological Collaboration, *Human Relations*, 46, 1, 77-95.

Eisenhardt, K.M. and C.B. Schoonhoven, 1996, Resource based view of strategic alliance information: Strategic and social effects in entrepreneurial firms, *Organizational Science*, 7, 2, 136-150.

Faems, D., B. Van Looy and K. Debackere, 2005, Interorganizational Collaboration and Innovation: Toward a Portfolio Approach, *Journal of Product Innovation Management*, 22, 238-250.

Feldman, M.P. and R. Florida, 1994, The Geographic Sources of Innovation: Technology Infrastructure and Product Innovation in the United States, *Annals of the Association of American Geographers*, 84, 2, 210-229.

Freel, M.S., 2003, Sectoral patterns of small firm innovation, networking and proximity, *Research Policy*, 32, 5, 751-770.

Geroski, P., 1995, Markets of technology: knowledge, innovation and appropriability, in *Handbook of the Economics of Innovation and Technological Change*, P. Stoneman (ed.), Blackwell Publishers, Oxford/Cambridge, 90-131.

Gulati, R.D., 1995, Does familiarity breed trust? The implication of repeated ties for contractual choice in alliances, *Academy of Management Journal*, 38, 85-112.

Gulati, R.D., 1999, Network location and learning: The influence of network resources and firms capabilities on alliance formation, *Strategic Management Journal*, 20, 5, 397-420.

Gulati, R.D., D. Lavie and H. Singh, 2009, The nature of partnering experience and the gains from alliances, *Strategic Management Journal*, 30, 1213-1233.

Gulati, R. and H. Singh, 1998, The architecture of cooperation: Managing coordination costs and appropriation concerns in strategic alliances, *Administrative Science Quarterly*, 43, 4, 781-814.

Hagedoorn, J., 1993, Understanding the rationale of strategic technology partnering: inter-organizational modes of cooperation and sectoral differences, *Strategic Management Journal*, 14, 5, 371-385.

Hagedoorn, J., 2002, Inter-firm R&D partnerships: an overview of major trends and patterns since 1960, *Research Policy*, 31, 4, 477-492.

Hamel, G., 1991, Competition for competence and inter-partner learning within international strategic alliances, *Strategic Management Journal*, 12, 83-103.

Harabi, N., 1994, Appropriability of technical innovations: an empirical analysis, *Research Policy*, 24, 981-992.

Heimeriks, K, 2008, *Developing alliance capabilities*, Palgrave McMillan.

Heimeriks, K. and G. Duysters, 2007, Alliance capability as a mediator between experience and alliance performance: an empirical investigation into the alliance capability development process, *Journal of Management Studies*, 44, 1, 25-48.

Hitt, M.A., R.E. Hoskisson and H. Kim, 1997, International diversification: Effects on innovation and firm performance in product-diversified firms, *Academy of Management Journal*, 40, 767-798.

Hoang, H. and T.F. Rothaermel, 2005, The effect of general and partner-specific alliance experience on joint R&D project performance, *Academy of Management Journal*, 48, 332-45.

Howells, J., A.D. James and K. Malik, 2004, Sourcing external knowledge: a decision support framework for firms, *International Journal of Technology Management* 27, 143-154.

Kleinknecht, A. and P. Mohnen, 2002, *Innovation and firm performance: Econometric explorations of survey data*, Palgrave Publishers, Hampshire, UK.

Kleinknecht, A. and J. van Reijnen, 1992, Why do firms cooperate on R&D? An empirical study, *Research Policy*, 21, 347-360.

Knudsen, M. P., 2007, The Relative Importance of Inter-firm Relationships and Knowledge Transfer for New Product Development Success, *Journal of Product Innovation Management*, 24, 117-138.

Kogut, B. and U. Zander, 1992, Knowledge of the firm, combinative capabilities and the replication of technology, *Organization Science*, 3, 3, 383-97.

Kostova, T. and S. Zaheer, 1999, Organizational legitimacy under conditions of complexity: The case of the multinational enterprise, *Academy of Management Review*, 24, 64-81.

Krugman, P., 1991, Increasing returns and economic geography, *Journal of Political Economy*, 99, 3, 483-499.

Lane, P.J., J.E. Salk and M.A. Lyles, 2001, Absorptive capacity, learning, and performance in international joint ventures, *Strategic Management Journal*, 22, 1139-1161.

Lane, H.W. and P.W. Beamish, 1990, Cross-cultural cooperative behavior in joint ventures in LDCs, *Management International Review*, 30 (special issue), 87-102.

Laursen, K. and A. Salter, 2006, Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms, *Strategic Management Journal*, 27, 2, 131-150.

Lavie, D., 2006, The Competitive Advantage of Interconnected Firms: an extension of the Resource-Based View, *Academy of Management Review*, 31, 3, 638-658.

Lavie, D., 2009, Capturing Value from Alliance Portfolios, *Organizational Dynamics*, 38, 1, 26–36.

Lavie, D. and S.R. Miller, 2008, Alliance Portfolio Internationalization and Firm Performance, *Organizational Science*, 19, 4, 623-646.

Lavie, D. and L. Rosenkopf, 2006, Balancing exploration and exploitation in alliance formation, *Academy of Management Journal*, 49, 6, 797-818.

Lhuillery, S. and E. Pfister, 2009, R&D cooperation and failure in innovation projects: Empirical evidence from French CIS data, *Research Policy*, 48, 45-57.

Lim, K., 2004, The relationship between research and innovation in the semiconductor and pharmaceutical industries (1981-1997), *Research Policy*, 33, 2, 287-321.

Littler, D., F. Leverick and M. Bruce, 1995, Factors Affecting the Process of Collaborative Product Development: A Study of UK Manufacturers of Information and Communications Technology Products, *Journal of Product Innovation Management*, 12, 1, 16-32.

Madalla, G.S, 1984, *Limited Dependent and Qualitative Variables in Econometrics*, Econometric Society Monographs, Cambridge University Press, New York.

Marshall, A., 1920, *Principles of Economics*, MacMillan, London.

McDonald, D.G. and J. Dimmick, 2003, The conceptualization and measurement of Diversity, *Communication Research*, 30, 1, 60-79.

Merchant, H. and D. Schendel, 2000, How do international joint ventures create shareholder value, *Strategic Management Journal*, 21, 723-737.

Miotti, L. and F. Sachwald, 2003, Cooperative R&D: why and with whom? An integrated framework of analysis, *Research Policy*, 32, 1481-1499.

Mowery, D.C., J.E. Oxley and B.S. Silverman, 1998, Technological overlap and inter-firm cooperation: implications for the resource-based view of the firm, *Research Policy*, 27, 507-523.

Nambisan, S., 2003, Information Systems as a Reference Discipline for New Product Development, *MIS Quarterly*, 27, 1-18.

Narula, R., 2003, Understanding the growth of international R&D alliances, in Multinational Enterprises, Innovative Strategies and Systems of Innovation, Cantwell, J. and J. Molero (eds.), Edward Elgar Publishers, Cheltenham, UK.

Narula, R. and G.D. Santangelo, 2009, Location, collocation and R&D alliances in the European ICT industry, *Research Policy*, 38, 393-403.

Nieto, M.J. and L. Santamaria, 2007, The importance of diverse collaborative networks for the novelty of product innovation, *Technovation*, 27, 367-377.

Nooteboom, B., 1999a, Innovation and inter-firm linkages: new implications for policy, *Research Policy*, 28, 8, 793-805.

Nooteboom, B., 1999b, *Inter-Firm Alliances: Analysis and Design*, Routledge Publishers, London, UK.

Nooteboom, B., 2004, Inter-Firms Collaboration, Learning and Networks: An Integrated Approach, Routledge Publishers, London, UK.

Pakes, A and M. Schankerman, 1984, The rate of obsolescence of patents, research gestation lags, and private rate of return to research resources, in *R&D, Patents, and Productivity*, Griliches, Z. (ed.), University of Chicago Press, Chicago.

Pangarkar, N., 2009, Do Firms Learn from Alliance Terminations? An Empirical Examination, *Journal of Management Studies*, 46, 6, 982-1004.

Paternoster, R., R. Brame, P. Mazerolle and A. Piquero, 1998, Using the Correct Statistical Test for the Equality of Regression Coefficients, *Criminology*, 36, 4, 859-866.

Patil, G.P. and C. Taillie, 1982, Diversity as a Concept and its Measurement, *Journal of the American Statistical Association*, 77, 379, 548-561.

Phelps, C., 2005, Technological Explorations: a Longitudinal Study of the Role of Recombinatory Search and Social Capital in Alliance Networks, *PhD Dissertation*, University of Washington.

Phene, A., K. Fladmoe-Lindquist and L. Marsh, 2006, Breakthrough innovations in the U.S. biotechnology industry: The effects of technological space and geographic origin, *Strategic Management Journal*, 27, 369-388.

Pittaway, L., M. Robertson, K. Munir, D. Denyer and A. Neely, 2004, Networking and innovation: a systematic review of evidence, *International Journal of Management Reviews*, 5-6, 3-4, 137-168.

Powell, W., K. Koput and L. Smith-Doerr, 1996, Inter-organizational collaboration and the locus of innovation: networks of learning in biotechnology, *Administrative Science Quarterly*, 41, 1, 116-146.

Reuer, J.J., M. Zollo M. and H. Singh, 2002, Post formation dynamics in strategic alliances, *Strategic Management Journal*, 23, 135-151.

Reuer, J.J. and M. Zollo, 2005, Termination outcomes of research alliances, *Research Policy*, 34, 101-115.

Rosenkopf, L. and A. Nerkar, 2001, Beyond local search: boundary spanning, exploration and impact in the optical disk industry, *Strategic Management Journal*, 22, 287-306.

Santangelo, G., 2000, Corporate Strategic Technological Partnerships in the European Information and Communications Technology Industry, *Research Policy*, 29, 9, 1015-1031.

Saxenian, A., 1994, Regional Advantage: Culture and Competition in Silicon Valley and Route 128, Harvard University Press, Cambridge, MA.

Schreiner, M., P. Kale and D. Corsten, 2009, What really is alliance management capability and how does it impact alliance outcomes and success? *Strategic Management Journal*, 30, 13, 1395-1419.

Scott, J.T., 1996, Environmental research joint ventures among manufacturers, *Review of Industrial Organization*, 11, 655-679.

Simonin, B., 1997, The importance of collaborative know-how: An empirical test of the learning organization, *Academy of Management Journal*, 40, 5, 1150-1174.

Spender, J.C., 2007, Data, meaning and practice: how the knowledge-based view can clarify technology's relationship with organisations, *International Journal of Technology Management*, 38, 1-2, 178-196.

Stuart, T.E., 2000, Interorganizational alliances and the performance of firms: a study of growth and innovation rates in a high technology industry, *Strategic Management Journal*, 21, 8, 791-811.

Tether, B., 2002, Who cooperates for innovation and why: an empirical analysis, *Research Policy*, 31, 947-967.

Thomke, S., 2006, Capturing the real value of innovation tools, *Sloan Management Review*, January, 24-32.

Van Beers, C., E. Berghaell and T. Poot, 2008, R&D Internationalization, R&D Collaboration and Public Knowledge Institutions in Small Economies: Evidence from Finland and the Netherlands, *Research Policy*, 37, 2, 294-308.

Van der Panne, G. and C. van Beers, 2006, On the Marshall-Jacobs controversy: it takes two to tango, *Industrial and Corporate Change*, 15, 5, 877-890.

Von Hippel, E., 1988, *The Sources of Innovation*, Oxford University Press, New York.

Von Hippel, E., 2005, *Democratizing Innovation*, MIT Press, Cambridge, MA.

Wassmer, U., 2010, Alliance Portfolios: A Review and Research Agenda, *Journal of Management*, 36, 1, 141-171.

Wooldridge, J.M., 2002, Econometric analysis of cross section and panel data, MIT Press, Cambridge, MA.

Yang, K.-P., Y.-C. Chiao and C.-C. Kuo, 2010, The Relationship Between R&D Investment and Firm Profitability Under a Three-Stage Sigmoid Curve Model: Evidence From an Emerging Economy, *IEEE Transactions on Engineering Management*, 57, 1, 103-117.

Zahra, S. and G. George, 2002, Absorptive capacity: a review, reconceptualization and extension, *Academy of Management Review*, 27, 2. 185-203.

Zollo, M. and S.G. Winter, 2002, Deliberate learning and the evolution of dynamic capabilities, *Organization Science*, 13, 339-51.

The more original a discovery, the more obvious it seems afterwards. -- *Arthur Koestler*

ENTERPRISE SYSTEMS ADOPTION AND FIRM PERFORMANCE IN EUROPE: THE ROLE OF INNOVATION*

Abstract. Despite the ubiquitous proliferation and importance of Enterprise Systems (ES), little research exists on their post-implementation impact on firm performance, especially in Europe. This paper provides representative, large-sample evidence on the differential effects of different ES types on performance of European enterprises. It also highlights the mediating role of innovation in the process of value creation from ES investments. Empirical data on the adoption of Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Customer Relationship Management (CRM), Knowledge Management System (KMS), and Document Management System (DMS) is used to investigate the effects on product and process innovation, revenue,

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productivity and market share growth, and profitability. The data covers 29 sectors in 29 countries over a 5-year period. The results show that all ES categories significantly increase the likelihood of product and process innovation. Most of ES categories affect revenue, productivity and market share growth positively. Particularly, more domain-specific and simpler system types lead to stronger positive effects. ERP systems decrease the profitability likelihood of the firm, whereas other ES categories do not show any significant effect. The findings also imply that innovation acts as a full or partial mediator in the process of value creation of ES implementations. The direct effect of enterprise software on firm performance disappears or significantly diminishes when the indirect effects through product and process innovation are explicitly accounted for. The paper highlights future areas of research.

Keywords: Enterprise Systems, IT Adoption, Innovation, Firm Performance, Europe

1. Introduction

Enterprise Systems (ES) are large-scale, integrated, cross-functional, and data-centric application software that provide service to all or a group of organizational subunits. Enterprise systems consist of different categories, such as ERP (Enterprise Resource Planning), SCM (Supply Chain Management), CRM (Customer Relationship Management), KMS (Knowledge Management System), and DMS (Document Management System). Since 1990s firms have invested heavily in these systems such that the worldwide enterprise software market amounted to about $230 billion in 2008 and is estimated to reach around $315 billion by 2012 (Gartner 2008).

Numerous reports of successful ES projects with considerable operational and strategic benefits exist (Murphy and Simon 2002; Shang and Seddon 2002; Davenport 2000). Equally important, the failure of ES investments has been frequently acknowledged in the literature, ranging from 40 to 75 percent of implemented projects (Hong and Kim 2002; Liang et al. 2007; Scheer and Habermann 2000). The implementation of an enterprise system can go beyond the boundaries of a single department or even the whole organization and involves tremendous risks and uncertainties and a worrying level of complexity that should be managed (Davenport 1998; Huang et al. 2004; Rettig 2007; Sumner 2000). Moreover, ES initiatives are generally among the most lengthy and expensive Information Technology (IT) projects of companies nowadays (Markus et al. 2000; O'Leary 2000; Scott and Vessey 2002). While the average installation costs about $15 million, large organizations end up spending hundreds of millions of dollars on ES software (Rettig 2007).

The above characteristics of enterprise systems implementations make the systematic and rigorous assessment of their business value particularly important for corporate decision-makers. In this respect, the long-term, post-implementation assessment of ES software is of great import. Enterprise systems lead to diverse effects throughout their lifecycle (Gattiker and Goodhue 2005; Markus and Tanis 2000; Nicolaou and Bhattacharya 2006; Rajagopal 2002; Ross and Vitale 2000). Enterprise systems take a long time to be implemented and further to be customized and are largely used over a span of several years. Prior evidence suggests that enterprise systems benefits accrue over periods of time as opposed to one-time windfall gains and that a time-lag of few years is necessary before ES adopters begin to demonstrate positive differential performance in comparison to their non-adopting peers (Liu et al. 2008; Nicolaou

2004a, 2004b). Moreover, the success or failure of early stages (i.e. the implementation or shakedown phase) does not necessarily relate to the performance effects of later stages (i.e. the post-implementation or acceptance phase) (Bajwa et al. 2004; Chou and Chang 2008; Häkkinen and Hilmola 2008; Liang et al. 2007).

This paper analyzes *whether* and *how* the adoption of enterprise applications affects performance of companies after these systems are used for a sufficiently large period of time. The existing body of the empirical literature usually focuses on a single type of enterprise software (and mainly ERP) and uses case studies or, to a lesser degree, surveyed data from a limited number of (mainly US) sectors (e.g. Hendricks et al. 2007; Hitt et al. 2002; McAfee 2002). The literature on the innovation and performance impacts of other enterprise system types than ERP is either scarce or absent. Furthermore, most of existing literature focuses on immediate or short-term as opposed to long-term effects of ES (Esteves and Pastor 2001; Yu 2005). This paper differs from previous studies in four aspects. First, it provides large-sample, economy-wide evidence of the firm-level performance effects of ES adoption across the major industries of European countries. Second, it enables cross-system comparison by analyzing the differential effects of different enterprise systems on various innovation and performance measures of the firm. Third, it concentrates on the post-implementation stage of ES applications, rather than their selection, implementation, announcement or shakedown phase. Fourth, it differentiates between the direct and indirect effects of enterprise systems on firm performance and identifies product and process innovation as important mediating factors.

The present study enhances our understanding of what aspects of firm performance are influenced by different types of enterprise systems and through what mechanisms. The findings show that all ES types, which were examined, significantly increase the likelihood of product and process innovation. In addition, most of ES categories exhibit significantly positive impact on revenue, productivity and market share growth. In contrast, none of ES types significantly increase the odds of being profitable, while ERP systems even decrease the odds. The analysis further reveals that innovation plays a significant mediating role in linking ES adoption to firm performance. The direct effect of enterprise software on firm performance for most of ES categories completely disappears when the indirect effect through product and process innovation is explicitly accounted for.

We proceed by reviewing the literature in the next section to gain knowledge on the benefits, costs and effects of enterprise systems. Section three explicates a conceptual model to link ES adoption to firm performance. Three hypotheses are derived on the basis of this model and the reviewed literature. The next section describes the sample data. Section five discusses the econometric model used to test the hypotheses and explores the relevant operationalization issues. Estimation results are presented and discussed in section six. We finally conclude the paper and provide recommendations for future research.

2. Benefits, Costs and Effects of Enterprise Systems

2.1. Enterprise system types

The literature on critical success factors and organizational change management of enterprise systems identify factors that influence the quality and success of ES implementations (Al-Mashari et al 2003; Markus et al. 2000; Motwani et al. 2005; Nah et al. 2001). On the basis of the existing literature, we distinguish between two classes of enterprise systems. These classes differ by the extent of the organization that is (fundamentally) affected by installation of the system. Implementation of some enterprise systems requires a wide range of organizational units to be involved/changed, for these systems to provide full functionality according to their design specification. ERP systems, for instance, cannot effectively function unless the information, transactions, and functions of different domains of the organization, such as procurement, production, marketing and sales, distribution, finance, and human resource management are integrated through a shared data store (Davenport 1998; Willcocks and Sykes 2000). Similarly, SCM applications can best fulfill their functional promises by coordinating and streamlining the activities related to movement and storage of raw materials, work-in-progress inventory, and finished goods throughout the whole supply chain of the company (Liu et al. 2005; Lummus and Vokurka 1999). KMS software is also productive when the information and knowledge assets of the organization are all collected, organized, combined, processed, and shared (Alavi and Leidner 2001; King and Marks Jr. 2008). We categorize these enterprise systems whose implementation involves and affects a broad spectrum of organizational entities as *organization-wide systems.*

The other class of enterprise systems is more confined to a limited number of organizational units. These systems are typically simpler and easier-to-use and are not necessarily implemented throughout the whole organization. For example, CRM systems are used to gather, track, and analyze a company’s contacts and relationships with its current or prospective customers (Boulding et al. 2005). The Marketing and Sales department of the company is usually the organizational unit that is directly involved in and affected by a CRM installation. In fact, for a functional CRM system, all the separate firm departments are not necessarily integrated. DMS applications can be installed for separate departments and do not need full organizational integration as well (Knowles 1995; Laserfiche 2007). A DMS is a computerized system to collaboratively create, edit, archive, and publish electronic documents of a single or multiple domains of an organization with similar documentation processes and requirements. We categorize these enterprise systems whose implementation narrows to a limited array of organizational entities as *domain-specific systems*.

2.2. Benefits and costs of enterprise systems

Numerous benefits and costs have been attributed to enterprise systems in the literature. The benefits of enterprise software can be grouped into four categories (e.g. Botta-Genoulaz and Millet 2005; Botta-Genoulaz et al. 2005; Davenport 2000; Rikhardsson and Kraemmergaard 2006; Shang and Seddon 2002; Uwizeyemungu and Raymond 2009):

(1) *Information reach and richness*: enterprise systems make new, improved, more accurate, and otherwise inaccessible information available to different organizational units; this results in better governance and control of the firm, improved planning and coordination of activities, more informed decisions, and faster response times.

(2) *Process automation and integration:* business processes of the firm are changed and further streamlined according to built-in best practices of the enterprise software; this results in administrative savings through eliminating manual, repetitive procedures and operational savings through more efficient and aligned business processes.

(3) *Information systems maintenance and modification:* an enterprise software in the form of a central and integrated IT system instead of several loosely-coupled subsystems and separate business applications results in reduction of information systems costs through economies of scale and scope.

(4) *Organizational competence and effectiveness:* through different mechanisms, enterprise systems adoption leads to among others, organizational learning, employee empowerment, business agility, service quality, and customer satisfaction, which can be further translated to growth and competitive advantage of the firm.

The benefits of enterprise systems go together with certain costs and restrictions (e.g. Davenport 1998; Kremers and Van Dissel 2000; Robey et al. 2002; Soh et al. 2000). In addition to spending in software, hardware, training, maintenance, and consultancy services, the costs and restrictions of enterprise systems can be categorized into four groups:

(1) *Structural rigidities and misfits:* the built-in, generic best practices in the enterprise software might not optimally suit the particular, local requirements of the implementing organization.
(2) *Data standardization and organizational change:* the initial technological investment and later organizational change required for standardizing data and processes might result in various restraints and resistances by employees; changing workers' visions and attitudes towards technology also adds to the challenge.
(3) *Error- and change-escalating effects:* the tight coupling and interaction of IT components in the form of a unified, centralized enterprise system makes it hard to change or adjust a single subsystem without affecting others; an error or breakdown in one subunit quickly propagates throughout the whole system.
(4) *System size and complexity:* the huge size combined with high degree of complexity makes it complicated and time-consuming to learn, understand, configure, test and use enterprise software.

Complex organization-wide systems have more potential to generate business value and competitive gains. However, the extra benefit comes at the cost of more considerable risks, structural rigidities, organizational changes and error-escalating effects (Huang et al. 2004; Rettig 2007; Scott and Vessey 2002; Sumner 2000). In contrast, domain-specific applications are relatively smaller, simpler, cheaper and easier to implement, optimize, and use and therefore expected to exhibit higher probabilities of successful implementation.

2.3. Performance effects of enterprise systems

Two streams of research can be distinguished. First, the IT Business Value literature investigates information technology effects at different levels of analysis. The earlier studies are equivocal in pronouncing the business value of IT, with a number of them reporting negative, neutral or mixed effects (Byrd and Marshall 1997; Hitt and Brynjolfsson 1996), while the majority of the more recent studies confirm a significant positive impact (Bardhan et al. 2006; Bartel et al. 2007; Bharadwaj 2000). The second strand of the literature focuses on performance impact of enterprise systems as a specialized subclass of information technologies (Hendricks et al. 2007; Hitt et al. 2002). The existing empirical literature largely consists of trade articles, (collection of) case studies, field experiments, and (self-reported) industry surveys, mostly from the US (e.g. Akkermans et al. 2003; Kohli and Hoadley 2006; Mabert et al. 2001 and relevant references therein; McAfee 2002; Uwizeyemungu and Raymond 2009). These studies are useful by offering meaningful and concrete lessons for implementation strategies but lack a certain generalization of their results that is achievable through rigorous and representative empirical analyses.

The existing empirical studies based on objective data are equivocal about the performance effects of different types of enterprise systems. A number of studies report negative impacts during the implementation process or one to two years after ERP systems go live (known as shakedown, shakeout or brake-in phase) and only positive effects after two to three years of continued use (known as onward, upward or acceptance phase) (Hitt et al. 2002; Liu et al. 2008; Nicolaou 2004a). Several studies also report insignificant differences in profitability or financial performance between ERP-adopters and non-adopters (Poston and Grabski 2001; Wieder et al. 2006). On the contrary, a considerable group of the literature observes profound positive impacts of ERP adoption on order lead time (Cotteleer and Bendoly 2006), on profitability (Hendricks et al. 2007), on return on assets, return on investment and asset turnover (Hunton et al. 2003) or on information response time and order cycle (Mabert et al. 2000).

Although the majority of the existing literature on enterprise systems focuses on ERP[46] and uses US data, there are a handful of studies on other ES types and based on non-US data. Here, a distinction shall be made between two branches of the literature. The first group treats SCM, CRM and KMS concepts as a corporate policy, management practice or organizational capability (e.g. Li et al. 2006; Massey et al. 2002; Coltman 2007; Ryals 2005). The second group explicitly focuses on SCM, CRM, and/or KMS as IT-based enterprise systems.

[46] It is partly because ERP has been introduced into business earlier than most of the other enterprise applications and can act as a platform for implementing them (Ragowsky and Somers, 2002).

Dehning et al. (2007) investigate the financial benefits of SCM systems in 123 US manufacturing firms and report improvements in gross margin, inventory turnover, market share, return on sales, and general administrative expenses. Similarly, Hendricks et al. (2007) use a sample of 140 SCM implementations in the US and show that, on average, SCM adopters experience positive stock returns and improvement in profitability in comparison to their industry peers. Shin (2006), using a production function approach and a dataset of 525 Korean SMEs, finds that SCM adoption raises SMEs' productivity, especially in the manufacturing sector. Wieder et al. (2006) rely on a sample of 102 Australian firms to conclude that SCM software, when jointly used with ERP, results in higher performance at the level of internal business processes.

Hendricks et al. (2007) analyze a sample of 80 CRM implementations in the US and find no evidence for improvement in stock returns or profitability for firms invested in CRM. Using 21 responses from an exploratory survey conducted in the UK financial services sector, Karakostas et al. (2005) report limited benefits from IT-enabled CRM tools in terms of operational saving and absolutely no effect on internal processes. Feng et al. (2004) setup a pair-wise design and find that KMS-adopting firms significantly reduce administrative costs, improve productivity and gain competitive advantage over their non-adopting peers, especially in the second year after implementing the knowledge management system. In a similar study, Feng and Chen (2007) report that KMS adoption pays off in profitability, particularly in manufacturing firms.

2.4. Innovation effects of enterprise systems

The literature adopts two opposing views with regard to the innovation contribution of enterprise systems. Enterprise systems can impede but also stimulate innovation. One view deals with the inherent rigidities and complexities of enterprise systems and thus advocates the impeding effects. Enterprise applications can impose structural and procedural constraints, as they bring and install with themselves a set of generic, pre-programmed and fixed or hard-to-customize routines and procedures in the organization, which might fit the information needs, internal structures and specific idiosyncrasies of some organizations but misfit those of others (Kremers and Van Dissel 2000; Soh et al. 2000). In this view, enterprise systems are understood as constraining systems with inherent rigidity, inertia, and resistance to change (Davenport 2000). The tight coupling and cross-departmental integration of, especially organization-wide, enterprise systems make them highly complex, vulnerable to change and difficult to understand/manipulate and thereby hamper innovation (Gattiker and Goodhue 2000; Robey et al. 2002).

The other view focuses on information reach and richness promoted by these systems and therefore acknowledges an enabling role. Enterprise systems are enablers of innovation and change as information and knowledge are essential elements in the innovation processes of the firm (Leonard-Barton 1995). Enterprise systems enhance the access to and flow of timely and accurate information and relevant ideas internally and externally. This accelerates the problem solvings and decision makings involved in any innovation process. Furthermore, enterprise applications have the potential to significantly enhance the knowledge capabilities of the firm through increasing its absorptive capacity[47] (Kim 1998; Sirvardhana and Pawlowski 2007) and providing opportunities to acquire new knowledge[48] (Ko et al. 2005; Lee and Lee 2000; Volkoff et al. 2004).

3. Conceptual Model and Hypotheses

The conceptual model focuses on the post-implementation phase of enterprise systems. Among other researchers, Botta-Genoulaz et al. (2005) and Uwizeyemungu and Raymond (2009) emphasize on post-implementation assessment of ES business value as one of the important directions of future research on enterprise systems. This is essential as previous research reports that long-run benefits of enterprise systems can be completely different from their immediate after-effects (Nicolaou 2004a; Nicolaou and Bhattacharya 2006). In constructing the conceptual model, two notions are relevant: *the facilitating or supportive role of ES* and *the enabling or innovative role of ES*. As far as the first notion is concerned, IT in general and ES in particular can directly support and facilitate the status quo, i.e. current situation, in the firm. This includes increasing the efficiency/productivity of current workflows, automating existing business processes, facilitating present information routines and

[47] The efforts and interactions of organizational members to observe and resolve problems during the implementation and customization of an enterprise system significantly increase the absorptive capacity of the organization.

[48] The business knowledge pre-embedded in the architecture and reference model of the software as well as the expertise of consultants and advisors participating in system installation and maintenance are important sources of new knowledge.

communication channels, and supporting available product portfolios and service offerings of the firm. With regard to the second notion, IT and especially ES can substantially change the status quo and enable new or significantly modified practices, routines, processes, methods, channels, services, and/or products. The enabling role yields new processes, services and/or products and thus indirectly affects firm performance through these innovations. These two notions lead us to construct the model displayed in Figure 1.

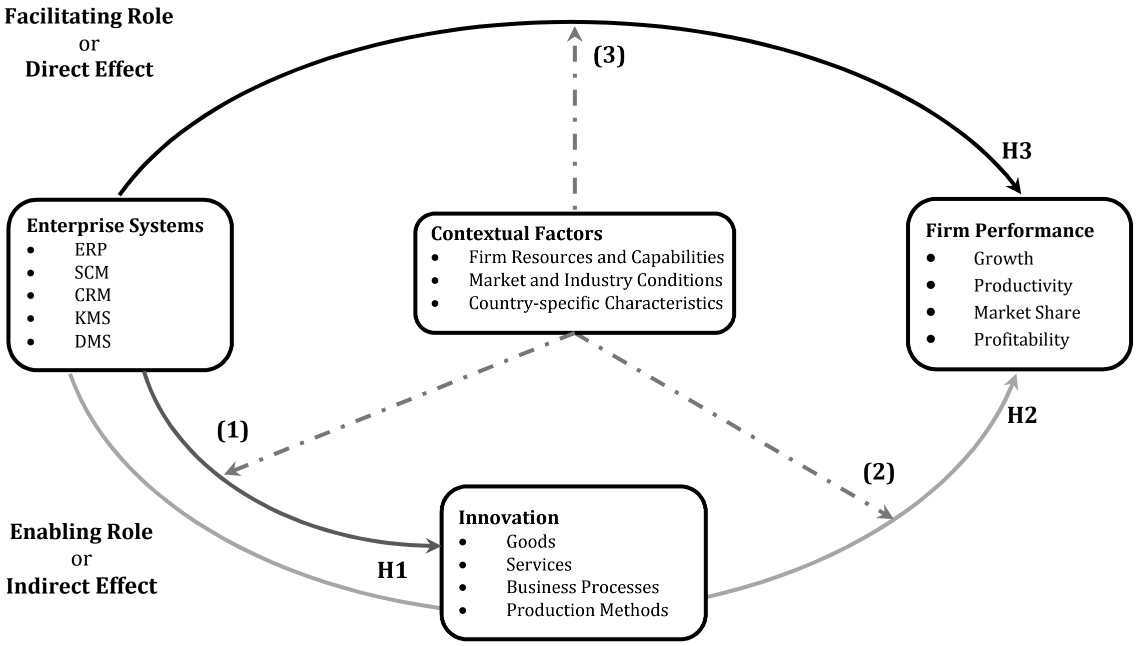

Figure 1: Conceptual Model of Relationships among Enterprise Systems, Innovation and Firm Performance

As shown in Figure 1, enterprise systems affect firm performance through two different paths. The upper path is the direct path without any intervening element in between. The lower indirect path, though, goes through innovation as the mediating factor. The central component of the model relates to firm-, market-, and country-specific characteristics that moderate the relationships in the model. This means that the effect of enterprise systems on corporate performance can differ from one firm to another, depending on the firm's resources and capabilities (e.g. the skills level or infrastructure of the firm), market and industry conditions (e.g. concentration of the market or knowledge-intensity of the sector), and country characteristics (e.g. the regulatory regime or intellectual property rights of the country). Below, different constructs and relationships in the model are substantiated in more details, leading us to formulate three research hypotheses.

3.1. Relationship between enterprise systems adoption and Innovativeness[49]

Innovation is a knowledge-intensive organizational process (Adamides and Karacapilidis 2006), where information and knowledge are the key determinants of success (Brown and Eisenhardt 1995). Innovation is a process where creative and knowledgeable people and communities frame problems and then search, select, and combine information to enhance their understanding and resolve the problems (Teece 2001; Von Hippel 1994). In an innovation process, for optimal decision making and problem solving, all the relevant information, ideas, and insights should be considered and all the obstacles and constraints shall be identified from all the relevant (distributed) sources and stakeholders. The required knowledge for the innovation process exists either inside or outside the boundaries of the firm. If the knowledge is available internally, it must become visible to everyone through gathering and codifying it at a central, accessible location; this way, the important information does not remain trapped in isolated minds, documents or applications. If the required knowledge is not available internally, it must be collected, structured, and processed through external sources (such as suppliers, customers, universities, and consultants). In this respect, enterprise systems facilitate information flow and communication among the diverse set of actors and teams involved in an innovation process. They help the corporation be more innovative as they aggregate, organize and integrate data, from internal and external sources, and process it into useful information (Richards and Jones 2008). Even more, they support transformation of information into organizational knowledge (O'Leary 2000).

The adoption of enterprise systems does not only come with benefits but also at certain costs. The hindering effects of enterprise software with respect to innovation can be summarized into two groups: (1) the inherent rigidity and inflexibility of enterprise systems due to their built-in business process models, which might not suit

[49] The terms "innovativeness" and "innovation" are used interchangeably in the literature as well as this paper.

every single organization (Davenport 2000; Soh et al. 2000) and (2) the difficult task of customizing these systems due to their high level of integration and complexity, which impedes their users' understanding, learning and change capability (Robey et al. 2002; Rettig 2007).

The benefits can be expected to outweigh the costs in the long run as a firm uses its enterprise application for a lengthy enough period of time.[50] In fact, we expect to face a *system lifecycle effect* as the main obstacles are primarily experienced during the implementation and early post-implementation (or shakedown) of the enterprise system, lasting for as long as 2-3 years (or, in some instances, more) (Hitt et al. 2002; Hunton et al. 2003; Liu et al. 2008; Markus et al. 2000; Poston and Grabski 2001; Rajagopal 2002). Afterwards, we expect that the positive effects become dominant. By the time we reach the so-called post-implementation phase of enterprise applications, the firm should have learned from its own or others' history and be more comfortable using and adapting the software to its own specific needs and thereby more benefits are likely after additional experience with the system (Scott and Vessey 2000; Shang and Seddon 2000); employees should have received the required trainings/incentives and have accepted and institutionalized the system as an inevitable part of their routine day-to-day business activities (Peterson et al. 2001); software flaws should have been adequately detected and removed and cross-functional coordination/integration has been probably realized (Nicolaou 2004a). In this respect, the recent empirical research shows that the performance contribution of ES implementations improves once time since adoption increases (e.g. Krasnikov et al. 2009; Wieder et al. 2006).

The internal, sectoral and national context in which the innovation process happens, consisting of among others workforce quality/education, organizational infrastructure, knowledge-intensity of the sector, and the national innovation system of the country, are also important elements in determining and shaping the outcomes of innovation (Damanpour 1991; Scott and Bruce 1994; Subramanian and Nilakanta 1996). The above discussion leads us to hypothesize that:

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[50] The existing research indicates that for an average ES application this time period is about two years (Hendricks et al. 2007; Mabert et al. 2000; McAfee, 1999; Nicolaou 2004a; O'Leary, 2000; Umble and Umble, 2002).

Hypothesis 1: The continued adoption of enterprise systems enhances innovativeness of the firm as measured by product and process innovation, controlling for contextual factors.

3.2. Relationship between innovation and firm performance

The link between innovation and firm performance has been the subject of some past studies (e.g. Koellinger 2008). Product innovation corresponds to the generation of a new production function (Beath et al. 1987). If demand for the new product exists in the market, sales can be expected to increase. Even if the new product substitutes an existing product of the firm, premium prices can be charged and sales growth is achievable, providing the new product is substantially differentiated from the existing offerings of the firm (Shaked and Sutton 1982). The above mechanism is conceivable for both physical goods and intangible services. Process innovation corresponds to the outward shift of an existing production function (Dasgupta and Stiglitz 1980). This can be translated to productivity increase (Ghosal and Nair-Reichert 2009) as more output can be generated using the same amount of inputs or the same amount of output with less inputs. This productivity gain can be captured in lower production costs of the process output(s). The resulting cost saving can be further transformed to lower prices. Assuming that the price elasticity of buyers is high enough to substantially react to the price difference, ceteris paribus, process innovation can lead to more revenues for the firm.

Although economic theory predicts that innovating firms will experience output growth and are more likely to survive in the market (Audretsch 1995), the ability of the firm to appropriate above-normal profits from its innovative sales and increase its market share is contingent on several, mostly external, contextual factors (Geroski et al. 1993; Levin et al. 1987; Stoneman and Kwon 1996). The firm is able to outperform its competitors and capture private rents until the moment that the innovation becomes technologically obsolete as the taste of buyers or market standards change over time or the (direct or indirect) competition copies the innovation (and its associated complementary assets) or introduces a better, cheaper or more novel product to the market (Teece 1986; 2006). Therefore, to sustain the payoffs, the innovator should put its effort to prohibit any sort of imitation or technology transfer. This is the appropriability problem (Geroski 1995) and depends on a number of factors. Some factors are internal to the firm such as its strategy towards forming strategic alliances with rivals, adopting diverse protective mechanisms (e.g. patenting, secrecy, and complementary service bundling) or timing of innovation, i.e. first-mover advantages (Harabi 1994). Other factors are exogenous and normally beyond the control of the firm (Melville et al. 2004) and include market concentration, type of rivalry, knowledge intensity of the industry, rate of obsolescence of the technology, intellectual property rights and regulatory regime of the country (see Roberts 1999 and relevant references therein). To capture the above effects, the conceptual model incorporates contextual characteristics as moderators of the links among ES adoption, innovation and firm performance.

The discussion in section 3.1 and 3.2 brings us to the following hypothesis:

Hypothesis 2: The continued adoption of enterprise systems enhances performance of the firm as measured by revenue growth, productivity growth, market share growth, and profitability via product and process innovation, controlling for contextual factors.

3.3. Direct relationship between enterprise systems adoption and firm performance

The direct effects of enterprise systems on firm performance are observable when they facilitate or support current processes, routines, work policies and product/service offerings of the firm to make them more efficient, without promoting radically new ways of doing or coordinating things or introducing fundamentally new products or services. For example, an ERP system results in administrative and operational saving by eliminating manual, repetitive tasks of data entry and reporting (e.g. Davenport 2000; Gupta and Kohli 2006). This can be translated to lower variable costs of production and thereafter to lower prices and hence higher sales if demand is price-elastic. Similarly, a SCM application leads to lower inventory levels and order processing times (Liu et al. 2005; Lummus and Vokurka 1999) which can again manifest in the form of lower production costs and higher revenues. KMS and DMS software result in internal efficiencies through facilitating knowledge sharing and document searching (King and Marks Jr. 2008) and thus promote productivity and growth.[51]

[51] These systems might result in some inefficiencies in the short run, as employees ought to spend some of their productive time to codify their otherwise tacit knowledge and keep the software updated. However, in the long run, collective productivity gains will be observed due to higher and faster accessibility of knowledge and information throughout the organization.

Contextual factors play an important role in moderating the direct link between ES adoption and firm performance as well. Internal efficiencies after installing an enterprise system are made ineffective in terms of price-cutting and growth promotion if other competing firms in the marketplace replicate these efficiencies through installing similar systems or adopting feasible alternatives. The discussion here leads to:

Hypothesis 3: The continued adoption of enterprise systems enhances performance of the firm as measured by revenue growth, productivity growth, market share growth, and profitability directly (by improving the efficiency of current practices and policies), controlling for contextual factors.

4. Data Descriptive Statistics

4.1. Data

The data in this study originates from the *Decision-maker Surveys* in years 2003, 2005, 2006, and 2007 (two surveys), executed by e-Business Market W@tch and sponsored by the Enterprise and Industry Directorate General of the European Commission. The objective of e-Business Market W@tch is to monitor the adoption and assess the impact of IT and e-Business practices in Europe by providing scientifically reliable, methodologically consistent, and internationally comparative empirical data of European enterprises in diverse sectors. For comparison purposes, the 2007 surveys are extended with a considerable number of US establishments. The surveys are conducted at the enterprise-level[52], from random, representative samples of the respective industry sector populations in each country. The surveys use a mix of CATI (computer-assisted telephone interview) method and face-to-face interviews. The target decision-maker in the enterprise is normally the person responsible for IT within the company, typically the IT manager or chief technology/information officer. Alternatively, in small enterprises without a separate IT unit, the managing director or the owner is interviewed.[53]

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[52] Defined as a business organization of one or more establishments that is comprised as one legal unit.

[53] Visit: http://www.ebusiness-watch.org/ for further methodological details on e-Business W@tch Decision-maker Surveys.

The 2003 survey includes 10315 enterprises in 25 countries and 22 sectors[54], the 2005 survey 5218 enterprises in 7 countries and 14 sectors, and the 2006 survey 14065 enterprises in 29 countries and 12 sectors. The 2007 survey was conducted in four separate sub-projects, two of which are relevant to this study: Manufacturing (MFG) and Retail, Transport & Logistics (RTL). The MFG survey covers a sum of 1821 enterprises in 8 countries and 5 sectors and the RTL survey 2023 enterprises in again 8 countries but only 4 sectors. If one pools all the datasets, [55] there are in total 33442 enterprises in 29 distinct European countries (EU-27 plus Norway and Turkey) and 29 different sectors (Manufacturing {NACE codes: 15, 17, 18, 19, 20, 21, 22, 24, 25, 17, 29, 30, 31, 32, 34, 35, and 36}; Construction {NACE code 45}; Services {NACE codes: 50, 52, 55, 60, 62, 63, 64, 72, 74, 85, and 92}). Before constructing the pooled dataset, the individual annual surveys were carefully cleaned and checked for internal consistency. That means that all the logical or systematic inconsistencies as well as entry or typo errors were detected (by means of computer programs) and manually removed from the dataset after carefully observing the survey responses one by one. Table 1 shows the distribution of enterprise observations in each sector-country group in the pooled version of the dataset.[56]

Table 1: Composition of Enterprise Observations in the Pooled Dataset (% of Sample Total)

Country / Sector	Manufacturing (%)	Construction (%)	Services (%)	% Sample
Austria	0.68	0.36	1.06	2.09
Belgium	0.78	0.30	1.02	2.10
Bulgaria	0.48	0.36	0.36	1.20
Cyprus	0.15	0.24	0.43	0.82
Czech Republic	3.28	0.48	1.62	5.38

[54] A sector is defined at 2-digit level (NACE rev. 1.1).

[55] Since enterprise unique identifiers are not available, constructing a panel data through linking the datasets is not possible; a pooled dataset is the only viable option for conducting a longitudinal analysis at the firm-level to benefit from the time dimension of the data.

[56] Due to space constraints, only the pooled version of the data and its descriptive statistics are presented; descriptives of the individual datasets are available upon request.

Denmark	0.39	0.30	1.11	1.80
Estonia	0.68	0.45	1.26	2.39
Finland	1.50	0.42	1.01	2.92
France	4.87	0.69	3.58	9.13
Germany	5.33	0.62	3.37	9.31
Greece	1.21	0.53	0.68	2.41
Hungary	1.55	0.45	1.02	3.03
Ireland	0.48	0.36	0.99	1.83
Italy	5.42	0.61	3.16	9.20
Latvia	0.46	0.39	0.89	1.74
Lithuania	0.31	0.36	0.71	1.38
Luxembourg	0.00	0.19	0.16	0.35
Malta	0.00	0.10	0.36	0.45
Netherlands	0.88	0.16	1.07	2.10
Norway	0.23	0.55	0.72	1.50
Poland	4.69	0.59	3.23	8.52
Portugal	0.94	0.00	1.17	2.11
Romania	0.39	0.36	0.57	1.32
Slovakia	0.53	0.38	0.91	1.82
Slovenia	0.36	0.50	1.15	2.01
Spain	5.20	0.64	3.32	9.16
Sweden	1.71	0.00	2.04	3.76
Turkey	0.52	0.22	0.45	1.20
United Kingdom	4.84	0.62	3.51	8.98
Total	**48.00**	**11.06**	**40.94**	**100.00**

- *Manufacturing sector* includes: Foods and beverages (NACE 15), Textile, apparel, footwear and leather products (17, 18 & 19), Wood, wood products and furniture (20& 36), Publishing, printing and pulp/paper products (21 & 22), Chemicals, chemical products, pharmaceuticals, rubber and plastics (24 & 25), Metals, metal products and machinery/ equipment manufacturing (27 & 29), ICT manufacturing, consumer electronics, electrical machinery and office equipment (30, 31 & 32), and Automotive/transport equipment manufacturing and aerospace industries (34 & 35).

- *Construction sector* includes: Construction (NACE 45).

- *Services sector* includes: Retail and Wholesale (NACE 50 & 52), Tourism, hotels and recreational/cultural activities (55, 62, 63 & 92), Transport and logistics (60 & 63), ICT services and telecommunications (64 & 72), Business services (74), and Health, hospital and social services (85).

We deal with 448 unique markets (sector-country pairs) with an average of 75 firms in each group. Large countries of Europe represented in the sample, namely Germany, France, United Kingdom, Italy, Spain, and Poland comprise more than half of the observations. The remaining countries constitute between 0.34% (Cyprus) and 5.30% (Czech Republic) of the sample. The manufacturing sector, covering almost all the important low- and high-tech industries, amounts to 48% of the sample. The services sector, making up 41% of the sample, covers almost all the important service industries except for banking, insurance/pension and financial intermediation (NACE 65-67). The construction sector represents the remaining 11% of the sample.

To assess the representativeness of the sample, we compared the sample characteristics with those of the National Accounts data for the available countries.[57] Two criteria were considered important: (1) the relative distribution of different sectors (in terms of the number of enterprises) in the surveyed countries, and (2) the relative distribution of different enterprise size classes in the sampled sectors. The comparisons corroborate the idea that the sample can be assumed to be a good representation of the underlying population in the respective countries, though, for those sectors of the economy which are relatively heavier and more advanced users of IT and e-Business.[58]

4.2. Descriptive statistics

Table 2 gives the descriptive statistics of the relevant variables.

Table 2: Descriptive Statistics of the Variables

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
	Innovation				
Product/Service Innovation	29681	.444	.497	0	1
Internal Process Innovation	29705	.393	.488	0	1
	Firm Performance				
Revenue Growth	30064	.511	.500	0	1
Productivity Growth	12464	.533	.499	0	1
Market share Growth	15819	.447	.497	0	1
Profitability	11182	.837	.369	0	1
	Firm & Market Characteristics				
# of Employees	32529	133.787	850.874	1	60000
% Higher Education	27909	26.058	30.724	0	100
% R&D Employees	14876	11.032	22.228	0	100

[57] The control data is supplied by Eurostat (available at: http://epp.eurostat.ec.europa.eu/portal/page/portal; last access: 11 Sep. 2009). The correlation tables and accompanying tests are not presented due to space constraints but accessible upon request.

[58] The Financial sector is an exception, whereas it is an intensive user of IT but non-represented in our sample due to the decision of e-Business W@tch to cover it in another separate survey. Our sample is also not a good representation of Agriculture/Forestry, Fishery, Mining, Energy, and Public supplies with relatively low levels of IT usage. Moreover, among the different size classes, large enterprises (with more than 249 employees) are slightly under-represented in the sample.

International Competition	22846	.176	.380	0	1
Western Europe*	33442	.687	.464	0	1
Eastern Europe**	33442	.288	.453	0	1
Manufacturing	33442	.479	.500	0	1
Services	33442	.409	.492	0	1
Construction	33442	.112	.316	0	1
Market Share ∈ [0,5]	33442	.178	.383	0	1
Market Share ∈ (5,10]	33442	.051	.221	0	1
Market Share ∈ (10,25]	33442	.068	.251	0	1
Market Share ∈ (25,100]	33442	.229	.420	0	1
IT Infrastructure & Enterprise Systems					
Broadband Internet	31346	.711	.453	0	1
% Internet-enabled Employees	22232	29.757	38.889	0	100
e-Business Maturity	32844	.190	.393	0	1
Enterprise Resource Planning	31711	.200	.400	0	1
Supply Chain Management	31698	.111	.314	0	1
Customer Relationship Management	31798	.141	.348	0	1
Knowledge Management System	27355	.112	.315	0	1
Document Management System	20005	.192	.394	0	1
Enterprise System *(of any type)*	30463	.398	.489	0	1

**Western Europe* includes: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, and United Kingdom.

***Eastern Europe* includes: Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.

Forty-four percent of the firms in the sample have introduced at least an innovative product or service to the market in the annual period they were surveyed, while less than 40% of them have had an internal process innovation in the same period. About half of the firms have experienced sales growth when comparing the financial year prior to the survey with the year before. More than half of them have experienced productivity increase while less than 45% have had market share growth in their primary market(s). More than 83% of the sampled firms have been profitable in the past year (with reference to when they were surveyed).[59] These promising

[59] As expected, the output measures are not independent. The Pearson correlation coefficients reveal the highest correlations among the growth indicators: revenue growth and productivity growth (0.61) and revenue growth and market share growth (0.56). The lowest correlations exist between innovation measures and profitability: process innovation and profitability (0.05) and product innovation and profitability (0.07). The complete correlation table is accessible on request.

performance indicators partly reflect the expansionary, upgoing business cycle in the period of analysis (2003-2007).

The average firm in the sample has about 134 employees, of which about a quarter has at least a college or university degree and about one-tenth is primarily engaged in R&D activities. The standard deviation of these variables indicates a rather large spread of their values around their mean and thereby high heterogeneity among the sampled firms in these respects. Eighteen percent of the sampled companies actively compete in international markets; sixty-nine and twenty-nine percent belong to Western and Eastern Europe respectively.[60] Around 18% of the firms have a market share of up to 5% and 23% a market share of more than 25% with the rest lying somewhere in between. When it comes to IT infrastructure, 71% of the enterprises have access to some sort of broadband internet with an average of 30% (i.e. less than one-third) of their employees connected to high-speed internet at their workplace. The standard deviation of this variable confirms that it is wide-ranging around its average point among the surveyed companies. Overall, 19% of the sampled firms are mature in adopting e-Business technologies or conducting e-Business processes, which shows that there is plenty of room for improvements in this area in Europe.

With respect to the variables of main interest, i.e. enterprise systems, two-fifth of the sampled enterprises is using at least one type of ES software by 2007. ERP and DMS are the most commonly used applications, with an average adoption rate of 1 out of 5 enterprises, followed by CRM, KMS, and SCM; this can be partly explained by the fact that ERP usually acts as a common platform for installing CRM and SCM applications and that many companies prefer a less complex system of information management like DMS to a sophisticated one like KMS. [61] Moreover, CRM, KMS, and SCM systems are relatively new compared to ERP and DMS.

The average IT budget (incorporating hardware, software, services and personnel) as percentage of the company total costs and turnover is 7.78% and 1.51% respectively.[62]

[60] Cyprus, Malta, and Turkey were not classified in either Western or Eastern Europe.

[61] In our sample, about half of the firms with a CRM or SCM system also have an ERP installed. About half of the firms which decided to implement an information management system have only opted for DMS while only less than 30% of them have gone for KMS.

[62] The budgetary data is not presented in Table 2 as this information is not available for the whole period of analysis but only for some years of the survey.

The available macro data (Eurostat 2009) indicates a comparable trend of IT expenditure (as percentage of GDP) in most of the sampled countries, although the average for the whole European Union (EU-27) for the sub-period 2004-2006 is higher, i.e. 2.70%. The average share of IT practitioners (responsible for implementation and maintenance of IT infrastructure and computer networks) as a percentage of corporate employees (in absolute terms) is 8.85%. An important notion is that the surveyed firms in our sample, on average, are using ERP, SCM, CRM, and KMS systems in their daily business for 66, 48, 42, and 44 months respectively, by the time they were questioned.[63,64] Comparing these numbers with the available observations in the literature, which imply an average of 17-21 months for full installation and a comparable or shorter period for optimization of ES applications (Hendricks et al. 2007; Mabert et al. 2000; McAfee 1999; O'Leary 2000; Umble and Umble 2002), indicates that the average firm in our sample has already passed the implementation, customization and adaption phases of enterprise systems and is likely in a diffusion, routinization or institutionalization stage where it is capable of utilizing the installed applications effectively and productively (Rajagopal 2002).

Finally, the comparison of ES adoption rates over time and in different enterprise size classes and industrial sectors in Europe yields interesting results. Figure 2 shows an overall growing trend of ES adoption in Europe in the period 2003-2007. The most considerable growth for all the ES types under consideration is seen from year 2003 to 2005. From 2005 to 2007, the ES market in Europe seems to be more stable. Over this period, ERP adoption has hardly experienced any growth, while SCM and CRM utilization have grown modestly.

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[63] Taking into account the adoption frequency of different enterprise systems in the sample, these figures can be translated into a weighted average of more than 52 months (or about 4.5 years) as an overall ES maturity indicator.

[64] The medians are 54, 38, 30, and 35 months and the percentiles with less than one year of adoption are 7%, 13%, 15%, and 14% for ERP, SCM, CRM and KMS respectively. The minimum of adoption duration for all the ES categories is one month and the maximum more than 167 months.

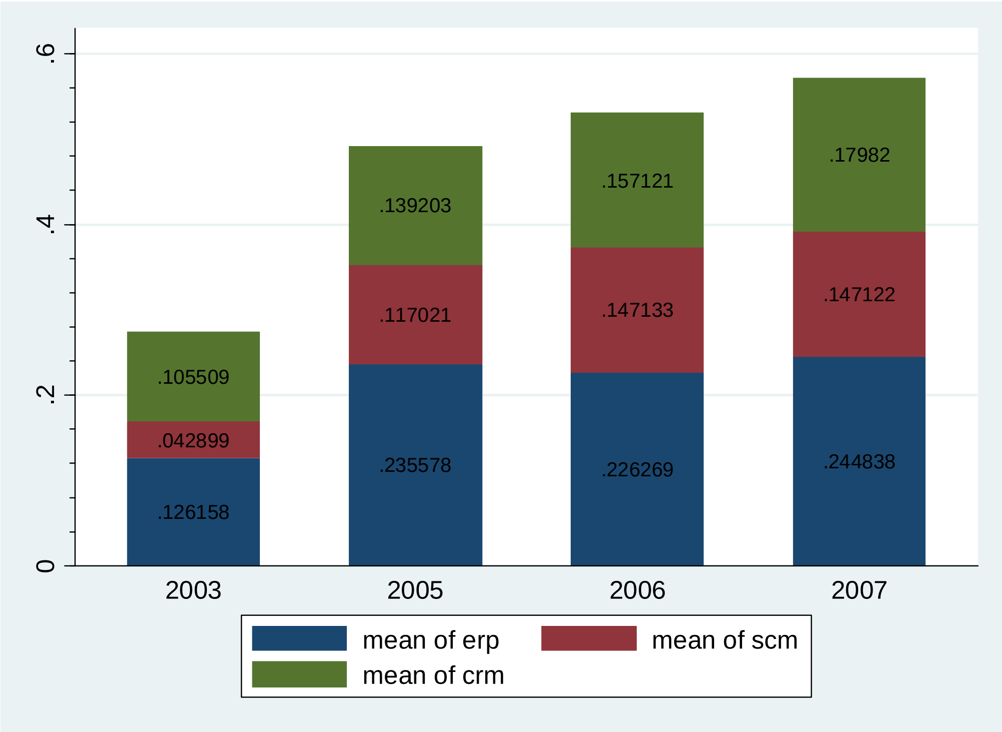

Figure 2: Development of the Mean Values of Enterprise Systems Adoption Rate in Europe over the Period 2003-2007

Figure 3 clearly indicates that large enterprises (with more than 249 employees) use ES software of any type significantly more than their medium and small counterparts.[65] This can be partly attributed to availability of investment capital and other organizational resources, which are necessary for implementing and maintaining these systems, in large corporations. Moreover, ES applications typically imply substantial organizational changes and governance implications, which make them impractical or unjustified for rather smaller organizations with lower levels of structural complexity and information need.

65 One-way ANOVA was used to test the significance of the differences. The test results are available on request.

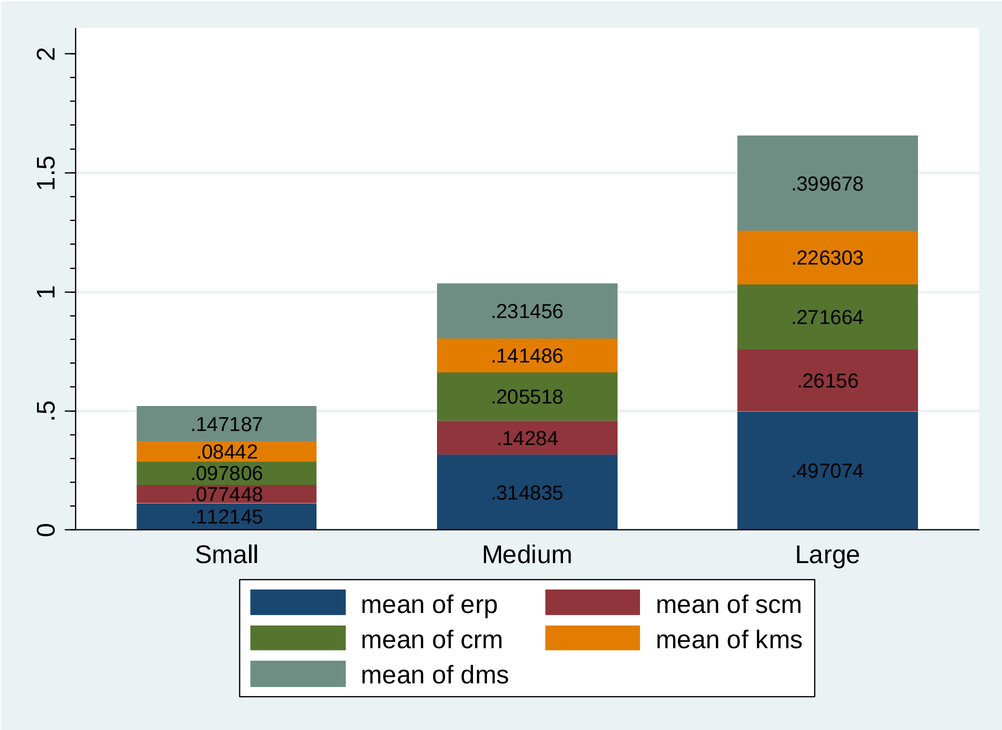

Figure 3: Mean Values of ES Adoption Rate in Different Enterprise Size Classes in Europe

Figure 4 shows that the construction sector (with a relatively lower degree of technology adoption, innovation, and skilled labor) generally adopts enterprise systems less than the manufacturing and services sectors. Between the manufacturing and services, ERP and SCM are more common to manufacturing firms while CRM, KMS and DMS to services companies. This can be explained by the nature of core business functions, internal processes and final products of these two broad sector categories. In the manufacturing, the core activities of the corporate value chain include procurement, inbound logistics, and operations to transform the physical inputs into finished goods (Porter 1985). In the services, supply chain management, materials handling and physical operations are of a lesser significance, while marketing/sales, after-sales services, and customer relationships are more important due to the more intangible character of the final products. Furthermore, services firms are usually more knowledge-intensive than their manufacturing counterparts.

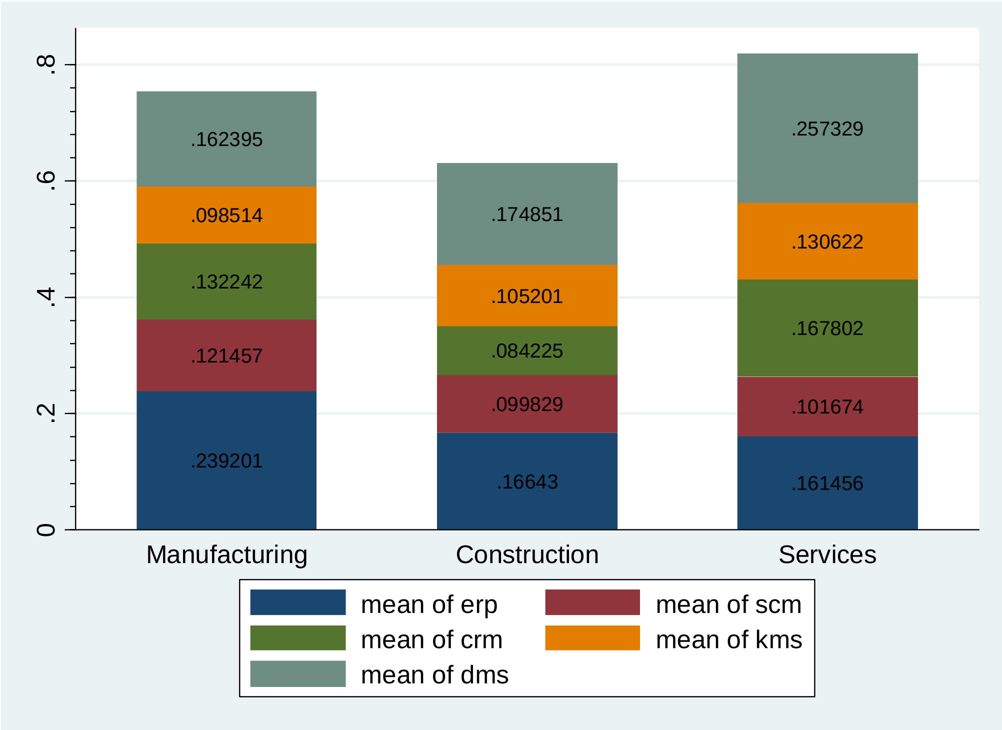

Figure 4: Mean Values of ES Adoption Rate in Different Sectors of the Economy in Europe

5. Econometric Model, Operationalization and Regression Method

5.1. Model specifications

The following general logistic model is used to relate enterprise systems adoption to firm-level innovativeness.

$$\ln\left[\frac{p(Innovation_{i,j}=1)}{1-p(Innovation_{i,j}=1)}\right]=\alpha_0+\overline{\alpha_1}\,\overline{ES}_{i,j}+\alpha_2 Size_{i,j}+\alpha_3 Education_{i,j}+\alpha_4 Internet_{i,j}+\alpha_5 eBusiness_{i,j}+\sum Market_{i,j}+\sum Time_{i,j}+u_j+\varepsilon_{i,j} \quad (1)$$

where i and j refer to the firm and the market in which the firm operates respectively and u_j and $\varepsilon_{i,j}$ specify unobserved market- and firm-specific effects.

A similar estimating equation is used to model the total (including both the direct and indirect) effects of enterprise systems adoption on firm performance.

$$\ln\left[\frac{p(Performance_{i,j}=1)}{1-p(Performance_{i,j}=1)}\right]=\beta_0+\overline{\beta}_1\overline{ES}_{i,j}+\beta_2Size_{i,j}+\beta_3Education_{i,j}+\beta_4Internet_{i,j}+\beta_5eBusiness_{i,j}+$$
$$\sum Market_{i,j}+\sum Time_{i,j}+u_j+\varepsilon_{i,j} \quad (2)$$

The dependent variable in the above estimation models is the log odds of a measure of innovativeness or performance. We distinguish between two innovation types: product innovation and process innovation. We also deal with four performance indicators: revenue growth, productivity growth, market share growth, and profitability. These are among the key measures of firm performance as recommended by, among others, Chand et al. (2005) and March and Sutton (1997).

In this study, we differentiate between the direct (or facilitating) and indirect (or enabling) effects of enterprise systems on firm performance. Innovation is predicted to act as a mediator in transmitting the indirect effects. Robust and systematic identification of indirect effects, especially when the mediation factor is dichotomous, presents conceptual and practical difficulties in nonlinear models such as Logit (Li et. al 2007; MacKinnon 2007; Van der Laan and Petersen 2004). Among the available path-analytic methods, we employ the following 3-step approach to yield easy-to-interpret results (Baron and Kenny 1986; Cohen et al. 2003; Hair et al. 2006: 867-868):[66]

1. First, model (2) above is used to estimate the total (i.e. the qualitative sum of the direct and indirect) effect of enterprise systems on firm performance.[67]
2. We then develop model (3) below where two innovation dummies are included as additional predictors of firm performance. This model extracts and only estimates the direct effect of enterprise systems on firm performance.

$$\ln\left[\frac{p(Performance_{i,j}=1)}{1-p(Performance_{i,j}=1)}\right]=\gamma_0+\overline{\gamma}_1\overline{ES}_{i,j}+\overline{\gamma}_2\overline{Innovation}_{i,j}+\gamma_3Size_{i,j}+\gamma_4Education_{i,j}+\gamma_5Internet_{i,j}+$$
$$\gamma_6eBusiness_{i,j}+\sum Market_{i,j}+\sum Time_{i,j}+u_j+\varepsilon_{i,j} \quad (3)$$

3. At last, we compare the estimation results of model (2) and (3). If the relationship between ES adoption and firm performance remains significant

[66] Known as the Sobel-Goodman mediation test.

[67] A simple arithmetic summation does not give a precise estimate as we work with log-linear models.

and unchanged once innovation is included in the model, then mediation (and, consequently, the indirect effect) is not supported. If the relationship reduces but still remains significant, then *partial mediation* is supported. If the relationship is reduced to a point where it is not significant anymore, then *full mediation* is verified.

5.2. Construction of variables

Table 3 summarizes the output measures in models (1)-(3) and their definitions. These dichotomous variables take a value of 1 if the firm exhibits a certain characteristic and 0 otherwise. In other words, if the corresponding response is "yes" or indicates a positive change (i.e. "increased") the measure is coded 1 and 0 otherwise. "Don't Know [DK]", "Refused to Say", and "Not Applicable [NA]" responses are recoded as missing.

The qualitative output measures used in this research have two advantages. The first one is that they provide information on the changes and dynamics of the performance measures. Information on the (absolute) level of turnover, productivity, market share, or profit of the firm per se would not reveal insights about the comparative performance improvements (due to ES adoption) as tracking these levels over time is not possible in a pooled dataset. Second, in contrast to common input-based indicators, such as R&D intensity, or indirect, output-oriented measures (such as patent counts), the qualitative innovation measures employed in this study imply explicit, actual innovative output of the firm rather than an innovation-related activity (which may or may not finally lead to an innovative output).

Table 3: Innovation and Performance Measures and their Source Questions

Dependent Variable	Type	Relevant Question from the Survey to Construct the Variable
		Innovativeness
Product Innovation	Dummy	• During the past 12 months, has your company launched any new or substantially improved product or services? (*yes/ no/ DK, refused or NA)**
Process Innovation	Dummy	• During the past 12 months, has your company introduced any new or significantly improved internal processes, for example for producing or supplying goods or services? (*yes/ no/ DK, refused or NA)*

	Performance	
Revenue Growth	Dummy	• Has the turnover of your company changed when comparing the last financial year with the year before? *(increased/ decreased/ stayed roughly the same/ DK/ NA)*
Productivity Enhancement	Dummy	• Has the productivity of your company changed when comparing the last financial year with the year before? *(increased/ decreased/ stayed roughly the same/ DK)*
Market Share Increase	Dummy	• Has the share of your company in its most significant market changed over the past 12 months? *(increased/ decreased/ remained roughly the same/ DK/ NA)*
Profitability	Dummy	• Has your company been profitable over the past 12 months? *(yes/ no/ DK, refused or NA)*

*DK: Don't Know; NA: Not Applicable

The set of explanatory variables in models (1)-(3) consists of both the ES adoption variables and the observed control variables. Table 4 summarizes the relevant covariates and describes their source question(s) in the survey.

Table 4: Independent Variables and their Source Questions in the Survey

Independent Variable	Type	Relevant Question(s) to Construct the Variable
	Enterprise Systems	
ERP	Dummy	• Does your company use an ERP (i.e. Enterprise Resource Planning) system?* *(yes/ no/ don't know what this is/ DK)*
SCM	Dummy	• Does your company use a SCM (i.e. Supply Chain Management) system?* *(yes/ no/ don't know what this is/ DK)*
CRM	Dummy	• Does your company use a CRM (i.e. Customer Relationship Management) system?* *(yes/ no/ don't know what this is/ DK)*
KMS	Dummy	• Does your company use a KMS (i.e. Knowledge Management System) system?* *(yes/ no/ don't know what this is/ DK)*
DMS	Dummy	• Does your company use a DMS (i.e. Document Management System) system?* *(yes/ no/ don't know what this is/ DK)*

Control Variables		
# of Employees	Continuous	• How many employees does your company have in total, including yourself? *(numerical value/ DK/ no answer)*
% Highly-educated Employees	Continuous	• What is the estimated percentage share of employees with a college or university degree in your company? *(numerical value/ DK/ no answer)*
Broadband Internet	Dummy	• Does your company have access to broadband internet, i.e. via DSL/ADSL/SDSL, Cable, direct Fibre/Fixed connection, Wireless connection, or other Broadband connections? *(yes/ no/ DK)***
e-Business Maturity	Dummy	• According to the overall experience of your company, would you say that e-business constitutes a significant part of the way your company operates today, or some part or none at all? *(significant part/ some part/ none at all/ DK)**** *or* • Would you say that most of your business processes are conducted electronically as e-business, a good deal of them, some, or none? *(most/ a good deal/ some/ none/ DK)*
Market Share	Set of Dummies	• How large is the market share of your company in its primary, most significant market? *(0-5%/ 5%-10%/ 10%-25%/ 25-100%/ DK)*

DK: Don't Know; NA: Not Applicable

* The ES questions are accompanied by short descriptions about what the system is and what it is used for.

** Depending on the year of the survey, all or a combination of different connection types has been questioned.

*** Depending on the year of the survey, one of these two questions has been asked in the interview questionnaire.

$\overline{ES_{i,j}}$ is a vector of system variables that takes two versions.[68] The basic specification only includes a dummy variable tracking if the firm uses enterprise systems (of any

[68] For the sake of robustness check, we ran four versions of each model. Two versions (with a single dummy or dummies for all application types) are presented in this paper. The other two models (with dummies for

type). The comprehensive specification extends this overall indicator into a set of five dummies referring to ERP, SCM, CRM, KMS and DMS adoption separately. We include the natural log number of employees (*Size*$_{i,j}$) to control for size and hence economies-of-scale effects. Larger firms are more likely to have introduced innovations due to higher availability of financial and knowledge resources. The logarithmic form is used to reduce the effect of skewness, as the number of employees is right-skewed. Percentage of higher-educated employees (*Education*$_{i,j}$) is a measure of general skills- and knowledge-level, or shortly, professionalism of the workforce, which matters to both innovation and business performance of the firm (Damanpour 1991; Scott and Bruce 1994; Subramanian and Nilakanta 1996). Investments in IT, in general, and ES software, in particular, are associated with the availability as well as the share of labor that is highly educated and skilled (Brynjolfsson and Hitt 2002; Chun 2003). Bartel and Lichtenberg (1987) also argue that better educated workers have a comparative advantage in learning-to-use, implementing and using new technologies and innovating as they assimilate and transform new ideas and perspectives more readily. As a result, exclusion of this variable from the model would result in an upward bias in estimating the ES effects.

IT infrastructure is the next influential factor. High internet penetration and strong IT infrastructure in the workplace lead many companies to rethink their business practices and encourage them to utilize e-Business applications (Mendelson 1999; Zhu 2004). Among infrastructure variables, broadband internet connectivity enhances innovation (Van Leeuwen et al. 2009). Internet-enabled employees are also more productive, ceteris paribus, as (fast) internet allows them to promptly obtain and share information through internal and external sources (SCB 2008). Moreover, the broadband intensity of the firm is considered as a good predictor of how advanced its IT infrastructure and how large its IT capital stock is (Eurostat 2008). To capture the effect, we use *Internet*$_{i,j}$ as a dummy variable to indicate if the firm uses any type of broadband internet. Finally, it is questionable to compare the effect of ES adoption on firm performance in firms with divergent degrees of engagement in (or reliance on) e-Business. We therefore use *eBusiness*$_{i,j}$ as a binary variable to distinguish firms with a significant part of their business processes being conducted electronically from those

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only organization-wide or domain-specific systems) yielded comparable results in terms of the sign and significance of the estimates.

with only minor or none involvement in e-Business. If ES adoption is associated with more e-Business use in general and e-Business adoption affects firm performance positively, then omitting this explanatory variable would result in upward-biased estimates of the ES variables.

In models (1)-(3), we also control for market effects through market share measures. Firms enjoying large market shares have more market power, benefit from premium prices and private profits (for instance, through monopolistic behavior), have access to more funds and protective mechanisms, and are more likely to engage in innovative activities (e.g. Blundell et al. 1999). Thereby, we include a set of four dummies for different market share classes, as explained in Table 4. Lastly, we correct for economy-wide transitory shocks to performance by including a dummy variable for each survey year.[69]

5.3. Regression method: conditional fixed-effects Logit

We employ conditional fixed-effects Logit for qualitative outcomes to estimate the models explained earlier (Chamberlain 1980). This method is required to generate consistent results, taking into account the nature of our data. Correction is needed for unobserved heterogeneity including firm-, sector-, and country-specific effects in order to attain unbiased estimates. Firm-specific effects (and omitted-variables bias) are controlled for as far as relevant firm-level regressors are included in the model. Further control is not feasible as repeated firm observations cannot be identified in our dataset. However, sector- and country-specific effects can be better accounted for since repeated observations over different sectors and countries can be well traced in

[69] We also ran regressions with a number of additional explanatory variables to check for the sensitivity of the results with respect to alternative specifications and to increase the overall fit of the model. In one version, we included "the share of employees directly engaging in research and development activities" as an extra quality measure of the corporate human capital. In another attempt, we replaced $Internet_{i,j}$ with "the share of employees with broadband internet access at their workplace" as an alternative, continuous indicator of fast internet connectivity. Finally, we estimated the models with an additional market-related control that indicates if the firm competes in international markets or not. Including additional explanatory variables did not improve the overall fit of the model significantly. In all the cases, comparable results were gained in terms of the sign and significance of all the estimates. Due to smaller sample size of these variations (caused by more missing values) and thereby reduced representativeness of the estimation sample, we decided to stick to the basic specification with the original set of independent variables explained in the text. Non-reported results are accessible upon request.

the dataset. The economic and regulatory conditions of each industry sector differ from one country to another. Besides, the economic and structural conditions of different sectors within a single country vary greatly. However, the conditions of one sector in a single country can be assumed to be reasonably comparable for all firms operating in that sector and rather stable over time. Therefore, a sector-country group or market is the preferred economic unit for eliminating exogenous fixed effects.

We opt for modeling the relationship between observable characteristics and performance outcomes of the firm in an error component model with separate controls for firm- and market-specific effects, i.e. models (1)-(3). We further opt for using a conditional variation of Logit for estimating the effects of interest. Our choice of specification model and regression method is based on three reasons. First, maximization of the fixed-effects likelihood function can generate inconsistent estimations if there is a considerable large number of matched case-control groups with a rather small number of observations per group relative to the sample size (Chamberlain 1980). Second, contrary to an unconditional fixed-effects model (with only firm-specific but not market-specific effects), the error components in model (1)-(3) relax the assumptions that market effects are independent of observed and unobserved firm effects (i.e. $E\lfloor u_j \mid \bar{x}_{i,j} \rfloor \neq 0$ and $E\lfloor u_j \mid \varepsilon_{i,j} \rfloor \neq 0$). These assumptions are generally unrealistic, as market and country characteristics have certain effects on formation, development and decline of firms as well as their characteristics that are shaped over time (e.g. Dunne et al. 1988; 1989). Third, adding separate industry and country dummies into the regression model (i.e. DV method) is not the preferred approach to control for sector- and country-specific heterogeneity as: (1) the DV method implies that a sector, although different from other sectors, is identical in all countries, while sectors expose diverse structural and economic characteristics in different countries; and (2) this method would confound sampling and real effects, due to the heterogeneous coverage of industries among the sampled countries (Koellinger 2008).[70]

[70] We observe data for a number of industry sectors in different countries but it is not necessarily the case that all sectors are covered in each country. See Table 1 for the distribution of markets in our sample.

6. Regression results and discussion

6.1. Impact of enterprise systems adoption on firm innovativeness

Table 5 reports the regression results for model (1) (see arrow 1 in Figure 1).

Table 5: Regression Results for Assessing the Effect of ES Adoption on Firm Innovativeness

Regression	1	2	3	4
	Product Innovation (Model 1)		Process Innovation (Model 1)	
	Odds Ratio (Standard Error)			
ES	1.776*** (.060)	---	2.025*** (.070)	---
ERP	---	1.275*** (.069)	---	1.328*** (.072)
SCM	---	1.231*** (.077)	---	1.522*** (.096)
CRM	---	1.783*** (.105)	---	1.691*** (.099)
KMS	---	1.298*** (.082)	---	1.423*** (.090)
DMS	---	1.287*** (.076)	---	1.477*** (.088)
ln(Employees)	1.136*** (.011)	1.135*** (.015)	1.270*** (.013)	1.216*** (.017)
%Higher Education	1.007*** (.001)	1.006*** (.001)	1.005*** (.001)	1.004*** (.001)
Broadband Internet	1.250*** (.048)	1.266*** (.063)	1.529*** (.061)	1.519*** (.081)
e-Business Maturity	1.790*** (.071)	1.826*** (.094)	1.857*** (.073)	1.916*** (.099)
Market Share controls	Yes	Yes	Yes	Yes
Time controls	Yes	Yes	Yes	Yes
Model Diagnostics				
Observations	22666	13712	22703	13731
Groups	256	189	257	190
Ave. Obs./Group	88.5	72.6	88.3	72.3
Log-likelihood	-13215	-7764	-12658	-7307
Model Significance	0.000	0.000	0.000	0.000

*, **, and *** indicate significance at 90%, 95%, and 99% confidence level respectively. Fixed-effects Logit, conditioned on market-specific effects, is used. Estimates are shown in Odds Ratios (OR = exp(b)). Standard Errors have also been transformed according to OR presentation. Groups indicate sector-country pairs.

As shown in Table 5, the adoption of enterprise systems increases the likelihood of being product and process innovator by 77.6% and 102.5% respectively.[71] The impact of enterprise applications on process innovation is stronger as ES adoption entails various process changes in the organization and provides vast process information that can be later used for process innovation. All five types of ES software under assessment are significantly and positively associated with product and process innovation. Comparatively, CRM exhibits the largest impact on both types of corporate innovation, followed by KMS for product and SCM for process innovation. This is in line with the argument that more specialized systems, especially the external ones, are more difficult to implement but once implemented properly are more effective (Aral et al. 2006; Shin 2006). Moreover, this highlights the very crucial role of customers (as lead users) in innovation processes of the firm as emphasized by Von Hippel (1988; 2005). On the basis of the findings, we cannot reject *Hypothesis 1* for any of the ES types we studied.

The results also suggest that larger firms have more access to the required resources and expertise to innovative and thus are more likely to be (product and process) innovator. A one-percent increase in the number of employees results in 13.5% and 21.6% increase in the odds of being product and process innovator respectively. A one-percentage point increase in the share of employees with a university degree leads to 0.4% to 0.7% growth in the odds of being innovator as well. As expected, broadband connectivity (as a major component of the firm IT infrastructure) and e-Business maturity do matter for innovation.

6.2. Overall impact of enterprise systems adoption on firm performance

The dependent variable in model (2) is the log odds of experiencing revenue, productivity or market share growth or being profitable. Table 6 reports the estimation results.

[71] For all the regressions, we also calculated the Conditional Likelihood Function and the Average Marginal Effects in addition to Odds Ratios. Because the results are perfectly comparable and yield similar conclusions, we stick to the Odds Ratio that is the more flexible, easy-to-interpret, and common representation (in the IS literature).

Table 6: Regression Results for Assessing the Total Effect of ES Adoption on Firm Performance

Regression	5	6	7	8	9	10	11	12
	Revenue Growth (Model 2)		Productivity Growth (Model 2)		Market Share Growth (Model 2)		Profitability (Model 2)	
	Odds Ratio (Standard Error)							
ES	1.239***	---	1.340***	---	1.267***	---	0.973	---
	(.042)		(.064)		(.054)		(.078)	
ERP	---	1.107*	---	1.099	---	1.025	---	0.771*
		(.060)		(.072)		(.067)		(.110)
SCM	---	1.069	---	1.148*	---	1.177**	---	1.113
		(.067)		(.083)		(.085)		(.218)
CRM	---	1.288***	---	1.224***	---	1.126*	---	1.202
		(.076)		(.085)		(.077)		(.212)
KMS	---	1.003	---	1.197**	---	1.342***	---	0.928
		(.063)		(.090)		(.098)		(.167)
DMS	---	1.131**	---	1.156**	---	1.195***	---	1.071
		(.066)		(.080)		(.082)		(.176)
ln(Employees)	1.145***	1.150***	1.179***	1.178***	1.075***	1.069***	1.065***	1.125***
	(.012)	(.016)	(.018)	(.020)	(.015)	(.018)	(.022)	(.039)
%Higher Education	1.004***	1.004***	1.005***	1.005***	1.004***	1.003***	1.001	1.002
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)	(.002)
Broadband Internet	1.261***	1.238***	1.276***	1.280***	1.292***	1.282***	1.157**	1.257*
	(.047)	(.059)	(.071)	(.074)	(.069)	(.076)	(.085)	(.150)
e-Business Maturity	1.445***	1.433***	1.672***	1.627***	1.565***	1.634***	1.289***	1.251
	(.058)	(.074)	(.097)	(.100)	(.077)	(.098)	(.126)	(.184)

Market Share controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Model Diagnostics								
Observations	21337	13049	9799	9126	12212	8963	8610	3557
Groups	256	190	160	160	194	159	143	62
Ave. Obs./Group	83.3	68.7	61.2	57.0	62.9	56.4	60.2	57.4
Log-likelihood	-13130	-7968	-5946	-5514	-7505	-5408	-3287	-1262
Model Significance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*, **, and *** indicate significance at 90%, 95%, and 99% confidence level respectively. Fixed-effects Logit, conditioned on market-specific effects, is used. Estimates are shown in Odds Ratios (OR = exp(b)). Standard Errors have also been transformed according to OR presentation. Groups indicate sector-country pairs.

Ceteris paribus, adopting enterprise systems goes together with more sales, productivity, and market share but not with profitability. Distinguishing between different types of ES applications, CRM has the largest total impact on revenues and productivity and KMS on market share. CRM-adopting enterprises are 28.8 and 22.4 percent more likely than their non-adopting peers to show revenue and productivity growth respectively. This finding strongly corroborates the positive evidence provided by numerous researchers in the field, although it contradicts with a number of previous studies (Hendricks et al. 2007; Karakostas et al. 2005) which report insignificant contribution of CRM systems to firm performance. CRM software are showed to play an important role in effectively contacting/targeting customers, gathering data on their ideas and needs, and providing them with accustomed after-sales services (Ahearne et al. 2007; Bligh and Turk 2004). A customer-centric shift in the company culture and structure leads to better brand recognition and customer acquisition, satisfaction and retention and thus more sales (and productivity) (Karakostas et al. 2005; Mithas et al. 2005). Furthermore, CRM compared to a system like ERP is more domain-specific (as it affects a smaller part of the enterprise) and less complex and thus its installation as well as customization is easier, faster and more likely to be successful (Rettig 2007).

The likelihood of market share growth, ceteris paribus, is 34.2% and 19.5% higher for KMS-and DMS-adopters. This finding endorses previous studies that report the competitive advantage of KMS-adopters over their non-adopting peers (e.g. Feng and Chen 2007) and highlights the important role of organizational learning and knowledge management in the contemporary firm (Al-Mashari et al. 2002). It also supports the idea that knowledge-oriented systems are more important to market share of the firm than process-oriented systems.[72] The strong influence of knowledge-oriented systems on market share can also be explained by the fact that these systems, in the long-term, create additional added value and demand for customers through substantial product/service quality improvements and customer satisfaction (e.g. Ofek and Sarvary 2001).

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[72] In this respect, ERP, SCM and CRM can be considered as *process-oriented systems*, as they affect and integrate business processes of an organization in the first place. KMS and DMS can be understood as *knowledge-oriented systems*, as they affect and integrate knowledge assets of an organization above all.

In addition to CRM and KMS, ERP and DMS also exhibit significant positive impact on revenue growth. Except for ERP, all the ES applications studied significantly improve productivity and market share of the firm. Some surprising findings are that SCM and KMS do not significantly enhance the likelihood of revenue growth (regression 6). The effect of ERP adoption on productivity and market share growth is also insignificant (regression 8 and 10). Sales and productivity are respectively influenced by ERP and SCM systems at only 10% significance level (regression 6 and 8). This suggests that European enterprises have not managed to effectively utilize their ERP, SCM and to some extent KMS investments, which can be attributed to more sophisticated and extensive nature of these systems compared to simpler and smaller counterparts such as CRM and DMS. Organization-wide systems involve and affect a larger number of parties/domains inside or outside the organization and thus entail more organizational changes after implementation. On the contrary, domain-specific applications require lower degrees of cross-functional integration and process standardization and create/modify fewer inter-departmental dependencies and therefore are more likely to be implemented successfully and become fruitful (at least in the short- or medium-term after adoption). Recent market research upholds this argument as well (Gartner 2009a; 2009b).[73]

Another surprising finding relates to the ambiguous relationship between enterprise systems adoption and profitability. Adopting an enterprise system per se does not make the firm more likely to be in the group of profitable firms (regression 11). A closer look reveals that, everything else held constant, ERP adoption might be disadvantageous for firm profitability while other system types are not related to profitability at all; ERP-adopters are 22.9% less likely to be profitable (regression 12). This finding substantiates a number of past studies (Poston and Grabski 2001; Wieder et al. 2006). Two possible explanations for these non-positive results can be put forward. First, due to their complex and expansive nature, enterprise systems might require a much larger investment time-lag (than the average time span of 52 months observable in our sample) after full implementation in order to be properly embedded in the organization. Only after this time-lag, they might reveal substantial benefits that

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[73] Gartner reports that the CRM applications generating the most interest in 2009 are often implemented as discrete, departmental and channel-specific projects, rather than as part of a larger transformation program of the whole organization.

cancel out the huge initial investment costs (and hence result in a net positive effect). Second, in contrast to a common expectation, on average, the main stakeholders of ES projects (i.e. software vendors, consultants, and the adopting organizations), after about two decades, have not yet seemingly reached a high level of maturity and expertise in implementing enterprise systems, adapting them to a particular organization, reengineering the necessary business processes, and utilizing these systems effectively. In this case, the very complex and intertwined nature of enterprise systems might hinder understanding, learning-to-use and modifying them by the management and employees to readily fit them to the profit-making objectives of the firm (see e.g. Rettig 2007).[74, 75]

With respect to control variables, larger firms tend to be more likely to exhibit increasing turnover and productivity, growth in their market and profitability (due to economy-of-scale effect and price setting power). The share of higher-educated employees is positively related to higher odds of revenue, productivity and market share growth but not (short-term) profitability. Access to high-speed internet and advance in e-Business practices increase the probability of the enterprise to be in the group of firms experiencing revenue, productivity, or market share improvement. This can be attributed to the fact that broadband-enabled employees tend to be more productive and IT-induced processes to be more efficient (Eurostat 2008; SCB 2008). The positive effects of infrastructure interconnectivity and e-Business maturity on firm profitability are weaker. Still, firms with high-speed internet access at their workplace and those with a significant part of their processes conducted electronically (i.e. mature in e-Business adoption) are 15.7 and 28.9 percent more likely to be profitable.

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[74] This suggests a shallow *learning curve* of progress in the mastery of enterprise systems.

[75] From a contingency theory perspective, two more explanations are conceivable as well. First, the required critical success factors for ES implementations might have been absent or not advanced enough in our sampled firms. Failing to provide these factors in the right time would generate suboptimal returns. Second, the average firm in the sample might have failed to effectively protect the strategic advantages of enterprise systems from being imitated by the competition. The firm is then only able to yield temporary excess returns at best, lasting as long as replication occurs.

6.3. Direct versus indirect impact of enterprise systems adoption on firm performance

Model (3) is used to disentangle the direct and indirect effects of enterprise systems adoption on firm performance (compare arrow 2 and 3 in Figure 1). Table 7 reports the estimation results.

Table 7: Regression Results for Assessing the Direct Effect of ES Adoption on Firm Performance (Model 3)

Regression	13	14	15	16
	Revenue Growth	Productivity Growth	Market Share Growth	Profitability
	Odds Ratio (Standard Error)			
ERP	1.047	1.028	0.977	0.756*
	(.058)	(.069)	(.066)	(.109)
SCM	1.006	1.050	1.087	1.105
	(.064)	(.079)	(.081)	(.217)
CRM	1.163**	1.055	0.971	1.163
	(.071)	(.076)	(.068)	(.206)
KMS	0.959	1.121	1.270***	0.899
	(.061)	(.086)	(.095)	(.162)
DMS	1.058	1.064	1.109	1.038
	(.063)	(.076)	(.079)	(.172)
Product Innovation	1.585***	1.667***	1.811***	1.211*
	(.067)	(.086)	(.093)	(.133)
Process Innovation	1.537***	1,783***	1.549***	1.222*
	(.068)	(.097)	(.083)	(.136)
ln(Employees)	1.122***	1.147***	1.042**	1.106***
	(.016)	(.020)	(.018)	(.039)
%Higher Education	1.003***	1.003***	1.002**	1.001
	(.001)	(.001)	(.001)	(.002)
Broadband Internet	1.181***	1.220***	1.225***	1.199
	(.058)	(.072)	(.074)	(.145)
e-Business Maturity	1.305***	1.404***	1.423***	1.237
	(.069)	(.089)	(.088)	(.184)
Market Share controls	Yes	Yes	Yes	Yes
Time controls	Yes	Yes	Yes	Yes
Model Diagnostics				
Observations	12824	8960	8811	3502
Groups	190	160	159	62
Ave. Obs./Group	67.5	56.0	55.4	56.5
Log-likelihood	-7675	-5265	-5178	-1243
Model Significance	0.000	0.000	0.000	0.000

*, **, and *** indicate significance at 90%, 95%, and 99% confidence level respectively. Fixed-effects Logit, conditioned on market-specific effects, is used. Estimates are shown in Odds Ratios (i.e. OR = exp(b)). Standard Errors have also been transformed according to OR presentation. Groups indicate sector-country pairs.

Product and process innovation lead to higher performance.[76] Being innovative boosts the chance of being a better performer irrespective of the performance measure considered. Being innovative goes together with higher possibility of a positive profit as well by 21.1% to 22.2%. When comparing the results in Table 7 with those in Table 6, the most interesting finding is that the estimates of almost all ES variables lose their significance when innovation is explicitly included in the model. This means that innovation variables pick up almost all the effects of ES variables on firm performance. The two exceptions here are the effects of CRM on revenue growth and KMS on market share growth, which preserve their significance (regression 13 and 15); even in these cases, the effects are diminished. Adoption of a CRM or KMS system increases the probability of turnover or market share growth by 28.8% or 34.2% respectively, which are reduced to 16.3% and 27.0% when only the direct impact of these systems is considered.[77]The findings in Table 6 and 7 indicate that *Hypothesis 2* cannot be rejected for most of ES application types and performance measures under investigation, except for profitability. As far as firm profitability is concerned, *Hypothesis 2* is rejected for all ES categories even at 10% significance level. Furthermore, our observations lead us to reject *Hypothesis 3* for almost all ES types and performance measures studied, except for the two incidents noted above.

Following the 3-step approach explained earlier in section 5.1, we conclude that innovation plays the role of a *full mediation* factor in mediating the positive impact of several types of enterprise systems on firm performance. In some instances, though, the role of innovation is reduced to *partial mediation*. Put it differently, the findings corroborate the idea that the enabling role of enterprise systems represents a very substantial part of their performance impact and that their facilitating role only accounts for a minor (and mainly statistically insignificant) part. This finding perfectly matches the argument put forward by McAfee and Brynjolfsson (2008) that companies make a competitive difference and lead their rivals through investing in IT (and

[76] Comparatively, product innovation is more important than process innovation to revenue and market share growth, while process innovation is more influential to productivity growth. The effect on profitability is comparable for both product and process innovation.

[77] Running the Wald Test in a simultaneous Seemingly Unrelated Regression (SUR) model also confirms that the ES estimates in model (2) and (3) differ significantly (at 1%). The test results are available upon request.

especially ES) if they can use the technology to come up with new and better ways of doing and making things. In their view, innovating with the help of technology is the next critical step and management challenge after deploying technology in order to survive and thrive in the current competitive environment: "Deploy, innovate, and propagate" (McAfee and Brynjolfsson 2008: 103).

CRM and KMS effects on revenue and market share growth are somewhat distinctive when it comes to the extent of mediation through innovation. CRM systems exhibit significant direct effects on corporate sales. This can be attributed to the very important and explicit role of CRM systems to support existing sales and marketing practices of the firm through better targeting/communicating customers and increasing sales force efficiency (e.g. Dong and Zhu 2008; Richards and Jones 2008 and relevant references therein). KMS systems reveal significant direct effects on market share. This highlights the important role of these systems in supporting the knowledge assets of the company and increasing the efficiency of existing knowledge sharing processes (Alavi and Leidner 2001; Ofek and Sarvary 2001). The direct role of information and knowledge in gaining and sustaining competitive advantage (e.g. Ofek and Sarvary 2001; Porter and Millar 1985; Vives 1990) explains the considerable (direct and indirect) impact of KMS systems on market share as well.

6.4. Direction of causality

Because the data at our disposal is of a cross-sectional character, endogeneity problem (as a result of simultaneity) may arise once modeling the relationship between ES adoption and firm performance.[78] With models (1)-(3), we suggested that causality runs from independent ES variables to dependent performance indicators (and not the other way around). Our inference is based on the following four arguments:

(1) There are a number of theoretical and empirical academic studies that explicitly deal with this causality issue and indeed support the interpretation

[78] Cross-sectional techniques for casual inference from observational data (such as traditional matching, potential outcomes, propensity score, and regression discontinuity) have serious data/measurement limitations (Mithas and Krishnan 2009; Winship and Morgan 1999). Working with a panel dataset does not resolve the causality issue per se, but only allows for more options and specific techniques to explicitly test for causality (Winship and Sobel 2004).

of causality from ES adoption to firm performance (e.g. Byrd and Marshall 1997; Melville et al. 2004; Pare´ et al. 2008). Especially, Aral et al. (2006) explicitly focus on the causality issue between ES adoption and performance improvements and document strong empirical evidence (and theoretical explanation) for the fact that the use of enterprise systems actually causes performance gains rather than strong performance inspiring or driving the purchase or adoption of enterprise IT systems.

(2) An important assumption of causality is that the cause precedes the effect temporally. This means that the cause must have occurred at an earlier point in time than the effect. A careful look at the survey design and the dependent and main independent variables used in this study reveals that the dependent variables capture a phenomenon (i.e. change in performance or occurrence of innovation) within the past year of the survey while the explanatory ES adoption variables deal with an incident (i.e. adoption of an enterprise system) much further back in time (on average between 3.5 and 5.5 years, depending on the system type). The system adoption is then an ongoing course of action prior to observation of the output changes. This built-in time-lag discards the assumption of causality running from firm performance to ES adoption to a great extent.

(3) The opinion of IT practitioners who responded to the analyzed surveys might seem somehow subjective and/or relative, though, is a valuable source of information on what they believe about the pattern(s) of cause and effect in their organizations. A particular module of the surveys explicitly deals with IT impacts and implications. Specifically, responded were asked to rate, according to their experience, the impact of information and communication technologies (including internet and e-business applications) on the business of their company. Several impact areas are covered by this module. Table 8 summarizes the respondents' beliefs about the direction of causality and IT impacts.

Table 8: Impact of IT and e-Business: Percentage of Respondents by Business Area and Firm Size

Business Area	Size Class	Number of Respondents	Positive Influence (fairly to very)	Insignificant influence	Negative Influence (fairly to very)
Collaboration and knowledge exchange among employees	S	3,837	47.41%	50.64%	1.95%
	M	1,702	60.16%	37.96%	1.88%
	L	611	71.36%	27.49%	1.15%
Availability of information for management and planning	S	3,851	58.41%	40.66%	0.93%
	M	1,697	69.89%	29.46%	0.65%
	L	609	76.52%	22.66%	0.82%
Internal processing of commercial transactions	S	3,738	41.39%	56.50%	2.11%
	M	1,629	50.65%	47.88%	1.47%
	L	593	58.51%	39.97%	1.52%
Product innovation	S	3,732	41.83%	56.54%	1.63%
	M	1,626	45.14%	53.26%	1.60%
	L	586	49.66%	48.46%	1.88%
Revenue growth	S	9,191	47.93%	50.63%	1.44%
	M	3,029	54.74%	43.84%	1.42%
	L	1,147	61.12%	37.66%	1.22%
Efficiency of business processes	S	9,242	60.69%	37.87%	1.44%
	M	3,100	72.16%	26.52%	1.32%
	L	1,187	79.95%	18.70%	1.35%
Internal work organization	S	9,315	55.78%	42.36%	1.86%
	M	3,129	72.32%	25.92%	1.76%
	L	1,201	82.60%	15.57%	1.83%
Procurement cost of supply goods	S	9,173	40.54%	56.64%	2.82%
	M	3,034	47.30%	49.57%	3.13%
	L	1,144	53.58%	44.41%	2.01%
Quality of products and services	S	9,258	39.68%	58.20%	2.12%
	M	3,092	47.87%	49.90%	2.23%
	L	1,182	58.63%	40.19%	1.18%
Quality of customer service	S	9,305	54.96%	43.05%	1.99%
	M	3,116	64.99%	33.12%	1.89%
	L	1,196	70.57%	28.51%	0.92%
Productivity growth	S	9,292	55.05%	43.20%	1.75%
	M	3,114	66.92%	31.31%	1.77%
	L	1,186	76.73%	22.34%	0.93%

Size Classes: S (Small): # of employees < 50; M (Medium): 50 ≤ # of employees < 250; L (Large):# of employees ≥ 250.

Table 8 strongly corroborates our argument in favor of the causal effects of IT in large enterprises. With regard to all the business areas under question, the majority of surveyed respondents in large organizations believed that IT exposes a significantly positive casual impact. In some cases, the share of respondents who disbelieved in the casual effect was as small as one-fourth of those who believed in it (e.g. see the effect of IT on business process efficiency or internal work organization of the firm). As shown in Table 8, the general argument of IT causality is still defensible for SMEs (Small and Medium Enterprises), although the evidence is rather weaker for some business areas (such as procurement cost of supply goods and quality of products and services).

(4) To partially investigate the reverse causality issue, we conducted two series of tests: MANOVA/ANOVA and 3SLS/2SLS. The results of these tests also support our argument on the direction of causality. We had access to two particular questions in the surveys asking whether or not any of the firm's product or process innovations are directly related to or enabled by IT (and not necessarily ES).[79] Almost half (i.e. 47.26%) of product innovators in our sample indicated that at least one of their product or service innovations has been directly related or enabled by IT. This proportion amount to about two-thirds (i.e. 64.98%) in case of process innovators.

The MANOVA test indicates that the adopters of enterprise systems are significantly more likely to jointly exhibit IT-enabled product and process innovations. Similar conclusions are drawn whether individual ES types or a combination of them (in the form of a compound indicator) are used to model the joint variation of the dependent (innovation) variables. The ANOVA tests lead to comparable results when the effects of enterprise systems adoption on IT-enabled innovation are separately considered for product and process innovation.

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[79] These questions are different from those used to construct our innovation measures in this study. They explicitly ask the respondent about IT-enabled innovation while the dependent variables in model (1) are based on questions asking about innovativeness of the firm in general. To increase the validity of our research findings (see Straub 1989; Straub et al. 2004) we did not use these questions to build our outcome variables. However, they can be perfectly used for testing causality as they explicitly establish the direction of causality for the respondent. If deploying enterprise systems boosts the possibility and probability of innovating for the firm, then, ceteris paribus, we expect to find a disproportional share of firms having IT-enabled innovation(s) across subsamples with and without ES adoption. This is exactly what we examine through the MANOVA and ANOVA tests.

Alternatively, we estimated a simultaneous system where we estimate an additional equation that allows for systems adoption to depend on output measures, in addition to make innovation and performance indicators dependent on ES adoption. When we estimate the system of equations by 3SLS or 2SLS, we find that the reverse causality is statistically insignificant (in case of any of the output measures). This means that we could not find any significant impact of our output (i.e. innovation and performance) measures on the decision to adopt enterprise systems; the inverse relationship was though found to be significant (for all the output measures). Appendix A presents more details on the test results.

7. Conclusions, Limitation and Recommendations

7.1. Conclusions

This paper investigates *whether* and *how* enterprise systems affect innovativeness and performance of the firm. It contributes to the debate on the performance payoff of enterprise systems by providing new evidence (to answer the "what" question) and insights (to answer the "how" question). We use a representative pooled dataset of 33,442 enterprises across 29 European countries (EU-27 plus Norway and Turkey) and 29 sectors (covering all the major non-financial economic activities) over a 5-year period (2003-2007). Six measures of organizational performance (i.e. product and process innovation, revenue, productivity and market share growth and profitability) in a conditional fixed-effects Logit model are analyzed.

Four major and two minor conclusions can be drawn based on the research results. First, with regard to the innovation effects, the findings support a significant contribution of ES adoption to product and more strongly to process innovation for all the application types studied. As a consequence, this research can be considered as an attempt to mitigate the argument on the hampering effects of enterprise systems with respect to innovation. Second, as to the performance effects of ES adoption, the analysis reveals that almost all enterprise applications significantly contribute to corporate sales, productivity and market share. However, no ES software is found to be supportive to profitability likelihood of the firm, which makes profit a critical measure of performance that requires special attention when it comes to assessing the business value of enterprise systems. Third, this research sheds light on the important mediating role of innovation in the ES value creation process of the firm. Enterprise systems are found to significantly contribute to organizational performance insofar as they enable the adopting firm to substantially change/improve its internal production processes and/or introduce new products/services to the market. In other words, those systems that only facilitate the existing business processes and product portfolios of the firm without leading to innovations seem not to generate significant performance improvements. This result gives weight to the necessity of innovating with enterprise systems when optimum outcomes are sought for. As to the fourth major conclusion, the findings reflect the fact that discrete, departmental applications that are less complex and easier to understand/use such as CRM and DMS are, on average, more beneficial to firm performance compared to expansive and sophisticated counterparts such as ERP, SCM, and KMS that mandate radical organizational changes and affect the whole structure of the firm.[80, 81] Domain-specific, in contrast to organization-wide, applications only influence a (few) specific units of the firm, are easier to learn and integrate into the daily works of employees and have shorter payback periods and, therefore, are more likely to result in a successful implementation.

Concerning the minor conclusions of the research, we find that ERP systems, as the most common type of ES software in business, are on average ineffective in boosting the productivity and market share of the firm; their impact on corporate revenue, too, is only weakly significant. This finding supports the hampering view about ERP software that is mainly attributed to their structural inflexibility, technical complexity, gigantic size and complicated interactions with other organizational entities, which make the complete implementation of an ERP system a nightmare for corporate officers. ERP packages are purchased with the hope to make firm operations simplified, while in reality they seem to make things even more complicated. Finally, our observations support us to conclude that educated workforce, broadband accessibility, and e-business processes are (very) strong determinants of organizational innovation and performance.

[80] In our study, domain-specific systems are found to be the only group of applications with a significantly positive impact on all the output measures under investigation (except for profitability). As far as our analysis is concerned, this conclusion is valid for European corporations with an average of 3-5 years since their first use of ES software in daily business.

[81] This conclusion supports Rettig's argument that ES software has introduced so many complex, difficult technical and business issues that just making it to the finish line with one's shirt on can be considered a win. "Is enterprise software just too complex to deliver on its promises?" she further questions (Rettig 2007, pp. 25).

7.2. Limitations of the research and recommendations for future research

The pooled data at our disposal is limited in the sense that it does not allow for other panel data techniques or dynamic specifications, which would provide the opportunity to better control for unobserved firm-specific heterogeneities and to deal with the causality issue more explicitly. In a panel setting, quantitative measures of output would be more desirable as they contain a greater amount of information about the performance of the firm. Before and after (i.e. within-firm) comparisons can also be conducted in certain panel datasets, resulting in greater understanding of the adoption pattern of ES at the firm level. In connection to this issue, future research should concentrate on the longer-term performance effects of enterprise systems that would lead us to better understand and appraise the ultimate value of ES and the extent of time-lags between costs incurred and benefits accrued.

Additionally, we have not really conducted a cross-sectoral or -country analysis, as we aimed at the overall, economy-wide effects of enterprise systems in Europe. However, such analyses can be very illuminating by unraveling the considerable differences among different sectors and countries with regards to how they use and create value from information technology in general and enterprise systems in particular. Finally, more research should be devoted to analyzing the critical success factors that ultimately make a specific ES project a success or a failure. For example, future research needs to search for and clarify complementarities between enterprise systems and certain organizational characteristics and practices. In this respect, synergies among different types of enterprise systems, especially when they are jointly adopted, shall be studied as well.

References

Adamides, E. D., and Karacapilidis, N. 2006. "Information technology support for the knowledge and social processes of innovation management," *Technovation* (26), pp. 50–59.

Ahearne, M., Hughes, D. E., and Schillewaert, N. 2007. "Why Sales Reps Should Welcome Information Technology: Measuring the Impact of CRM-based IT on Sales Effectiveness," *International Journal of Research in Marketing* (24:4), pp. 336-349.

Akkermans, H. A., Bogerd, P., Yucesan, E., and Wassenhove, L. N. 2003. "The impact of ERP on supply chain management: Exploratory findings from a European Delphi study," *European Journal of Operational Research* (146), pp. 284–301.

Alavi, M., and Leidner, D. 2001. "Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues," *MIS Quarterly* (25:1), pp. 107-136.

Al-Mashari, M., Al-Mudimigh, A., and Zairi, M. 2003. "Enterprise resource planning: a taxonomy of critical factors," *European Journal of Operational Research* (146), pp. 652-364.

Al-mashari, M., Zairi, M., and Alathari, A. 2002. "An empirical study of the impact of knowledge management on organizational performance," *The Journal of Computer Information Systems* (42:5), January, pp. 74-82.

Aral, S., Brynjolfsson, E., and Wu, D. J. 2006. "Which Came First, IT or Productivity? The Virtuous Cycle of Investment and Use in Enterprise Systems," *Proceedings of the Twenty-Seventh International Conference on Information Systems (ICIS)*, Milwaukee, WI, December, pp. 1-22.

Audretsch, D. 1995. "Innovation, growth and survival," *International Journal of Industrial Organization* (13), pp. 441–457.

Bajwa, D. S., Garcia, J. E., and Mooney, T. 2004. "An integrative framework for the assimilation of enterprise resource planning systems: phases, antecedents, and outcomes," *Journal of Computer Information Systems* (44), pp. 81-90.

Bardhan, I., Whitaker, J., and Mithas, S. 2006. "Information technology, production process outsourcing, and manufacturing plant performance," *Journal of Management Information Systems* (23:2), pp. 13-40.

Baron, R. M., and Kenny, D. A. 1986. "The moderator-mediator variable distinction in social psychological research: Conceptual, strategic and statistical considerations," *Journal of Personality and Social Psychology* (51), pp. 1173-1182.

Bartel, A., Ichniowski, C., and Shaw, K. 2007. "How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills," *Quarterly Journal of Economics* (122:4), pp. 1721-1758.

Bartel, P., and Lichtenberg, F. 1987. "The comparative advantage of educated workers in implementing new technology," *Review of Economics and Statistics* LXIX, pp. 1-11.

Beath, J., Katsoulacos, Y., and Ulph, D. 1987. "Sequential product innovation and industry evolution," *Economic Journal* (97), pp. 32–43.

Bharadwaj, A. S. 2000. "A Resource-Based Perspective on Information Technology Capability and Firm Performance: An empirical Investigation," *MIS Quarterly* (24:1), pp. 169-196.

Bligh, P., and Turk, D. 2004. *CRM unplugged – releasing CRM's strategic value*, Hoboken: John Wiley & Sons.

Blundell, R., Griffith, R., and Van Reenen, J. 1999. "Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms" *The Review of Economic Studies* (66:3), pp. 529-554.

Botta-Genoulaz, V., and Millet, P-A. 2005. "A classification for better use of ERP systems," *Computers in Industry* (56), pp. 573–587.

Botta-Genoulaz, V., Millet, P-A., and Grabot, B. 2005. "A survey on the recent research literature on ERP systems," *Computers in Industry* (56), pp. 510-522.

Boulding, W., Stelin, R., Ehret, M., and Johnston,W. 2005. "A customer relationship management roadmap: What is known, potential pitfalls, and where to go," *Journal of Marketing* (69:4), October, pp. 155-166.

Brown, S. L., and Eisenhardt, K. M. 1995. "Product development: past research; present findings, and future directions," *Academy of Management Review* (20:3), pp. 343–378.

Brynjolfsson, E., and Hitt, L. 2002. "Information technology, workplace organization and the demand for skilled labor: firm-level evidence," *Quarterly Journal of Economics* (117), pp. 339–376.

Byrd, T. A., and Marshall, T. 1997. "Relating Information Technology Investment to Organizational Performance: A Causal Model Analysis," *Omega* (25:1), pp. 43-56.

Chamberlain, G. 1980. "Analysis of covariance with qualitative data," *Review of Economic Studies* (47:1), pp. 225–238.

Chand, D., Hachey, G., Hunton, J., Owhoso, V., and Vasudevan, S. 2005. "A balanced scorecard based framework for assessing the strategic impacts of ERP systems," *Computers in Industry* (56), pp. 558–572.

Chou, S.-W., and Chang, Y.-C. 2008. "The implementation factors that influence the ERP (enterprise resource planning) benefits," *Decision Support Systems* (46), pp. 149-157.

Chun, H. 2003. "Information Technology and the Demand for Educated Workers: Disentangling the Impacts of Adoption versus Use," *The Review of Economics and Statistics* (85:1), pp. 1-8.

Cohen, J., Cohen, P., West, S. G., and Aiken, L. S. 2003. *Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences*, Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Coltman, T. 2007. "Why Build a Customer Relationship Management Capability?" *Journal of Strategic Information Systems* (16:3), pp. 301-320.

Cotteleer, M., and Bendoly, E. 2006. "Order lead-time improvement following enterprise-IT implementation: an empirical study," *MIS Quarterly* (30:3), September, pp. 643-660.

Damanpour, F. 1991. "Organizational Innovation: A Meta-Analysis of Effects of Determinants and Moderators," *The Academy of Management Journal* (34:3), September, pp. 555-590.

Dasgupta, P., and Stiglitz, J. 1980. "Industrial structure and the nature of innovative activity," *Economic Journal* (90), pp. 266–293.

Davenport, T. H. 1998. "Putting the enterprise into the enterprise system," *Harvard Business Review* (76:4), pp. 121–131.

Davenport, T. H. 2000. *Mission Critical: Realizing the Promise of Enterprise Systems*, Boston, MA: Harvard Business School Press.

Dehning, B., Richardson, V. J., and Zmud, R. W. 2007. "The financial performance effects of IT-based supply chain management systems in manufacturing firms," *Journal of Operations Management* (25), pp. 806–824.

Dong, S., and Zhu, K. 2008. "The Business Value of CRM Systems: A Resource-Based Perspective," *Proceedings of the Forty-First Hawaii International Conference on System Sciences*, pp. 277.

Dunne, T., Roberts, M. J., and Samuelson, L. 1988. "Patterns of firm entry and exit in U.S. manufacturing industries," *Rand Journal of Economics* (19), pp. 495–515.

Dunne, T., Roberts, M. J., and Samuelson, L. 1989. "The growth and failure of U.S. manufacturing plants," *Quarterly Journal of Economics* (104), pp. 671–698.

Esteves, J., and Pastor, J. 2001. "Enterprise Resource Planning Systems Research: An Annotated Bibliography," *Communications of AIS* (7:8), pp. 2-54.

Eurostat 2008. Information Society: ICT impact assessment by linking data from different sources (Final Report), August, Eurostat Grant Agreement Number: 49102.2005.017-2006.128.

Eurostat 2009. *Structural Indicators: Innovation and Research*, accessible at: http://epp.eurostat.ec.europa.eu/portal/page/portal/structural_indicators/indicators/innovation_and_research, last access: 29th of November 2009.

Feng, D., and Chen, E. T. 2007. "Firm performance effects in relations to the implementation and use of knowledge management systems," *International Journal of Innovation and Learning* (4:2), pp. 172-185.

Feng, K., Chen, E. T., and Liou, W. 2004. "Implementation of Knowledge Management Systems and Firm Performance: An Empirical Investigation," *The Journal of Computer Information Systems* 45(2), January, pp. 92-104.

Gartner 2008. Forecast: Enterprise Software Markets, Worldwide 2007-2012, December, ID Number: G00164243.

Gartner 2009a. *What's 'Hot' in CRM Applications in 2009*, June, ID Number: G00168405.

Gartner 2009b. CRM Software Market Share Analysis, Worldwide 2008, July, ID Number: G00169112.

Gattiker, T., and Goodhue, D. 2000. "Understanding the plant level costs and benefits of ERP: Will the ugly duckling always turn into a swan?" *Proceedings of the Thirty-Third Annual Hawaii International Conference on System Sciences (HICSS)*, Los Alamitos, CA, January, pp. 7017.

Gattiker, T., and Goodhue, D. 2005, "What happens after ERP implementation: understanding the impact of interdependence and differentiation on plant-level outcomes?" *MIS Quarterly* (29:3), pp. 559-585.

Geroski, P. 1995. "Markets of technology: knowledge, innovation and appropriability," in *Handbook of the Economics of Innovation and Technological Change*, P. Stoneman (ed.), Oxford/Cambridge: Blackwell Publishers, pp. 90-131.

Geroski, P., Machin, S., and Van Reenen, J. 1993. "The profitability of innovating firms," *Rand Journal of Economics* (24:2), pp. 198-211.

Ghosal, V., and Nair-Reichert, U. 2009. "Investments in modernization, innovation and gains in productivity: Evidence from firms in the global paper industry," *Research Policy* (38), pp. 536-547.

Gupta, M., and Kohli, A. 2006. "Enterprise resource planning systems and its implications for operations function," *Technovation* (26), pp. 687-96.

Hair Jr., J. F., Black, W. C., Babin, B. J., Anderson, R. E., and Tatham, R. L. 2006. *Multivariate Data Analysis*, Upper Saddle River, NJ: Pearson Education Inc.

Häkkinen, L., and Hilmola, O.-P. 2008. "ERP evaluation during the shakedown phase: lessons from an after-sales division," *Information Systems Journal* (18:1), pp.73-100.

Harabi, N. 1994. "Appropriability of technical innovations: an empirical analysis," *Research Policy* (24), pp. 981–992.

Hendricks, K. B., Singhal, V. R., and Stratman, J. K. 2007. "The impact of enterprise systems on corporate performance: A study of ERP, SCM, and CRM system implementations," *Journal of Operations Management* (25), pp. 65–82.

Hitt, L., and Brynjolfsson, E. 1996. "Productivity, Business Profitability and Consumer Surplus: Three Different Measures of Information Technology Value," *MIS Quarterly* (20:2), pp. 121-142.

Hitt, L. M., Wu, D. J., and Zhou, X. 2002. "Investment in enterprise resource planning: Business impact and productivity measures," *Journal of Management Information Systems* (19:1), pp. 71-98.

Hong, K. K., and Kim, Y. G. 2002. "The critical success factors for ERP implementation: an organizational fit perspective," *Information & Management* (40), pp. 25–40.

Huang, S.-M., Chang, I.-C., Li, S.-H., and Lin, M.-T. 2004. "Assessing risk in ERP project: identify and prioritize factors," *Industrial Management and Data System* (104:8), pp. 681-688.

Hunton, J. E., Lippincott, B., and Reck, J. L. 2003. "Enterprise resource planning systems: comparing firm performance of adopters and non-adopters," *International Journal of Accounting Information Systems* (4), pp. 165-184.

Karakostas, B., Kardaras, D., and Papathanassiou, E. 2005. "The state of CRM adoption by the financial services in the UK: an empirical investigation," *Information & Management* (42), pp. 853–863.

Kim, L. 1998. "Crisis construction and organizational learning: capability building in catching-up at Hyundai," *Organization Science* (9:4), pp. 506–521.

King, W. R., and Marks Jr., P. V. 2008. "Motivating knowledge sharing through a knowledge management system," *Omega* (36), pp. 131-146.

Knowles, R. 1995. "Electronic document management systems: how to select and implement the right documentation management system for your organization," *The Electronic Library* (13:6), December, pp. 527-532.

Ko, D-G., Kirsch, L. J., and King, W. R. 2005. "Antecedents of knowledge transfer from consultants to clients in enterprise system implementation," *MIS Quarterly* (29:1), pp. 59–85.

Koellinger, P. 2008. "The relationship between technology, innovation, and firm performance-Empirical evidence from e-business in Europe," *Research Policy* (37), pp. 1317-1328.

Kohli, R., and Hoadley, E. 2006. "Towards developing a framework for measuring organizational impact of IT-enabled BPR: case studies of three firms," *The Data Base for Advances in Information Systems* (37:1), pp. 40-58.

Krasnikov, A., Jayachandran, S., and Kumar, V. 2009. "The Impact of CRM Implementation on Cost and Profit Efficiencies: Evidence from US Commercial Banking Industry," *Journal of Marketing* (73:6), November, pp. 61-76.

Kremers, M., and van Dissel, H. 2000. "Enterprise resource planning: ERP system migrations," *Communications of the ACM* (43:4), pp. 53–56.

Laserfiche 2007. Document Management Overview: A guide to the benefits, technology, and implementation essentials of digital document management solutions, Long Beach, CA: Compulink Management Center Inc.

Lee, Z., and Lee, J. 2000. "An ERP implementation case study from a knowledge transfer perspective," *Journal of Information Technology* (15:4), pp. 281–288.

Leonard-Barton, D. 1995. Wellsprings of Knowledge: Building and Sustaining the Sources of Innovation, Cambridge, MA: Harvard Business School Press.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R., and Griliches, Z. 1987. "Appropriating the returns from industrial research and development," *Brookings Papers on Economic Activity* (3), pp. 783-831.

Li, S., Ragu-Nathan, B., Ragu-Nathan, T. S., and Rao, S. S. 2006. "The impact of supply chain management practices on competitive advantage and organizational performance," *Omega* (34), pp. 107-124.

Li, Y., Schneider, J. A., and Bennett, D. A. 2007. "Estimation of the mediation effect with a binary mediator," *Statistics in Medicine* (26), pp. 3398-3414.

Liang, H., Sharaf, N., Hu, Q., and Xue, Y. 2007. "Assimilation of Enterprise Systems: The Effect of Institutional Pressures and the Mediating Role of Top Management," *MIS Quarterly* (31:1), pp. 59-87.

Liu, L., Miao, R., and Li, C. 2008. "The Impacts of Enterprise Resource Planning Systems on Firm Performance: An Empirical Analysis of Chinese Chemical Firms," in *Research and Practical Issues of Enterprise Information Systems II Volume 1*, L. Xu, A. Tjoa and S. Chaudhry (eds.), Boston, MA: Springer, pp. 579-587.

Liu, J., Zhang, S., and Hu, J. 2005. "A case study of an inter-enterprise workflow-supported supply chain management system," *Information & Management* (42), pp. 441-454.

Lummus, R. R., and Vokurka, R. J. 1999. "Defining supply chain management: a historical perspective and practical guidelines," *Industrial Management & Data Systems* (99:1), pp. 11-17.

Mabert, V. A., Soni, A. K., and Venkataramanan, M. A. 2000. "Enterprise resource planning survey of US manufacturing firms," *Production & Inventory Management Journal* (41:20), pp. 52-58.

Mabert, V. A., Soni, A. K., and Venkataramanan, M. A. 2001. "Enterprise Resource Planning: Common Myths Versus Evolving Reality," *Business Horizons* (44:3), pp. 69-76.

MacKinnon, D. P., Lockwood, C. M., Brown, C. H., Wang, W., and Hoffman, J. M. 2007. "The intermediate endpoint effect in logistic and probit regression," *Clinical Trials* (4), pp. 499-513.

March, J. G., and Sutton, R. I. 1997. "Organizational performance as a dependent variable," *Organization Science* (8:6), pp. 698–706.

Markus, M. L., Axline, S., Petrie, D., and Tanis, C. 2000. "Learning from adopters' experience with ERP: problems encountered and success achieved," *Journal of Information Technology* (15), pp. 245-265.

Markus, M. L., and Tanis, C. 2000. "The enterprise systems experience-From adoption to success," in *Framing the Domains of IT Research: Glimpsing the Future Through the Past*, R. W. Zmud (ed.), Cincinnati, OH: Pinnaflex Educational Resources Inc, pp. 173-205.

Massey A. P., Montoya-Weiss M. M., and O'Driscoll T. M. 2002. "Knowledge Management in Pursuit of Performance: Insights from Nortel Networks," *MIS Quarterly* (26:3), pp. 269-289.

McAfee, A. 1999. "The impact of enterprise resource planning systems on company performance," *The Wharton Electronic Supply Chain Conference*, Philadelphia, PA, December.

McAfee, A. 2002. "The impact of enterprise information technology adoption on operational performance: an empirical investigation," *Production and Operations Management* (11:1), pp. 33-53.

McAfee, A., and Brynjolfsson E. 2008. "Investing in the IT That Makes a Competitive Difference," *Harvard Business Review* (86:7/8), pp. 98-107.

Melville, N., Kraemer, K., and Gurbaxani, V. 2004. "Review: Information Technology and Organizational Performance: An Integrative Model of IT Business Value," *MIS Quarterly* (28:2), pp. 283-322.

Mendelson, H. 1999. *Dell Direct*, Graduate School of Business Case Study, Stanford University, Stanford, CA.

Mithas, S., and Krishnan, M. S. 2009. "From Association to Causation via a Potential Outcomes Approach," *Information Systems Research* (20:2), pp. 295-313.

Mithas, S., Krishnan, M. S., and Fornell, C. 2005. "Why do customer relationship management applications affect customer satisfaction?" *Journal of Marketing* (69:4), pp. 201-209.

Motwani, J., Subramanian, R., and Gopalakrishna, P. 2005. "Critical factors for successful ERP implementation: Exploratory findings from four case studies," *Computers in Industry* (56), pp. 529-544.

Murphy, K. E., and Simon, S. J. 2002. "Intangible benefits valuation in ERP projects," *Information Systems Journal* (12), pp. 301-320.

Nah, F., Lau, J., and Kuang, J. 2001. "Critical factors for successful implementation of enterprise systems," *Business Process Management Journal* (7), pp. 285-296.

Nicolaou, A. I. 2004a. "Firm Performance Effects in Relation to the Implementation and Use of Enterprise Resource Planning Systems," *Journal of Information Systems* (18:2), pp. 79-105.

Nicolaou A. I. 2004b. "Quality of post-implementation review for enterprise resource planning systems," *International Journal of Accounting Information Systems* (5), May, pp. 25-49.

Nicolaou A. I., and Bhattacharya, S. 2006. "Organizational performance effects of ERP systems usage: The impact of post-implementation changes," *International Journal of Accounting Information Systems* (7), pp. 18-35.

Ofek, E., and Sarvary, M. 2001. "Leveraging the Customer Base: Creating Competitive Advantage Through Knowledge Management," *Management Science* (47:11), pp. 1441-1456.

O'Leary, D. 2000. Enterprise Resource Planning Systems, Life Cycle, Electronic Commerce and Risk, New York, NY: Cambridge University Press.

Pare´, G., Bourdeau, S., Marsan, J., Nach, H., and Shuraida, S. 2008. "Re-examining the causal structure of information technology impact research," *European Journal of Information Systems* (17), pp. 403-416.

Peterson, W. J., Gelman, L., Cooke, D. P. 2001. *ERP Trends*, The Conference Board Research Report R-1292-01-RR, New York, NY.

Porter, M. E. 1985. *Competitive Advantage*, New York, NY: The Free Press.

Porter, M. E., and Millar V. E. 1985. "How Information Gives Competitive Advantage," *Harvard Business Review*, July-August, pp. 149-174.

Poston, R., and Grabski, S. 2001. "The financial impacts of enterprise resource planning implementations," *International Journal of Accounting Information Systems* (2), pp. 271-294.

Ragowsky, A., and Somers, T. M. 2002. "Enterprise resource planning," *Journal of Management Information Systems* (19:1), pp. 11-15.

Rajagopal, P. 2002. "An innovation-diffusion view of implementation of enterprise resource planning (ERP) systems and development of a research model," *Information & Management* (40), pp. 87-114.

Rettig, C. 2007. "The Trouble with Enterprise Software," *MIT Sloan Management Review* (49:1), pp. 21-27.

Richards, K. A., and Jones, E. 2008. "Customer relationship management: Finding value drivers," *Industrial Marketing Management* (37), pp. 120-130.

Rikhardsson, P., and Kraemmergaard, P. 2006. "Identifying the impacts of enterprise system implementation and use: Examples from Denmark," *International Journal of Accounting Information Systems* (7), pp. 36-49.

Roberts, P. W. 1999. "Product innovation, product market competition and persistent profitability in the US pharmaceutical industry," *Strategic Management Journal* (20), pp. 655-670.

Robey, D., Ross, J. W., and Boudreau, M-C. 2002. "Learning to implement enterprise systems: an exploratory study of the dialectics of change," *Journal of Management Information Systems* (19:1), pp. 17-46.

Ross J. W., and Vitale, M. R. 2000. "The ERP Revolution: Surviving vs. Thriving," *Information Systems Frontiers* (2:2), pp. 233-241.

Ryals, L. J. 2005. "Making CRM work: The measurement and profitable management of customer relationships," *Journal of Marketing* (69:4), pp. 252-261.

SCB 2008. *Yearbook on Productivity 2008*, Statistics Sweden, Garnisonstryckeriet, Sweden.

Scheer, A. W., and Habermann, F. 2000. "Making ERP a success," *Communications of the ACM* (43:4), pp. 57-61.

Scott, S. G., and Bruce, r. A. 1994. "Determinants of Innovative Behavior: A Path Model of Individual Innovation in the Workplace," *The Academy of Management Journal* (37:3), June, pp. 580-607.

Scott, J. E., and Vessey, I. 2000. "Implementing enterprise resource planning systems: the role of learning from failure," *Information Systems Frontiers* (2:2), pp. 213-232.

Scott, J. E., and Vessey, I. 2002. "Managing risks in enterprise systems implementations," *Communication of the ACM* (45:4), pp. 74-81.

Shaked, A., and Sutton, J. 1982. "Relaxing product competition through product differentiation," *Review of Economic Studies* (49), pp. 3-13.

Shang, S., and Seddon, P. B. 2000. "A Comprehensive Framework for Classifying Benefits of ERP Systems," *Proceedings of the Americas Conference on Information Systems (AMCIS)*, Long Beach, California, August, pp. 1005-1014.

Shang, S., and Seddon, P. B. 2002. "Assessing and managing the benefits of enterprise systems: the business manager's perspective," *Information Systems Journal* (12:4), pp. 271-99.

Shin I. 2006. "Adoption of Enterprise system Software and Firm Performance," *Small Business Economics* (26), pp. 241-256.

Soh, C., Kien, S. S., and Tay-Yap, J. 2000. "Cultural fits and misfits: is ERP a universal solution," *Communications of the ACM* (43:4), pp. 47-51.

Srivardhana T., and Pawlowski, S. D. 2007. "ERP systems as an enabler of sustained business process innovation: A knowledge-based view," *Journal of Strategic Information Systems* (16), pp. 51-69.

Stoneman, P., and Kwon, M. J. 1996. "Technology adoption and firm profitability," *Economic Journal* (106:437), pp. 952–962.

Straub, D. W. 1989. "Validating Instruments in MIS Research," *MIS Quarterly* (13:2), pp.147-169.

Straub, D. W., Boudreau, M.-C., and Gefen, D. 2004. "Validation Guidelines for IS Positivist Research," *Communications of the AIS* (13), pp. 380-427.

Subramanian, A., and Nilakant, s. 1996. "Organizational Innovativeness: Exploring the Relationship Between Organizational Determinants of Innovation, Types of Innovations, and Measures of Organizational Performance," *Omega* (24:6), pp. 631-647.

Sumner, M. 2000. "Risk Factors in Enterprise-Wide/ERP Projects," *Journal of Information Technology* (15), pp.317-327.

Teece, D. J. 1986. "Profiting from technological innovation: implications for integration, collaboration, licensing and public policy," *Research Policy* (15), pp. 285-305.

Teece, D. J. 2001. "Strategies for managing knowledge assets: the role of firm structure and industrial context," in *Managing Industrial Knowledge: Creation, Transfer and Utilization*, I. Nonaka and D. J. Teece (eds.), London, UK: Sage Publications, pp. 125-144.

Teece, D. J. 2006. "Reflections on Profiting from innovation", *Research Policy* (35), pp. 1131-1146.

Umble, E. J., and Umble, M. M. 2002. "Avoiding ERP Implementation Failure," *Industrial Management* (44:1), pp. 25-33.

Uwizeyemungu, S., and Raymond, L. 2009. "Exploring an alternative method of evaluating the effects of ERP: a multiple case study," *Journal of Information Technology* (24), pp. 251-268.

Van Der Laan, M. J., and Petersen, M. L. 2004. *Estimation of direct and indirect causal effects in longitudinal studies*, Technical Report, University of California, Berkeley, Division of Biostatistics, August.

Van Leeuwen, G., Polder, M., Mohnen, P., and Raymond, W. 2009. "Productivity effects of innovation modes," *Advancing the Study of Innovation and Globalization in Organizations (ASIGO) Conference*, Nurnberg, Germany, May.

Vives, X. 1990. "Information and Competitive Advantage," *International Journal of Industrial Organization* (8), pp. 17-35.

Volkoff, O., Elmes, M. B., and Strong, D. M. 2004. "Enterprise systems, knowledge transfer and power users," *Journal of Strategic Information Systems* (13:4), pp. 279-304.

Von Hippel, E. 1988. *The Sources of Innovation*, Oxford, UK: Oxford University Press.

Von Hippel, E. 1994. "Sticky Information and the Locus of Problem Solving: Implications for Innovation," *Management Science* (40:4), pp. 429-439.

Von Hippel, E. 2005. *Democratizing Innovation*, Cambridge, MA: MIT Press.

Wieder, B., Booth, P., Matolcsy, Z. P., and Ossimitz, M. L. 2006. "The impact of ERP systems on firm and business process performance," *Journal of Enterprise Information Management* (19:1), pp. 13-29.

Willcocks, L. P., and Sykes, R. 2000. "The role of the CIO and the IT function in ERP," *Communications of the ACM* (43:4), pp. 22-28.

Winship, C., and Morgan, S. L. 1999. "The estimation of causal effects from observational data," *Annual Review of Sociology* (25), pp. 659-706.

Winship, C., and Sobel, M. 2004. "Causal inference in sociological studies," in *Handbook of Data Analysis*, M. Hardy and A. Bryman (eds.), London, UK: Sage Publications, Ch. 21, pp. 481-503.

Yu, C.-S. 2005. "Causes influencing the effectiveness of the post-implementation ERP system," *Industrial Management and Data Systems* (105), pp. 115-132.

Zhu, K. 2004. "The Complementarity of Information Technology Infrastructure and E-Commerce Capability: A Resource-Based Assessment of Their Business Value Source," *Journal of Management Information Systems* (21:1), pp. 167-202.

Appendix A: Tests to Assess the Direction of Causality

<u>MANOVA/ANOVA</u>:

Table A1: Testing for Causality through the Analysis of Variance

MANOVA *(joint IT-enabled product and process innovation)*	**Model Statistic**		**F-value**	**P-value**
Wilks' lambda	0.879		206.95	0.000
Pillai's trace	0.121		201.33	0.000
Lawley-Hotelling trace	0.136		212.58	0.000
Roy's largest root	0.130		406.37	0.000
ANOVA *(IT-enabled product innovation)*	**Sample Mean*** **ES=0**	**ES=1**	**F-value**	**P-value**
ERP	0.18 (0.38)	0.31 (0.46)	447.13	0.000
SCM	0.19 (0.39)	0.32 (0.47)	298.82	0.000
CRM	0.17 (0.38)	0.41 (0.49)	1336.15	0.000
KMS	0.19 (0.39)	0.41 (0.49)	724.01	0.000
DMS	0.18 (0.39)	0.32 (0.47)	373.41	0.000
ANOVA *(IT-enabled process innovation)*	**Sample Mean** **ES=0**	**ES=1**	**F-value**	**P-value**
ERP	0.21 (0.41)	0.44 (0.50)	1323.12	0.000
SCM	0.23 (0.39)	0.45 (0.47)	810.68	0.000
CRM	0.21 (0.41)	0.49 (0.50)	1474.64	0.000
KMS	0.22 (0.41)	0.47 (0.50)	853.63	0.000
DMS	0.23 (0.42)	0.41 (0.49)	502.40	0.000

*For sample means, the standard deviations are reported in parentheses.

Different statistics of the MANOVA test show that the model consisting of all the ES types significantly explains the joint variation of IT-enabled product and process innovation among the sampled firms. We also attained significant results when we used individual ES types (rather than their combination) to model the effects (all p-values significant at 99%). In case of the ANOVA tests, sample means indicate the proportion of firms with IT-enabled product or process innovation in the two subgroups of adopters and non-adopters of a specific system type. The corresponding F-values indicate that the differences in sample means are statistically significant in all cases, meaning that ES adoption has indeed led to (more) innovation(s). We also conducted the Bonferroni, Scheffe, and Sidak multiple-comparison tests and found significant results at 99% for all the system types. More details are accessible upon request from the authors.

3SLS/2SLS:

$$\begin{cases} product\_innovation = f(ES, broadband\_internet, ebusiness\_maturity, controls) \\ process\_innovation = f(ES, broadband\_internet, ebusiness\_maturity, controls) \\ revenue\_growth = f(ES, broadband\_internet, ebusiness\_maturity, controls) \\ productivity\_growth = f(ES, broadband\_internet, ebusiness\_maturity, controls) \\ marketshare\_growth = f(ES, broadband\_internet, ebusiness\_maturity, controls) \\ ES = f(product\_innovation, process\_innovation, revenue\_growth, productivity\_growth, \\ \quad marketshare\_growth, IT\_budget, international\_competition, controls) \end{cases} \quad (4)$$

We estimate a simultaneous system of six equations using three-stage and two-stage least squares. Controls in each equation include firm size, share of higher educated employees, size of market share and sector, country and year dummies. To satisfy the order condition (necessary for model identification) two new exogenous variables are included in the ES equation. *IT_budget* (Mean: 7.862%, Std. Dev.: 18.100) measures the share of IT budget, including hardware, software, services and personnel, as percentage of the total company costs. *international_competition* (Mean: 0.174, Std. Dev.: 0.379) indicates whether or not international markets (in contrast to regional and national markets) constitute the main sales area of the firm. The following table only reports the estimates of the variables of main interest. More details on the remaining parameter estimates have not been shown in the table for the sake of simplicity and are available upon request from the authors.

Table A2: Testing for Causality through the System of Simultaneous Equations

Dependent → / Independent ↓		ES	Product Innovation	Process Innovation	Revenue Growth	Productivity Growth	Market Share Growth
ES	*3SLS*	---	1.318***	1.266***	.869***	1.079***	1.247***
			(.289)	(.273)	(.246)	(.268)	(.294)
	2SLS	---	1.318***	1.266***	.869***	1.079***	1.247***
			(.290)	(.273)	(.246)	(.269)	(.295)
Product Innovation	*3SLS*	.352	---	---	---	---	---
		(.334)					
	2SLS	.228	---	---	---	---	---
		(.348)					
Process Innovation	*3SLS*	.915	---	---	---	---	---
		(.569)					
	2SLS	.827	---	---	---	---	---
		(.577)					
Revenue Growth	*3SLS*	1.058	---	---	---	---	---
		(.859)					
	2SLS	.829	---	---	---	---	---
		(.924)					
Productivity Growth	*3SLS*	.465	---	---	---	---	---
		(.862)					
	2SLS	.132	---	---	---	---	---
		(.937)					
Market Share Growth	*3SLS*	.692	---	---	---	---	---
		(.440)					
	2SLS	.250	---	---	---	---	---
		(.540)					

*** indicates significance at 99% confidence level. Three- and two-stage least squares are used for estimation of the system. Standard errors are shown in parentheses. All the equations, as indicated above, include exogenous and control variables (not shown).

Not everything that can be counted counts, and not everything that counts can be counted. -- *Albert Einstein*

INFORMATION TECHNOLOGY, ORGANIZATIONAL CHANGE AND FIRM PRODUCTIVITY: A PANEL STUDY OF COMPLEMENTARITY EFFECTS AND CLUSTERING PATTERNS IN MANUFACTURING AND SERVICES*

Abstract. For information technology (IT) investments to be productive specific complementary organizational practices and policies need to coexist or be developed in parallel. These complementarities affect firm performance through certain configurations or clusters of practices. Organizational change (OC) is an important complementarity. Firms need to change their processes, structures and/or boundaries

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according to their technology investments in order to gain substantial benefits. This paper investigates complementarities between the IT capital of the firm and different dimensions of its change initiatives. Furthermore, it analyzes the impact of different clusters of IT and OC on productivity of firms in the manufacturing and services sectors of the Dutch economy. For this purpose, three distinct econometric methods (i.e. interaction, systems, and two-stage) and a unique and detailed sample of 32,619 firm-level observations in the Netherlands over the period 1994-2006 are used. The results reveal a marginal productivity of IT much larger than that of non-IT capital. The output elasticity of IT is higher for the services than the manufacturing sector. OC is found to affect firm productivity positively should it be combined with proper levels of technology investments. The observed complementarity effects are stronger for services than for manufacturing firms. Among different types of change, structure and boundary changes have stronger effects on productivity than process changes. The effects become stronger if different types of change combine with each other and form clusters. On the opposite, non-IT capital and OC exhibit a substitutability relationship. As to another finding of the research, IT is found to play a dual role in organizations: (1) generating or stimulating change and (2) complementing change. The first role is more dominant among manufacturing firms while the second among services.

Keywords: Information Technology, Organizational Change, Firm Productivity, Complementarities, Clustering Patterns, Manufacturing, Services

1. Introduction

The productivity paradox of information technology (IT) has been the subject of a heated debate among economists, management scientists, and IT business value scholars over the two last decades (Brynjolfsson 1993, Solow 1987, Triplett 1999). At the firm-level, the debate was concerned with the following *what* question: "*what* is the effect of IT investment on firm productivity?" Since mid-1990s, researchers started to add another dimension to the inquiry by asking "*how* does IT affect firm performance?" The *how* question is the central theme of the research that promotes disaggregate, process-oriented models of IT value creation (Barua et al. 1995, Kelley 1994, Mukhopadhyay and Cooper 1993). The evidence reported so far in the literature provides insights into how IT contributes to organizational performance and corroborates the idea that the paradox has been resolved (Bartel et al. 2007, Bharadwaj et al. 1999, Brynjolfsson and Hitt 1996, Sircar and Choi 2009; see Melville et al. 2004 for an extensive review). Since the beginning of the 21st century, many scholars started to raise another essential research question. They wondered "*why* some firms reap substantial benefits from their IT investments while others don't?" The *why* aspect concerns the availability and quality of certain organizational complementarities that enable or facilitate a firm to benefit more from its IT investment (Bharadwaj et al. 2007, Bresnahan et al. 2002, Brynjolfsson and Hitt 2000, Devaraj and Kohli 2003).

Following the configurational school of thought, activity and decision choices of firms do not act independently but interact with each other to form systems or clusters of tightly coupled and interconnected practices (Ichniowski et al. 1997, Levinthal 1997). Complementary resources jointly affect firm performance and lead to competitive advantage (Brynjolfsson et al. 2002, Milgrom and Roberts 1995, Rivkin 2000). Resource compatibility is even understood as the most feasible path to create sustained competitive advantage from IT adoption (Kettinger et al. 1994, Powell and Dent-Micallef 1997). At the same time, misperceiving the existing complementary interactions may be very costly for managers (Siggelkow 2002). According to Brynjolfsson and Saunders (2010), the study of organizational complementarities is one of the frontier research opportunities that hold the greatest promise for future IT studies.

Consistent with Milgrom and Roberts (1990), complementarity exists when the total value added by combining two or more economic factors in a production system exceeds the value that would have been otherwise generated through these factors in isolation. When it comes to studying the complementarity and clustering patterns between information systems (IS) and organizational practices, only a few specific areas have received attention in the past. Practices that aim at development of human capital, internal organization of the work, and design of compensation systems account for the majority of these studies (Arvanitis 2005, Black and Lynch 2001, Bresnahan et al. 2002, Caroli and Van Reenen 2001, Hitt and Brynjolfsson 1997). Organizational change (OC) has only recently received explicit consideration in the literature on complementarities (e.g. Giuri et al. 2008; see Ennen and Richter 2010 for a comprehensive review). Still, the existing studies typically treat OC as a very narrow concept, primarily limiting it to occupational structures and incentive schemes of the firm. Moreover, the main focus has always been the firm's internal organization, leaving changes in the external relations of the firm (as a consequence of IT use) an underresearched phenomenon.

The two main research questions of this paper are: 1) "Do different types of organizational change and IT capital of the firm complement each other's effects on productivity?" and 2) "Are there differences between manufacturing and services industries in terms of IT effects and organizational complementarities?" We investigate complementarities between IT and OC. The notion of OC in the present paper incorporates both intra- and inter-organizational aspects of change. In contrast to dominant conceptualizations of OC in the literature that only concentrate on internal practices and structures of the firm, we give particular attention to external developments in firm boundaries and its relations with external actors, taking into account the strong evidence on boundary spanning effects of IT systems (Aral et al. 2006, Hitt 1999, Pickering and King 1995, Sahaym et al. 2007, Zammuto et al. 2007). The main contribution of this paper is its analysis of the complementarities between IT and OC due to changes in external firm boundaries. We also perform a cross-sector analysis on comparative differences between manufacturing and services firms with respect to IT effects and organizational complementarities. We are not aware of any paper addressing the links between IT, OC and productivity in a cross-sector setting as we do here.

The empirical analysis is based on a unique and extensive dataset of 32,619 firm-level observations in the Netherlands over the period 1994-2006. In addition to interaction and systems approaches that are common in the literature, we also use a new methodological approach in order to account for the issue of endogeneity (of organizational change) which is a serious concern in the existing studies on complementarities. The interaction approach looks at simple pair-wise interactions between the IT capital and OC practices of the firm in an augmented production function setting. The systems approach extends the analysis by examining the effect of different configurations of change on firm productivity. The two-stage approach simultaneously looks at both the enabling and complementarity effects of IT.

The findings show that strong complementarity exists between the IT assets and change initiatives of the firm. When different dimensions of OC are disaggregated, complementarities are found to be stronger with structure and boundary changes and weaker with process changes. Especially, we observe that complementarities typically occur when IT investments are combined with not only one type of change but rather multiple types at the same time. This points to potential interrelational dynamics between different types of organizational change and leads to different clusters with optimum productivity effects in different sectors. In general, process changes seem to have devastating productivity effects (at least in the short run). In order to mitigate these effects, process changes need to be combined with structure and/or boundary changes to produce positive impacts on productivity. Services firms are found to enjoy higher output elasticities as well as stronger complementarity effects compared to manufacturing firms. On the opposite, IT is found to be a more important driver or initiator of change for manufacturing than for services firms. The two-stage approach reveals a significant reduction in IT elasticity when enabling effects of IT are explicitly modeled. This suggests a need for an extension of the existing theories and potential research directions for future.

The next section develops the theoretical background of the two research questions and reviews the relevant empirical literature. Section 3 formulates the research hypotheses in the framework of a conceptual model. In section 4, we develop the empirical models and discuss the existing methods for the analysis of complementarities. In section 5, we describe the empirical panel data and explain how the variables used in this research are constructed. Section 6 reports the regression results. Thereafter, we reflect on the initial hypotheses by reconciling and discussing the results in section 7. Finally, section 8 concludes the paper and identifies some interesting avenues for future research.

2. Theoretical and Empirical Background

2.1. Complementarities theory as a theory of organizational change

Several theories have been developed to study the role of technological and organizational elements and their interrelationship in the process of organizational change (Barrett et al. 2006, Markus and Robey 1988). The type of theories used in the IS and OC literature are rather divergent, suggesting that the two strands of literature have much to learn from each other (Orlikowski and Barley 2001). In this study, the theory of complementarities constitutes the theoretical background. The theory of complementarities borrows certain notions from the contingency and configurational theories and develops a new conceptual and methodological outlook in organizational science.[82] The complementarities theory follows the contingency theory (Fiedler 1964, Kast and Rosenzweig 1973, Otley 1980) in seeing "fit" as an essential element in designing the organization and improving its performance. However, it moves beyond the reductionist, disaggregated view of the organization as proposed by the contingency theory which characterizes the organization as a set of loosely coupled elements. Instead, the complementarities theory follows the configurational school of thought (Miller 1987 and 1996, Mintzberg 1979) by adopting a holistic, aggregated view of the organization: "[organizations are] composed of tightly interdependent and mutually supportive elements such that the importance of each element can best be understood by making reference to the whole configuration" (Miller and Friesen 1984: 1).

The complementarities line of thought extends the configurational theory along two dimensions. First, the theory of complementarities conceives the dynamics of organizational transformation a more complex and contingent phenomenon, as described by Milgrom and Roberts (1995: 191): "changing only a few of the system elements at a time to their optimal values may not come at all close to achieving all the benefits that are available through a fully coordinated move, and may even have negative payoffs." This suggests that partial or piecemeal implementation of organizational change might lead to worse outcomes, compared to the unchanged status quo. In relation to this, Brynjolfsson et al. (1997) report that productivity losses occur if IT investments do not go along with changes in organizational structures of the investing firm. Second, the complementarities perspective extends the analysis of organizational configurations through systematic investigation of the separate contribution of individual elements to the performance of the whole, while the

[82] See Meyer et al. (1993) for a historical account of the move from contingency to configuration theory.

traditional configuration theory treats configurations as a black box. This extension is worthwhile as practices might reveal positive contribution to performance when they are coupled with their complements whereas their individual, isolated effects might be negative or neutral (see e.g. Ichniowski et al. 1997).

2.2. Empirical studies of organizational complementarities

The complementarities line of thought originates from the work of Milgrom, Roberts and their coauthors in early 1990s (Milgrom and Roberts 1990, 1994 and 1995, Milgrom et al. 1991) and is further advanced by among others, Amit and Schoemaker (1993), Brynjolfsson and Mendelson (1993) and Radner (1993). Notably, Milgrom and Roberts (1990) adopted the notion of supermodularity as a formal approach for modeling and testing complementarities. This gave rise to a number of empirical publications on the topic of complementarities in the second half of 1990s and throughout 2000s, among which some have investigated the interaction between IT and non-IT (NIT) resources of the firm (Ennen and Richter 2010). This strand of the literature is especially important because in order to fully understand the performance implications of IT, it is necessary to open up the black box of the organization by considering the system configurations in which IT resources are embedded and bundled together with non-IT resources (Black and Boal 1994).

When it comes to the choice of specific non-IT resources, most studies tend to focus on (1) skills level of the workforce and human resource management (HRM) practices aiming at developing employees' competencies and/or (2) workplace organization and structural design of the firm relating to decision authorities, decentralization and delayering of the workplace, teamwork and multitasking. In this respect, a relevant phenomenon is the concept of skill-biased technical and organizational change (SBTC and SBOC, respectively). SBTC concerns a shift in the production technology of the firm that favors skilled/educated over unskilled labor, thereby changing the relative demand and wage differential between the two groups of labor. SBOC refers to a related bias in the relative share of skilled and unskilled employees (in favor of the former) as a result of a series of technology-induced transformations in the organizational structure of the firm, such as decentralization of authority, delayering of managerial functions, and increased multitasking and team-based working. Comparing the effects of SBTC and SBOC, reorganizational strategy is shown to be more responsible for labor upskilling and occupational shifts than technological change alone (Greenan 2003, Piva et al. 2005). Caroli and Van Reenen (2001) show that organizational change reduces the demand for unskilled workers in France and the

UK and leads to greater productivity gains in establishments with larger skill endowments. Similarly, Bresnahan et al. (2002) investigate the complementarity between IT, workplace reorganization and new product/service offerings of the firm and their joint effect on labor demand in the US. They find that the upskilling effects of IT on labor demand are larger when IT is combined with certain investments in organizational and human capital. In similar studies using data from Switzerland and the US, workplace organization (such as team-working, job rotation, delegation of competences, joint decision making, team-/incentive-based compensation and flexible working hours), human capital (skilled and trained workers), and IT assets of the firm are found to be important determinants of firm performance, with their impacts being strengthened when they collectively exist (Arvanitis 2005, Black and Lynch 2001).

In addition to human capital and workplace organization, there are also other non-IT resources or elements that have received attention in a limited number of studies on complementarities. Bharadwaj et al. (2007) report complementarity between IS capability of the firm and its interfunctional and interorganizational coordination mechanisms, manifested in marketing, manufacturing and supply chain processes. Their results indicate that the above complementarity effects are significant predictors of manufacturing performance. Using data from 147 US firms from 1999 to 2002, Aral and Weill (2007) demonstrate that firms derive additional value from their IT investments through a mutually reinforcing system of organizational capabilities built on complementary competencies and routines (including technical, business and end-user skills, management quality, culture of IT use, and digital/internet transactions capability). In a similar attempt, Jeffers et al. (2008) find that IT assets can alter the impact of non-IT resources and managerial capabilities of the firm (specifically, open communication culture and business work practices) on process performance of third-party logistics firms. As to the strategic choice of the firm, the payoff to IT investments is found to be greater for firms with higher levels of (related) diversification (Chari et al. 2008). Our review of the literature suggests that an analysis of the (potential) complementarities between IT assets of the firm and its change efforts, especially in a broad sense that captures different aspects of the organization, is still a disregarded topic of research.

3. Hypothesis Development

Organizational change is a broad concept covering three primary dimensions (Armbruster et al. 2008, Whittington et al. 1999): changing processes, changing structures, and changing boundaries. Process changes imply innovations in the internal routines, production processes, service/distribution methods, human resource management, communications, operations, and support activities of the firm. Investment in human capital for cultivation of cross-unit teamworking and communication is an example of process changes (Nohria and Ghosal 1997). Significant changes in the procurement, production, or distribution processes of the firm, leading to new notions such as business process reengineering (Hammer and Champy 1993), quality circles and total quality management (Lawler et al. 1998, Zell 1997), lean production (Shah and Ward 2007), and just-in-time manufacturing (White et al. 1999) are also considered as process changes. Alternatively, the contemporary firm needs to be a communication-intensive and learning organization, which is supported through effective knowledge management policies. Introduction of knowledge management practices leads to important process changes as well (Alavi and Leidner 2001).

Structure changes reflect transformation of the structural elements of the organization (such as divisional structure of the functions) due to reorganization efforts, introduction of new management methods or significant changes in strategy. Examples include new, structurally-different forms of organizing the work including delayering of hierarchies and decentralization of work (Freeman and Cameron 1993, Geroski and Gregg 1994, Zeffane 1992), flexible and federal forms of organization (Bahrami 1992, Handy 1992), N-form corporation (Hedlund 1994), and cellular forms (Miles et al. 1997).

Boundary changes denote significant reforms in the relations of the company with other firms, such as public institutions, customers, suppliers, competitors or business partners that cross the formal boundaries of the firm. Increased competitive pressure and market heterogeneity force companies to further focus on their core competencies (Prahalad and Hamel 1990), manifesting itself in boundaryless organizations (Devanna and Tichy 1990, Tichy and Sherman 1996), hypertext organizations (Nonaka and Takeuchi 1995), disaggregated corporations (Zenger and Hesterly 1997), increased reliance on outsourcing, subcontracting and joint R&D collaborations (van Beers and Zand 2010, Benson and Ieronimo 1996, Wittington 1991), strategic alliances and joint ventures (Anand and Khanna 2000, Gulati et.al 2009, Merchant and Schendel 2000), and development of new sales/marketing channels (such as franchising, call centers and internet sales).

In relation to the above three dimensions of organizational change, we examine three hypotheses. Each hypothesis addresses the complementarity between IT assets of the firm and one of the three primary dimensions of organizational change with respect to firm performance. Figure 1 presents these hypotheses in the context of a conceptual model. As shown in the figure, we conceptualize the model such that the total effect of IT and OC on firm performance consists of an interactive part, which is subject to inquiry in this research, and a non-interactive part. Effects of IT and OC (arrow 1 and 2) partly complement each other (arrow 3) when affecting firm performance while the remaining parts affect performance directly (arrow 4 and 5).

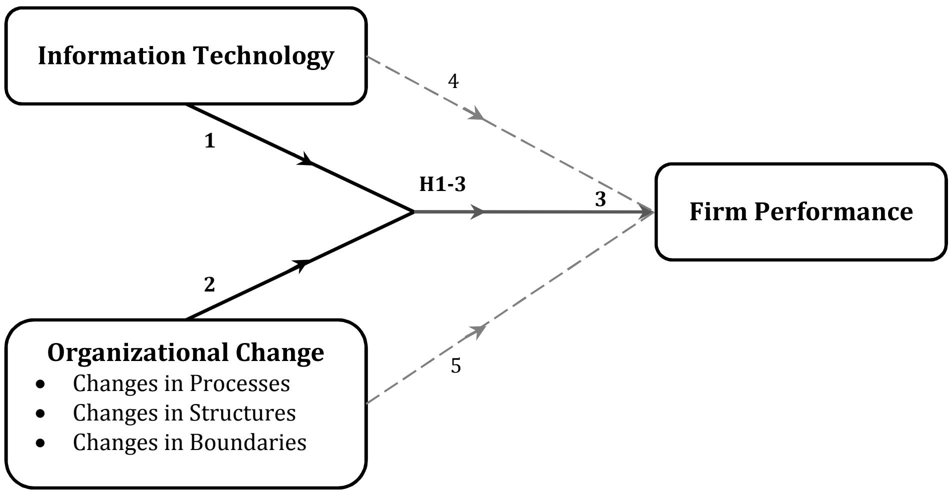

Figure 1: Conceptual Model and Research Hypotheses

3.1. Information technology and changes in processes of the firm

IT spawns process innovations like business process reengineering (BPR), total quality management (TQM), just-in-time production (JIT), and lean manufacturing (Davenport 1993, Martinsons 1995). These new forms of production processes and organizational practices arise from increasing capacity of IT in terms of communication and coordination roles, automation and computation power, and integration and transformation capability (Bharadwaj et al. 2007, Zammuto et al. 2007). In connection to IT-induced process transformation, higher levels of IT infrastructure capabilities are shown to positively affect efficiency and success of business process redesign (BPR) implementations (Broadbent et al. 1999). There is also evidence for the significant intermediation of process innovation in creating business value from IT adoption (Koellinger 2008, Zand and van Beers 2010). Another important aspect of process-oriented OC concerns knowledge management (KM) initiatives of the firm. It is shown that appropriate IT deployment should be combined and then aligned with KM policies/practices to ensure effective knowledge creation, sharing and utilization that further lead to organizational performance (Choi et al. 2008, Zack 1999).

An alternative way to look at the complementarity between IT assets and changes in processes of the firm is through configurational lenses (Jeffers et al. 2008). Application of IT resources to information- and/or coordination-intensive processes in a firm may generate process-level advantages, even if there are no other sources of comparative advantage involved in these processes per se. Alternatively, even if a firm's IT resources are not a source of distinction by themselves, they can be used to realize the full potential value of specific business processes and thus still generate advantage for the firm. The combined value of IT and organizational features for explaining organizational form and function originates from how they are enacted/woven together (Zammuto et al. 2007). IT interacts with the firm's processes to create value through visualizing the entire work process, creating real-time and flexible service, promoting virtual/mass collaboration and offering simulation/synthetic representations of use scenarios (Zammuto et al. 2007). Overall, the existing evidence in the literature suggests the idea that the distinctive capacities of IT, on the one hand, and information-, communication-, and coordination-intensive features of particular practices such as new forms of production/servicing and KM initiatives of the firm, on the other hand, reinforce each other's individual effects on firm performance.

H1: Changes in organizational processes of the firm due to knowledge management initiatives or introduction/alteration of (new) production methods, business processes or support activities increase the productivity of the firm's information technology assets.

3.2. Information technology and changes in structures of the firm

Hitt and Brynjolfsson (1997) suggest that IT leads to breaking down the hierarchical structure of the firm in favor of a system of decentralized authority and related practices. IT makes it easier and cheaper to generate, process and disseminate relevant information and knowledge to different layers of the organization where it is needed (Fulk and DeSanctis 1995, Leonardi 2007). IT makes it also possible and more convenient to exert relevant monitoring and control over the operations of lower level agents without a need for traditional command-and-control mechanisms. Increased availability of knowledge and facilitated control means greater possibility for delegation of decision rights and responsibility to a wider range of ordinary workers without requiring restrictive hierarchical structures (Zammuto et al. 2007, Zuboff 1988). Moreover, IT adoption spurs more flexible, flat and integrated forms of division of labor such as cross-functional teams and project-based forms of organization, in place of rigid traditional structures (Bahrami 1992, Giuri et al. 2008, Zenger and Hesterly 1997). This is a result of IT capability to facilitate cross-unit transactions, coordination of activities, and management of interdependencies of the firm (Rockart and Short 1989, Venkatraman 1991). Bertschek and Kaiser (2004) demonstrate that workplace reorganization in favor of group work and flat structures induces an increase in labor productivity that is partly attributable to complementarities between IT investments and reorganizational efforts. This suggests that the fundamental capabilities of IT are enhanced within such organizational contexts and managerial structures that promote decentralization, employee empowerment and job flexibility.

In addition to structural changes resulting from workplace reorganization policies or alteration/adaptation of (new) management methods, changes in corporate strategy are also responsible for structural shifts, which in turn complement the performance payoff of IT investments. A relevant example relates to the diversification strategies of firms (Chari et al. 2008). Diversified corporations, which own and operate businesses in multiple industries, are significant consumers of IT (Dewan et al. 1998). This strong association between IT use and implementation of diversification strategies and their related structural changes suggests that the performance effects of these strategies are contingent on developing coordination, communication and control capabilities that are brought to the organization by IT (Hill et al. 1992). The existing observations suggest that the new organizational structures developed due to strategic changes are more effective when they are combined with particular IT assets that enhance the capability of the organization to exercise its intended strategy.

H2: Changes in organizational structures of the firm due to workplace reorganization policies, alteration of management methods or adaptation/introduction of new strategies increase the productivity of the firm's information technology assets.

3.3. Information technology and changes in boundaries of the firm

In contrast to intra-organizational aspects of OC and their interaction with IT, the inter-organizational dimension has received less attention in the scholarly literature. This is surprising as IT has proven to lead to distinctive boundary-spanning/breaking effects on the firm. Increased (hyper)competition as well as globalization pressures encourage firms to focus on their core competencies and accordingly redraw their boundaries around a narrower sphere of activities that constitute their true core business and may lead to sustained competitive advantages (Prahalad and Hamel 1990). It is evident that "the once very rigid and unbreachable boundaries of business are fading in the face of change" (Kanter 1991). Firms' strategic decision for downsizing and downscoping their internal operations in favor of moving away from hierarchies, relying more on markets and focusing on core competencies is fueled by rapid development and proliferation of information technologies, as predicted by Malone and Smith (1988) and Malone et al. (1987). Zornoza and Alcami (1999) discuss the role of IT in enabling organizational transformation towards emergent forms of flexible and network-based organizations. In this respect, Brynjolfsson et al. (1994) find supportive evidence that investment in IT is significantly associated with subsequent shrinkage of the firm boundaries (i.e. decline in firm size). At the same time, the strategic choice of the firm to downscope its operations contributes to its ability to generate business value from specific types of IT that enhance interfirm coordination and market transactions.

For example, electronic data interchange (EDI) technologies are increasingly used to downsize the procurement and sales force of the company through automating/coordinating information flow and business transactions between a firm and its down/upstream trading partners and lead to networked organizations (Javenpaa and Ives 1994). These boundary changes are further stimulated through particular, external IT systems such as enterprise application integration (EAI) technologies, supply chain management (SCM) systems, interorganizational systems (IOS), and computer aided engineering (CAE) applications. These systems allow firms to effectively share information across their boundaries, increase visibility of supply chain activities, reduce transaction and market coordination costs, and enable cross-boundary projects. The extent and efficiency of e-commerce activities (Zhu 2004), strategic alliances (Faulkner 1994), subcontracting R&D (Whittington 1991), virtual new product development (NPD) teams (Montoya et al. 2009), and outsourcing/offshoring of (noncore) activities such as employee training, procurement functions or engineering tasks (Geroski and Gregg 1994, Leonardi and Bailey 2008, Sankaranarayanan and Sundararajan 2010) are also increased through appropriate external IT systems and infrastructures that enhance communication, group work and collaboration among firms.

IT not only leads to new forms of marketing and supply such as internet sales and e-procurement (which have consequences for boundaries of the firm), but also complements the effectiveness of these new forms in creating business value for the firm. For example, IT adoption complements the decision to engage in collaborative R&D or joint marketing with customers. At an industry level, and under certain conditions, this interaction is found to be further intensified, which gives rise to loosely-coupled organizational forms and alliances (Sahaym et al. 2007). There are also papers that report interaction effects in two directions. Hitt (1999) find that increased use of IT is associated with decreases in vertical integration, ultimately leading to virtual forms of the enterprise. At the same time, he highlights the catalytic role of OC by showing that firms which are less vertically integrated have higher demand for IT capital.

H3: Changes in organizational boundaries of the firm due to formation of alliances or R&D partnerships, outsourcing/subcontracting of activities or introduction of marketing innovations or new distribution/servicing methods increase the productivity of the firm's information technology assets.

4. Methods of Analysis and Empirical Models

4.1. Existing methods for analysis of complementarities

The existing literature uses one or a combination of the following three methods to investigate organizational complementarities empirically (See Athey and Stern 1998 and Lokshin et al. 2004 for useful reviews). The *adoption or correlation approach* is the most basic method (e.g. Bresnahan et al. 2002, Caroli and Van Reenen 2001, Giuri et al. 2008). Here, the presumption is that a firm's decision to adopt a particular resource depends on its decision to adopt or level of investment in other resources that exhibit complementarity with this resource. This method relies on reduced-form estimations of the adoption of a complement conditional on the adoption of other complements, controlling for exogenous attributes of the adopter. Another version of this method relies on conditional correlations among the residuals of reduced-form regressions of hypothesized complements on observable control variables. Caution is necessary in using this method as observed correlations between residuals might be the result of omitted exogenous variables or measurement errors common across equations. Moreover, this method suffers from simultaneity problem, although some attempts have been made to mitigate this concern (e.g. Arora 1996, Bertschek and Kaiser 2004).

Another limitation of the method is that it solely looks at the interrelationships between complementary resources and not their joint effect on firm performance, which is of particular interest in this research.

The second common approach is the *interaction or production function approach* (e.g. Bharadwaj et al. 2007, Black and Lynch 2001, Jeffers et al. 2008). This method relates a measure of firm performance, such as labor productivity, to a set of input factors, observed control variables, and interaction terms between (typically pairs of) hypothesized complements in a production function setting or structural equation modeling. In using this method, two issues require careful attention. First, the sample needs to include a reasonable number of observations that take different (and even non-optimal) combinations of practices under investigation; otherwise, the identification process is not consistent. Second, there should be no key performance-explaining variable omitted from the analysis that is highly correlated with the adoption of specific combination(s) of practices under study; otherwise, the estimation results can be biased. As a general shortcoming, the interaction approach simply looks at pair-wise (or higher-order) interactions without really considering the contextual conditions inside a system of interconnected variables that might potentially influence the relationship among these variables.

The third approach is the *systems or clustering approach* (e.g. Ichniowski et al. 1997, Mohnen and Roller 2005, Whittington et al. 1999). In this method, performance outcomes of different combinations of practices, known as clusters or systems, are studied. For testing the hypothesized complementarities, multiple inequality restrictions (Athey and Stern 1998, Carree et al. 2010) are used which are defined on the basis of the supermodularity theory (Milgrom and Roberts 1990, 1995). Compared to the interaction approach, the systems approach may generate less precise estimates as it examines variables in their reduced form. In other words, it requires transformation of continuous variables to dichotomous variables (each reflecting the adoption of a specific complement). This leads to (considerable) loss of information on variation of variables. On the opposite, the interaction approach does not take a reductionist perspective and retains a relatively higher degree of detail (by preserving the continuous form of the variables).

4.2. Empirical models of the research

We employ three different empirical models in this study, allowing us to come to robust and reliable conclusions.

(1) Interaction Approach:

We use the interaction method in an augmented production function setting. Following the general trend in the literature, we presume that firm *i* at time *t* produces according to a three-factor Cobb-Douglas production technology.

$$Y_{i,t} = A_{i,t} L_{i,t}^{\alpha} K_{i,t}^{\beta} IT_{i,t}^{\delta} \quad (1)$$

Firm output $Y_{i,t}$ is a function of labor $L_{i,t}$, non-IT or conventional capital $K_{i,t}$, IT capital $IT_{i,t}$ and total factor productivity (TFP) $A_{i,t}$. TFP captures all the variables that affect firm output above the effects of the three primary inputs. It reflects firm-specific heterogeneity such as production technology, process efficiency, and workforce knowledge. α, β and δ denote the elasticity of output with respect to the three input factors. Taking logarithms and re-writing the output in per-worker unit in (1) yields an equation where the dependent variable is labor productivity ($lp_{i,t}$) and the independent variables are logs of labor, non-IT and IT capital.[83]

$$lp_{i,t} = a_{i,t} + \lambda l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (2)$$

lp denotes the natural logarithm of output per full-time equivalent (fte) employee while *k* and *it* denote the logarithms of conventional capital and IT capital of firm *i* at time *t*. *l* equals logarithm of the number of employees in fte. The two sigmas respectively control for sector- and time-specific effects/shocks to labor productivity that affect the whole firms in a single industry or all firms in a specific year.[84] $\varepsilon_{i,t}$ is an i.i.d. normally distributed error term. The scale elasticity of the production function is identical to α+β+δ in (1) or alternatively α+β+λ+1 in (2). In order to examine the interactions between organizational changes and IT assets of the firm, we extend (2) with additional terms reflecting the direct contribution of OC to TFP as well as the interactions between OC and IT and non-IT capital of the firm. Lee (2008)

[83] We only transform the dependent variable to a per-worker measure (i.e. labor productivity). Non-IT and IT capital stock are not transformed to capital intensities because that would preclude our proper estimation and interpretation of interaction terms with OC.

[84] *sd* and *td* refer to sector and time dummies respectively. The sample includes 141 distinctive sectors at NACE-3 level over a time period of 13 years (i.e. m = {1,…,140} and n = {1,…,12}).

demonstrates that the multiplicative form is the best functional form to model complementarities.

$$lp_{i,t} = a_{i,t} + \lambda l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_j \gamma OC_{i,t,j} + \sum_j \mu OC_{i,t,j} * k_{i,t} + \sum_j \zeta OC_{i,t,j} * it_{i,t} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (3)$$

Among the three new sigmas included in (3), the first one is intended to capture the contribution of OC to TFP or the direct effect of OC on labor productivity. The second and third sigmas concern the interaction between OC and non-IT and IT capital of the firm respectively.[85] $j \in \{1, 2, 3\}$ specifies the three types of OC under study in this paper: changes in processes, structures and boundaries. Therefore, $OC_{i,t,j}$ measures the organizational change of type *j* of firm *i* at year *t*.

In addition to (3) above, we also employ a more basic specification of the model where the three types of OC are replaced with an overall composite indicator showing whether the firm has undergone major organizational changes at all or not (irrelevant of their types). We used factor analysis to extract one common factor out of the three OC constructs. We then transformed the yielded continuous factor for each firm to a dichotomous variable with respect to the average of the sector in which it operates. More details on this procedure will be presented later in section 5.3.

(2) Systems Approach:

Similar to the interaction approach, firm productivity is modeled as a function of labor, conventional capital, IT capital and organizational change. However, this time, the joint contribution of IT and OC is captured through a set of 16 unique systems or clusters (i.e. S_{abcd}: a, b, c, d$\in$ {0, 1}).

$$lp_{i,t} = \alpha l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_{a=0}^{1} \sum_{b=0}^{1} \sum_{c=0}^{1} \sum_{d=0}^{1} \gamma_{abcd} S_{i,t,abcd} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (4)$$

[85]The direct contribution of OC to TFP and interactions between non-IT and OC need to be included in the model to avoid confounding effects and thus misleading results.

$S_{i,t,abcd}$ denotes the state of firm *i* at year *t* depending on the adoption of four dichotomously-measured practices: (a) process OC, (b) structure OC, (c) boundary OC and (d) high IT intensity. As noted earlier, the systems approach works with reducing the continuous variables to dichotomous variables. High IT intensity is a dummy variable taking the value 1 if the share of IT capital in total capital of the firm is greater than the average level of the firm's industry and 0 otherwise. Process, structure and boundary OC are dummies indicating the occurrence of the corresponding organizational changes. The firm is at state $S_{abcd=0000}$ when it has neither introduced any sort of OC nor had a high IT intensity. It is at state $S_{abcd=1111}$ when it has undergone the three sorts of OC and at the same time possessed a high IT intensity. Other combinations of practices are defined similarly.

The theory of supermodularity (Milgrom and Roberts 1990) implies that two practices P_i^a and P_j^a are complementary to each other with respect to an objective performance function *f* if the following inequality holds for all possible values of the other arguments of *f* (with the inequality holding "strictly" for at least one combination of other arguments):[86]

$$f(P_i^1, P_j^1, .) - f(P_i^1, P_j^0, .) \geq f(P_i^0, P_j^1, .) - f(P_i^0, P_j^0, .) \quad (5)$$

Superscript *a* stands for adoption (*a*= 1) or lack of a practice (*a*= 0).[87] The above inequality posits that the marginal return of practice *j* is greater (or at least identical) under the condition that activity *i* exists, without respect to the adoption state of other practices that influence *f*. In case of four practices as in model (4), inequality (5) is translated to a set of 4 simultaneous inequality conditions for any of the 6 pairs of the practices.

$$\begin{array}{lll} \text{Complementary}\,(a-b): & \gamma_{11cd} - \gamma_{10cd} \geq \gamma_{01cd} - \gamma_{00cd} & \forall cd: \; cd \in \{00, 01, 10, 11\} \quad (6) \\ \text{Complementary}\,(a-c): & \gamma_{1b1d} - \gamma_{1b0d} \geq \gamma_{0b1d} - \gamma_{0b0d} & \forall bd: \; bd \in \{00, 01, 10, 11\} \\ \text{Complementary}\,(a-d): & \gamma_{1bc1} - \gamma_{1bc0} \geq \gamma_{0bc1} - \gamma_{0bc0} & \forall bc: \; bc \in \{00, 01, 10, 11\} \\ \text{Complementary}\,(b-c): & \gamma_{a11d} - \gamma_{a10d} \geq \gamma_{a01d} - \gamma_{a00d} & \forall ad: \; ad \in \{00, 01, 10, 11\} \\ \text{Complementary}\,(b-d): & \gamma_{a1c1} - \gamma_{a1c0} \geq \gamma_{a0c1} - \gamma_{a0c0} & \forall ac: \; ac \in \{00, 01, 10, 11\} \\ \text{Complementary}\,(c-d): & \gamma_{ab11} - \gamma_{ab10} \geq \gamma_{ab01} - \gamma_{ab00} & \forall ab: \; ab \in \{00, 01, 10, 11\} \end{array}$$

[86] The practices are substitutable in function *f* if the same inequality holds with the ≥ sign replaced by the ≤ sign.

[87] Alternatively, this can be translated to high and low adoption intensities.

(3) Two-stage Approach:

The previous two methods have roots in the microeconomic theory of production and the complementarities theory respectively. Yet, the character of OC variables in (3) and (4) may raise concerns about the endogeneity of OC in these models. Inherent in (3) and (4) is that OC and S variables are exogenous into the model. However, our literature review corroborates the idea that organizational changes could in fact be a function or consequence of past technological investments. Dedrick et al. (2003: 1) conclude from their review of studies on IT investment and firm productivity that "IT is not simply a tool for automating existing processes, but more importantly is an enabler of organizational changes that can lead to additional productivity gains." Similarly, Zammuto et al. (2007) attribute the capacity of IT to induce or support organizational change to its affordances such as visualizing entire work processes and provoking virtual collaboration. Adoption of advanced IT-based manufacturing or service management technologies is also reported to enable organizational change (Colombo and Delmastro 2002, Leonardi 2007). Alternatively, endogeneity of OC can be the result of simultaneity; firms' managers might decide on their level/type of technological investments and organizational changes simultaneously. Bocquet et al. (2007) posit the idea that IT adoption is a consequence of a simultaneous process by which firms seek to adopt a bundle of complementary strategies, organizational practices and advanced technologies all together. Aral and Weill (2007) find evidence for a simultaneous interrelation such that firms high in IT intensity tend to develop organizational capabilities more intensively and, at the same time, firms with strong organizational capabilities demand more IT.

To overcome the above concern, we decided to develop a method to control for potential endogeneity of OC in our estimations.[88] The recommended method consists of two stages. In the first stage, the three types of organizational change are related to the labor, capital and sectoral data of the firm. The three OC equations are then given by:

[88] Alternatively, we could employ an instrumental variable (IV) method. However, we could find proper, strong instruments for OC neither in the literature nor in our data.

$$OCP^*_{i,t} = a'_{i,t} + \lambda' l_{i,t} + \beta' k_{i,t} + \delta' it_{i,t} + \sum \varphi'_m sd_m + \sum \theta'_n td_n + \varepsilon'_{i,t} \tag{7}$$
$$OCS^*_{i,t} = a''_{i,t} + \lambda'' l_{i,t} + \beta'' k_{i,t} + \delta'' it_{i,t} + \sum \varphi''_m sd_m + \sum \theta''_n td_n + \varepsilon''_{i,t}$$
$$OCB^*_{i,t} = a'''_{i,t} + \lambda''' l_{i,t} + \beta''' k_{i,t} + \delta''' it_{i,t} + \sum \varphi'''_m sd_m + \sum \theta'''_n td_n + \varepsilon'''_{i,t}$$

OCP*, OCS* and OCB* are continuous variables signifying the level of process, structure and boundary changes of the firm respectively. However, the levels of change are latent and we only observe whether or not a firm experienced a certain type of OC. We thus define an indicator function *Ind*(.) that is equal to 1 if the condition that the firm has had a particular type of OC holds and 0 otherwise.

$$OCP_{i,t} = Ind(OCP^*_{i,t} > 0) \tag{8}$$
$$OCS_{i,t} = Ind(OCS^*_{i,t} > 0)$$
$$OCB_{i,t} = Ind(OCB^*_{i,t} > 0)$$

where OCP, OCS and OCB are dichotomous variables corresponding to the events that the firm has had process, structure and boundary changes respectively. The system of three equations in (8) is a trivariate probit model with $\varepsilon_{i,t} = (\varepsilon'_{i,t}, \varepsilon''_{i,t}, \varepsilon'''_{i,t})' \sim N(0, \sum)$. The first stage controls for the endogeneity of OC variables under the assumption that the labor and capital inputs are considered exogenous to productivity.

The second stage includes the estimation of an augmented production function as presented in (3) or (4) with OC interactions or state/cluster dummies replaced by a set of propensities calculated from the first stage. Propensities are calculated for each possible combination of OC variables and are included in the production function as proxies for OC. These propensities are likelihood predictions (as the actual OC variables are latent and endogenous), each taking the form of a variable between 0 and 1 ($Pr(x,y,z) \in [0,1]$) where x, y, $z \in \{0, 1\}$ contingent on the observation of process, structure and boundary changes respectively.[89] In addition to OC propensities, their interactions with non-IT and IT capital of the firm are also included in the model.

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[89] From the 8 possible combinations of Pr(0,0,0), Pr(0,0,1),…, Pr(1,1,1) we took the first category as the reference group to avoid perfect collinearity.

$$lp_{i,t} = a_{i,t} + \alpha l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \gamma_{xyz} Pr_{i,t}(x,y,z) + \sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \mu_{xyz} Pr_{i,t}(x,y,z) * k_{i,t} +$$
$$\sum_{x=0}^{1}\sum_{y=0}^{1}\sum_{z=0}^{1} \zeta_{xyz} Pr_{i,t}(x,y,z) * it_{i,t} + \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (9)$$

A similar approach could be applied to our overall OC indicator instead of the three OC dimensions. We then, in the first stage, model OC as a function of labor, IT and non-IT capital, and industry and time dummies. In the second stage, we predict the propensity of occurring OC and include it (and its interactions with capital stocks) in the production function. We yield the following equation, in which Pr(w) ={0, 1}where w∈ {0, 1} is a dummy variable denoting the observation of organizational change.

$$lp_{i,t} = a_{i,t} + \alpha l_{i,t} + \beta k_{i,t} + \delta it_{i,t} + \sum_{w=0}^{1} \omega_w Pr_{i,t}(w) + \sum_{w=0}^{1} \upsilon_w Pr_{i,t}(w) * k_{i,t} + \sum_{w=0}^{1} \phi_w Pr_{i,t}(w) * it_{i,t}$$
$$+ \sum \varphi_m sd_m + \sum \theta_n td_n + \varepsilon_{i,t} \quad (10)$$

5. Empirical Data, Descriptive Statistics and Operationalization of the Variables

5.1. Construction of the panel

Large-scale empirical studies are scarce in the field of IS, because of the paucity of quality data (Sircar et al. 2000). Datasets containing observations suitable for firm-level analysis are even scarcer than those suitable for industry-level studies (Sircar and Choi 2009). For the purpose of this research, we developed a unique and extensive panel dataset. The panel is characterized by three features. First, the data at our disposal is a large, representative sample of 32,619 firm-level observations from different enterprise size classes (i.e. small, medium, and large), over a majority of economic sectors (141 sectors at 3-digit Eurostat NACE rev. 1.1) and a longitudinal time span of 13 years (1994-2006). The existing studies mainly use rather small datasets on large firms, usually from a limited number of economic sectors (and mainly from the US) (Ennen and Richter 2010). This limits representativeness of the sample and generalization of results to different enterprise size classes, sectors and countries. Second, in contrast to most of earlier studies that use cross-section data, the size and time-series nature of the panel used in this study allows us to deal with identification and endogeneity problems and attain consistent and precise estimations. Third, the time span analyzed is an interesting period covering substantial developments as well as stagnations in IT spending and IT-related OC that happened prior or subsequent to the dotcom bubble burst in 2000.

The panel is the result of linking 38 individual datasets:[90] annual Production Statistics (PS) (1994-2006), annual Investment Survey (INVS) (1993-2005), bi-annual Community Innovation Survey (CIS) (1996, 1998, 2000, 2002, 2004, 2006), and bi-annual R&D Survey (RDS) (1995, 1997, 1999, 2001, 2003, 2005). PS includes detailed data on firm outputs (e.g. revenues, value-added, etc.), costs (e.g. labor costs, costs of goods sold, etc.), and employment (e.g. number of employees). INVS contains data on firm investments decomposed into several classes, such as machinery and equipment, transportation means, land, building and construction, computers, software, intangible assets, etc. CIS comprises data on variables related to product/process innovation and organizational change activities of the firm in a period of three years (for instance, 2004-2006), including input (e.g. innovation expenditures), process (e.g. collaboration partners and information sources), and output (e.g. innovative sales) variables. RTD consists of detailed information on research and development activities of the firm (e.g. R&D expenditures and number of R&D personnel) in every two years. The panel was further integrated with supplementary National Accounts (NA) data such as investment deflators, output price indices and depreciation rates.

5.2. Descriptive statistics of data

Table 1 reports the general descriptives of the relevant variables.

Table 1: Descriptive Statistics of the Sample

Variable	Mean	Std. Dev.	Observation
Employees (fte)	166.26	525.00	32619
• *Manufacturing*	*159.7*	*365.9*	*15613*
• *Services*	*177.6*	*700.8*	*13698*
Value-added (1000 €)	10875.31	52977.17	32619
• *Manufacturing*	*13605.5*	*71161.3*	*15613*
• *Services*	*9042.9*	*29350.9*	*13698*

[90] We are grateful to Statistics Netherlands for providing full access to the empirical data used in this research.

Total turnover (1000 €)	51426.58	239284.44	32619
• *Manufacturing*	*52785.7*	*266693.5*	*15613*
• *Services*	*56445.3*	*233746.7*	*13698*
Radical innovations share (%)	3.51	10.92	29487
• *Manufacturing*	*5.3*	*12.9*	*15206*
• *Services*	*1.8*	*8.5*	*11011*
Incremental innovations share (%)	6.58	15.04	30678
• *Manufacturing*	*10.4*	*18.1*	*15613*
• *Services*	*2.6*	*9.6*	*11757*
Exports share (%)	26.98	33.44	25302
• *Manufacturing*	*34.4*	*34.6*	*15596*
• *Services*	*18.6*	*29.7*	*7731*
Total costs (1000 €)	48181.16	224542.38	32619
• *Manufacturing*	*48490.8*	*243977.0*	*15613*
• *Services*	*53804.9*	*227237.1*	*13698*
Labor costs (1000 €)	6376.87	19611.13	32619
• *Manufacturing*	*6540.3*	*18776.7*	*15613*
• *Services*	*6272.6*	*22073.6*	*13698*
Innovation expenditure (1000 €)	684.20	7114.09	32455
• *Manufacturing*	*1168.2*	*10112.2*	*15613*
• *Services*	*272.6*	*1650.0*	*13534*
Total capital (1000 €)	19942.04	100247.36	32619
• *Manufacturing*	*32358.1*	*136779.2*	*15613*
• *Services*	*9369.9*	*45094.1*	*13698*
Non-IT capital (1000 €)	19286.58	99298.00	32619
• *Manufacturing*	*31811.7*	*135765.7*	*15613*
• *Services*	*8517.7*	*43550.7*	*13698*
IT capital (1000 €)	655.46	3558.37	32619
• *Manufacturing*	*546.2*	*3780.2*	*15613*
• *Services*	*852.2*	*3678.9*	*13698*
Non-IT capital share (%)	88.72	15.69	32619
• *Manufacturing*	*94.4*	*8.5*	*15613*
• *Services*	*82.4*	*19.6*	*13698*
IT capital share (%)	11.28	15.69	32619
• *Manufacturing*	*5.6*	*8.5*	*15613*
• *Services*	*17.6*	*19.6*	*13698*
Non-IT capital growth (%)	1.06	2.31	32619
• *Manufacturing*	*0.9*	*2.8*	*15613*
• *Services*	*0.8*	*1.8*	*13698*
IT capital growth (%)	13.90	3.71	32619
• *Manufacturing*	*11.8*	*3.9*	*15613*
• *Services*	*15.5*	*2.1*	*13698*
Group (%)	67.09	46.99	32619
• *Manufacturing*	*67.8*	*46.7*	*15613*
• *Services*	*67.8*	*46.7*	*13698*
Multinational (%)	20.76	40.56	32210
• *Manufacturing*	*25.1*	*43.3*	*15398*
• *Services*	*20.3*	*40.3*	*13698*
Innovation activities (%)	53.25	49.90	32619
• *Manufacturing*	*69.9*	*45.9*	*15613*
• *Services*	*40.2*	*49.0*	*13698*
Product/service innovations (%)	43.80	49.61	32615

• *Manufacturing*	*57.9*	*49.4*	*15613*
• *Services*	*33.3*	*47.1*	*13694*
Organizational change (%)	64.18	47.95	32619
• *Manufacturing*	*71.3*	*45.3*	*15613*
• *Services*	*59.6*	*49.1*	*13698*
Structure changes (%)	43.26	49.54	32619
• *Manufacturing*	*46.2*	*49.9*	*15613*
• *Services*	*41.6*	*49.3*	*13698*
Process changes (%)	42.11	49.37	32619
• *Manufacturing*	*51.2*	*50.0*	*15613*
• *Services*	*36.5*	*48.2*	*13698*
Boundary changes (%)	35.51	47.86	32619
• *Manufacturing*	*41.4*	*49.3*	*15613*
• *Services*	*31.9*	*46.6*	*13698*
Additional Descriptives			
Labor productivity (€/fte)	60136.20	114020.39	32619
• *Manufacturing*	*60799.0*	*62552.9*	*15613*
• *Services*	*65112.2*	*161902.8*	*13698*
Value-added to non-IT capital ratio	4.23	26.40	32619
• *Manufacturing*	*2.0*	*10.0*	*15613*
• *Services*	*6.7*	*37.8*	*13698*
Value-added to IT capital ratio	98.28	485.15	32619
• *Manufacturing*	*102.4*	*508.3*	*15613*
• *Services*	*94.1*	*495.2*	*13698*
Exports (1000 €)	24519.03	179813.87	25302
• *Manufacturing*	*28553.2*	*168122.2*	*15596*
• *Services*	*22575.5*	*220491.1*	*7731*
R&D expenditures (1000 €)	369.84	4675.06	32455
Manufacturing	*665.7*	*6679.9*	*15613*
Services	*107.0*	*813.1*	*13534*
Non-IT capital intensity (€/fte)	94819.49	238704.07	32619
• *Manufacturing*	*141380.5*	*259543.7*	*15613*
• *Services*	*58419.7*	*229065.6*	*13698*
IT capital intensity (€/fte)	3857.97	14051.06	32619
• *Manufacturing*	*2817.3*	*5033.8*	*15613*
• *Services*	*5476.0*	*20650.3*	*13698*

The sample contains 32,619 firm observations that during 1994-2006 produced an aggregate €1.81 and € 0.39 trillion in revenues and value-added respectively. The average firm in the sample has 166 employees and generates an annual €10.9 and €51.4 million in value-added and turnover, from which 3.5%, 6.6% and 27.0% can be considered as radical innovations, incremental innovations and exports respectively. The average firm incurs an annual cost of €48.2 million, from which €6.4 million is spent on labor costs and €684 thousand on innovation activities. The sampled firm, on average, has €19.9 million in total capital, from which €19.3 million can be considered as non-IT capital; this makes the share of IT capital in the sample 11.3%. However, on average, the IT capital of the firm in our sample has experienced an annual growth of 14% during the time span 1994-2006 while, in the same period, non-IT capital has only grown by 1% annually. Of the firms in the sample, 67% belong to a larger enterprise group and 21% are multinational. During the period 1994-2006, 53% of the sampled firms engaged in some sort of innovation projects, from which 44% managed to successfully launch an innovative product/service into the market.[91]

Organizational change has been a common phenomenon among the sampled firms as 64% of them introduced some kind of change in their organizations during the period 1994-2006. Structural changes are the most common type of OC with observations in 43% of the sample, followed by process and boundary changes with 42% and 36% respectively. Osterman (1994) and Wittington et al. (1999) report comparable, yet slightly higher proportions, for their surveys of American and European enterprises respectively. A reason why OC is more common in the aforementioned surveys is that these surveys primarily include large enterprises (which are more intensive adopters of OC) while our sample includes all enterprise size classes.

Comparing the manufacturing and services firms reveals interesting differences between the two sectors. Manufacturing and services firms in our sample are of comparable size, with firms in the latter group being slightly larger. The size distribution, though, is much diverse for the services sector. Manufacturing firms are by far more innovative. They spend more on R&D and innovation activities and produce more innovative products.[92] They are also more active in international markets in terms of exporting their products and more capital-intensive. Services firms, however, are more IT-intensive. In terms of both per worker and per euro of total fixed assets, services firms possess more IT capital. Per worker, services firms have almost twice as much IT as their manufacturing counterparts; per unit of capital, services firms are three times more IT-intensive. Another notable difference is the spread of IT intensity among companies, which is much larger among service firms. This shows more remarkable differences among services than manufacturing firms with respect to their IT-orientation. While the growth rate of non-IT capital is

[91] Additional descriptives are reported at the end of Table 1.

[92] This can be partly due to the fact that identifying and measuring innovations is traditionally easier when products are physical goods rather than intangible services. Brynjolfsson and Saunders (2010) make several notes on this issue in their recent book.

comparable between the two groups, services companies have experienced a greater growth in their stock of IT capital over the period 1994-2006. Furthermore, manufacturers seem to be more aggressive adopters of organizational transformations than service providers; organizational changes of any type, especially process and boundary changes, are more common among manufacturing companies. Yet, the spread of OC is more or less the same among the two sectors.

The sample covers both manufacturing and services industries. In addition to increasing the representatives of our analysis, this allows to conduct a comparative study to unveil the major differences in creating value from IT between manufacturing and services industries. Table 2 demonstrates the sectoral distribution of the sample.[93] Our sample consists of 48% manufacturing, 42% services and 10% construction companies. The sample represents almost all major manufacturing industries, although the IT-using sectors are better represented than the IT-producing sectors. The services sector of the sample is less representative. A number of very intensive users of IT such as the financial sector, telecom services and media/entertainment industry are almost missing. We expect that if our sample represented these missing industries, the difference in the level of IT-intensity between the services and manufacturing would be even larger while the difference in the degree of innovativeness between the two sectors would be smaller.

Table 2: Sectoral Distribution of the Sample

Sector	# of firms	% of sample
Manufacturing	**15613**	**47.87**
Pharmaceuticals, Chemicals and Related Products	1254	3.84
Machinery and Electrical Apparatus Manufacturing	2755	8.44
Electronics, Computers and Office Equipment	503	1.54
Medical/Optical, Audio/Video and Telecom Devices	652	2.00
Auto Industry and Transportation Equipment	653	2.00
Food, Beverage and Tobacco	2122	6.51
Textile, Clothing and Leather Industry	94	0.29
Paper and Related Materials	959	2.94
Printing and Publishing	155	0.48
Petroleum Industry	124	0.38
Rubber, Plastics and Synthetic Materials	1089	3.34
Glass, Pottery and Related Products	672	2.06

[93] We use sector indicators at 3-digit NACE in our analysis. However, for presentation, we report them at 2-digit. A more detailed sectoral break-down of the sample is available on request.

Base Metals Industry	458	1.41
Fabricated Metal Products	2780	8.52
Furniture and Wood Products, Recycling and Other Industries	1343	4.12
Construction (and Related Activities)	**3308**	**10.14**
Services	**13698**	**41.99**
Computer Services	351	1.08
Professional and Business Services	2383	7.31
Trade, Repair and Rental of Vehicles and Related Services	1172	3.59
Wholesale and Commission Trade	6868	21.05
Retail Trade and Catering Services	2849	8.73
Environmental, Cultural and Catering Services	75	0.23
Total	**32619**	**100**

5.3. Construction of the variables

Value-added (at factor costs) and full-time equivalent (fte) employment are directly available from PS and log labor productivity, the dependent variable of our models, can thus be readily constructed. However, since we use time-series, we need to deflate value-added to adjust for inflation effects. We obtain VA-based price deflators for this purpose from NA for each sector (at 3-digit NACE) and year (1994-2006) with 1993 taken as the base year. Output measures such as value-added and turnover are measured at the end of each year.

As to the independent variables, IT and non-IT capital stock measures are constructed using investment data and the Perpetual Inventory Method (PIM), as the most common method in the literature. $G_{c,i,t}$ i.e. firm's *i* capital goods of type *c* at period *t* results from its capital goods in the preceding period ($G_{c,i,t-1}$) plus relevant investments during the preceding year ($I_{c,i,t-1}$) in the following way:[94]

$$G_{c,i,t} = (1-d_{c,i})\,G_{c,i,t-1} + I_{c,i,t-1} \quad (11)$$

The previous year's capital stock needs to be deflated at an appropriate depreciation rate ($d_{c,i}$) before inserted into the formula. *c* denotes different types of capital, i.e. IT and non-IT. The above equation builds on the argument that capital investments take

[94] In contrast to a number of similar studies, we do not apply any sort of imputation in calculating the capital stocks. Firm's *i* capital at time *t* is only constructed if a continuous time-series for all the past investments preceding *t* is available at our disposal.

time (here, one year) after their installation before they become productive and part of the firm's bundle of effective inputs. In other words, $G_{c,i,t}$ is an indicator of the firm's capital input during period *t* measured at the beginning of the period (or, alternatively, end of the previous period). Later on, we relate $G_{i,t}$ to $Y_{i,t}$ to assess the contribution of capital stock to labor productivity. Therefore, we observe a time-lag of (at least) one year between when investments are incurred and benefits are accrued.

To obtain the initial capital goods, we rewrite (11) for the initial period (*t* = 1) by backward substitution in the following way:

$$G_{c,i,1} = I_{c,i,0} + (1-d_{c,i})\, I_{c,i,-1} + (1-d_{c,i})^2\, I_{c,i,-2} + (1-d_{c,i})^3\, I_{c,i,-3} + \ldots = \sum_{s=0}^{\infty} I_{c,i,-s}\, (1-d_{c,i})^s =$$

$$I_{c,i,0} \sum_{s=0}^{\infty} \left[\frac{1-d_{c,i}}{1+gr_{c,i}} \right]^s = \frac{I_{c,i,1}}{d_{c,i} + gr_{c,i}} \qquad (12)$$

$I_{c,i,1}$ indicates the amount of investment of type *c* of firm *i* in the first observed year (i.e. 1994). $gr_{c,i}$ is the average pre-period growth rate of capital type *c*. In other words, $gr_{c,i}$ specifies the average rate at which expenditures in capital type *c* has grown (or declined) over years prior to the beginning of our period of analysis (here, 1994-2006). Another complication in applying (12) refers to $I_{c,i,1}$ Investment behavior at the firm level can be erratic. Stated otherwise, investments may follow different cycles among firms over time. As a result, the initial capital stock yielded from (12) may be too dependent on the probability and extent of investments in the first year. This can be circumvented by replacing $I_{c,i,1}$ with the average (real) investment of type *c* observed over the period of interest (i.e. $I_{c,i,1} = \frac{1}{T}.\sum_{t=1}^{T} I_{c,i,t}$ with T = 13).

For using (11) to construct the capital stock, we require investment figures. We extract capital investments from INVS. IT investment includes expenditures in both hardware and software. Non-IT investment captures any other type of investment. Similar to output measures, nominal investment figures need to be transformed to real figures using appropriate investment deflators. Based on NA data, we calculate deflators for IT and non-IT for each sector (3-digit NACE) and each year (2004-2006) separately with 1993 taken as the base year. Deflators for IT capital are based on harmonized hedonic techniques to adjust for quality improvements of IT goods. Figure 2 depicts the development of output and investment deflators over the course of time. Deflator numbers shown in the figure are weighed averages over the whole Dutch economy. It is notable that prices of IT goods have declined over time while other types of goods have experienced price increases.

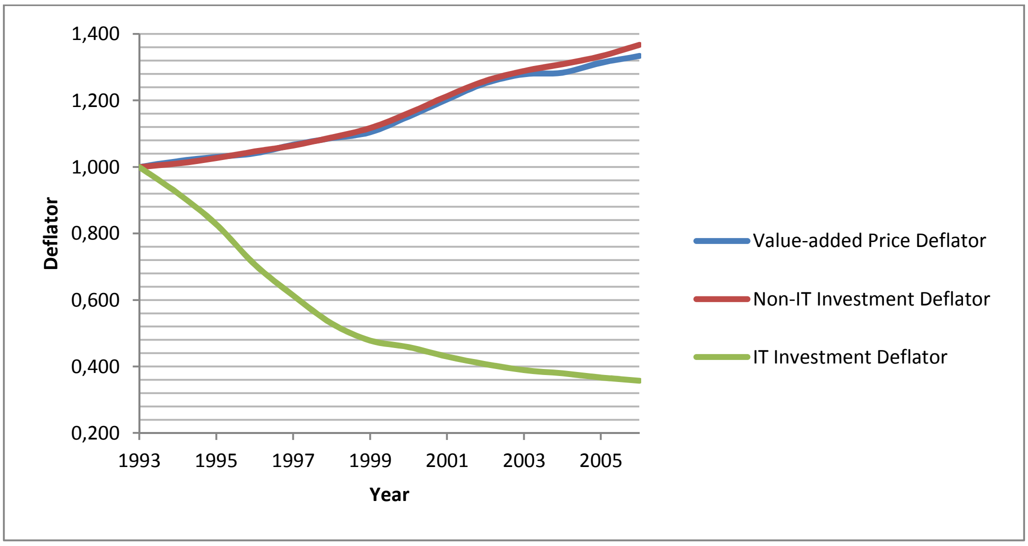

Figure 2: Development of Output and Input Deflators over the Period 1993-2006

For calculating depreciation rates and pre-period growth rates, NA supplied us with very detailed annual data on the composition of different categories of capital assets in different sectors. We also got access to data on the (expected) service life of different types of assets in different industries. These data allowed us to calculate the geometric average of the pre-period growth rates (of IT and non-IT capital) for different sectors with very high accuracy; the weighted averages for the Dutch economy used in this study amount to 51.341% and 4.378% for IT and non-IT capital respectively. For calculating economic depreciation rates, it is important to distinguish between the price effects of use and obsolescence (Statistics Canada 2007). Computers, for instance, may undergo relatively little physical depreciation over their service life and yet they may experience markedly declines in resale value due to quick obsolescence. We estimate the average rates of depreciation for IT and non-IT as the inverse of the weighted sum of the service lives of different types of fixed capital assets.

$$d_{c,i} = \frac{1}{\sum_{k_c} SL_{k_c,i} * W_{k_c,i}} \qquad (13)$$

k_c refers to different asset types forming capital stock *c*. For IT, this comprises hardware and software and for non-IT, all other types of economic assets accounted by NA (such as building, land, machinery, transportation, etc.). $SL_{kc,i}$ denotes the expected service life of asset type k_c depending on the sector of firm *i*. $W_{kc,i}$ represents the weights equal to the share of the value of different asset types in each sector. At the end, depreciation rates are estimated for individual sectors. The average figures for the Dutch economy was estimated as 26.377% and 6.439% for IT and non-IT capital respectively. Among the present sectors in our sample, the Audio/Video & Telecom Equipment and Furniture & Wood Products exhibit the highest (30.759%) and lowest (19.561%) depreciation rates for IT respectively. Trade, Repair & Rental of Motor Vehicles and Base Metals Industry appear to be the sectors with the highest (13.108%) and lowest (3.382%) depreciation rates for non-IT capital respectively. [95] Finally, we needed to have a dichotomous measure of the firm's IT intensity for constructing clusters in model (4). We calculate the share of IT capital in total capital and define a dummy variable accordingly. The dummy takes a value of 1 if a firm's IT share is above the average IT share of its respective industry and 0 otherwise. In our sample, 36.28% of firms (33.4% for manufacturing and 39.0% for services) have an IT share greater than their sector's average.

In addition to output and capital measures, we use organizational change variables as independent variables in our empirical models; these are the variables of main interest. OC variables capture three primary dimensions of change. Multi-dimensional measures of organizational configurations provide a more complete picture of reality as they contribute more to performance explanation of the firm (Ketchen Jr. et al. 1997). They also allow for comparative study among different dimensions of OC with respect to IT interactions and performance implications. OC variables in the present

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[95] In our models we allowed all parameters to vary between various subsectors of the economy. Otherwise stated, we opted to calculate individual price indices, investment deflators, depreciation rates and growth rates for different sectors and time periods covered in our analysis. Diverse sectors of the economy might possess totally different investment profiles and experience varied degrees of product obsolescence and price fluctuations. Similarly, the share of different types of fixed assets and their price changes in the economy differ from one year to another depending on cyclical effects. Consequently, we argue that the model parameters need to be accounted separately for different sectors and time periods, in contrast to previous studies that adopt a single average figure for the whole sample and period of analysis. This is crucial, if not necessary, to yield reliable and consistent estimates.

study are adopted from CIS. OCS, OCP and OCB, denoting different types of OC, are dummy variables. OCS takes a value of 1 if the firm has introduced significant changes/improvements in its internal organizational structures as a consequence of (1) new or significantly changed corporate strategy(ies), (2) implementation of fundamentally new, innovative or advanced management techniques/methods, or (3) radical reorganizations. These three components are directly questioned in CIS. The first three waves of CIS used to construct the panel (i.e. 1994-1996, 1996-1998, and 1998-2000 waves) deal with these aspects in separate questions.[96] Later waves (i.e. 2000-2002, 2002-2004, and 2004-2006) combine these three aspects in a single question. OCP takes a value of 1 if the firm has introduced significant changes/improvements in its internal business processes as a consequence of either (1) implementation of new or significantly improved production processes/technologies, operational routines or support activities or (2) implementation of knowledge management systems or concrete/clear knowledge managements policies. The three later waves of CIS include separate questions covering the above two components. Earlier waves of CIS only include data on the first condition. Finally, OCB takes a value of 1 if the firm has introduced significant changes/improvements in its boundaries with external parties as a consequence of (1) introduction of new or significantly improved marketing concepts or strategies, distribution methods or sales channels (such as internet sales, franchising, direct sales and licensing), (2) adoption of cooperative arrangements or formal partnerships with third parties (such as customers, suppliers, competitors or universities), or (3) significant/radical alteration of the firm’s relations with other enterprises or public institutions (such as through alliances, outsourcing, offshoring or sub-contracting). The first two components are readily questioned in all the waves of CIS. The third question is only available in the last three waves.

CIS is a bi-annual survey. The above OC-related questions are being surveyed every two years about the status of the firm within the previous triennium. For example, the last wave of CIS was conducted at early 2007 and asked about innovation activities and organizational changes of responding firms during the 3-year period 2004-2006.

[96] For these waves, OCS is 1 if the response to any of the corresponding three questions is “Yes”. It is 0 if the answer to all of the three questions is “No”. Finally, it is missing if any of the answers is missing and none is “Yes”. This scheme is used in all other cases where a logical OR operator is applied to individual components of a construct.

In constructing our panel, if a firm indicates that it has undergone some sort of OC during this period, we assume that the value of associated OC variable is true for the three years of the period (i.e. 2004, 2005, and 2006). This is a valid supposition as OC initiatives are not one-time, instantaneous but ongoing projects that might last for a long time before they complete. Looking back again to the issue of time-lags, suppose a firm observation has responded positively to a kind of OC in the 2004-2006 CIS. When *t*=2006, productivity of the firm is measured at the end of 2006, its capital stocks are estimated at the end of 2005 and its OC indicator is true throughout the period 2004-2006. As a result, our formulation of the empirical models is built on a time-lag of one year for capital investments and between 0 to 3 years for organizational changes (depending on the actual incidence of the related OC, being at the end of 2006 or beginning of 2004 in extreme cases).[97]

As noted earlier, in addition to the three basic OC variables studied in this paper, we also required an overall composite indicator showing whether or not the firm has undergone major organizational changes at all (without respect to the type of change). A simple approach could be combining the above three constructs with a logical OR operator, yielding a new dummy that is equal to 1 if any of the three components are true. This is the variable "organizational change" described in Table 1. However, this method does not account for communalities among the three constructs. It also ignores the level of a firm's change intensity. For example, a firm with only structural changes would be treated exactly the same as a firm with both structure and process changes or even one with all three types of change. To remedy, we employed confirmatory factor analysis (CFA). Principal Axis Factoring (PAF) as the preferred method of CFA in social and behavioral sciences (Widaman 1993), was used to extract the common or shared variance (while excluding the unique and error variances) of the three OC constructs into a single OC indicator. Kaiser criterion was used to extract factors. A Cronbach's alpha of 0.720 indicates that we can attain a reliable and consistent score. One single factor with eigenvalue greater than 1, accounting for 66.9% of variance was extracted (n= 32,619). A KMO measure of 0.735 also points to a satisfactory sampling adequacy. Finally, Bartlett's method was used to estimate factor scores. The resulting factor is a continuous, aggregate measure of organizational

97 Assuming a linear completion rate for OC projects, the average time-lag between measuring OC initiatives and firm productivity would be then 1.5 years.

change. In order to construct the clusters of practices for running model (4), we required a dummy variable for OC. Organizational change patterns and requirements are very dependent on the industry in which a firm operates. We therefore constructed a dummy variable based on the value of the firm's OC factor being above the average of its respective sector (based on 3-digit NACE) or not. It appears that 39.80% of the sampled firms (46.6% for manufacturing and 35.9% for services) have a larger OC factor than the average of their industries.

6. Empirical Results

6.1. Interaction approach

Table 3 reports the results of estimating model (3) for the whole sample (A) as well as distinguished to manufacturing (M) and services (S).

Table 3: Regression Results for Model (3), Interaction Approach: Maximum Likelihood Estimation

log (Labor Productivity)	**Sample**	**Regression (1)**	**Regression (2)**	**Regression (3)**	**Regression (4)**	**Regression (5)**	**Regression (6)**
ln(Employee)	A	**-.305(.005)**	**-.309(.005)**	**-.310(.005)**	**-.310(.005)**	**-.311(.005)**	**-.312(.005)**
	M	***-.167(.008)***	***-.174(.009)***	***-.176(.009)***	***-.176(.009)***	***-.176(.009)***	***-.179(.009)***
	S	***-.413(.008)***	***-.411(.008)***	***-.411(.008)***	***-.412(.008)***	***-.412(.008)***	***-.413(.008)***
ln(Capital)	A	**.155(.004)**	---	---	---	---	---
	M	***.120(.006)***	---	---	---	---	---
	S	***.186(.006)***	---	---	---	---	---
ln(NIT)	A	---	**.119(.004)**	**.119(.004)**	**.119(.004)**	**.126(.004)**	**.131(.004)**
	M	---	***.098(.006)***	***.098(.006)***	***.097(.006)***	***.103(.006)***	***.107(.006)***
	S	---	***.129(.006)***	***.128(.006)***	***.128(.006)***	***.136(.006)***	***.141(.007)***
ln(IT)	A	---	**.041(.003)**	**.040(.003)**	**.040(.003)**	**.035(.003)**	**.034(.003)**
	M	---	***.030(.004)***	***.029(.004)***	***.029(.004)***	***.025(.004)***	***.024(.005)***
	S	---	***.054(.004)***	***.053(.004)***	***.053(.004)***	***.049(.004)***	***.049(.005)***
OC	A	---	---	**.025(.005)**	---	**.079(.047)**	---
	M	---	---	***.017(.007)***	---	*.055(.067)*	---
	S	---	---	***.037(.008)***	---	***.146(.073)***	---
OCP	A	---	---	---	**.014(.005)**	---	-.017(.049)
	M	---	---	---	***.019(.007)***	---	***-.119(.067)***
	S	---	---	---	***.018(.008)***	---	***.249(.077)***
OCS	A	---	---	---	-.006(.005)	---	**.283(.046)**
	M	---	---	---	*-.009(.007)*	---	***.301(.065)***
	S	---	---	---	*-.008(.008)*	---	***.143(.076)***
OCB	A	---	---	---	**.027(.005)**	---	**-.133(.051)**
	M	---	---	---	***.015(.007)***	---	*-.077(.070)*
	S	---	---	---	***.035(.009)***	---	*-.134(.085)*
OC*ln(NIT)	A	---	---	---	---	**-.015(.003)**	---
	M	---	---	---	---	***-.009(.005)***	---
	S	---	---	---	---	***-.017(.005)***	---

OC*ln(IT)	A	**---**	**---**	**---**	**---**	**.014(.003)**	**---**
	M	**---**	**---**	**---**	**---**	***.009(.005)***	**---**
	S	**---**	**---**	**---**	**---**	***.011(.004)***	**---**
OCP*ln(NIT)	A	**---**	**---**	**---**	**---**	**---**	-.002(.003)
	M	**---**	**---**	**---**	**---**	**---**	***.008(.005)***
	S	**---**	**---**	**---**	**---**	**---**	***-.015(.005)***
OCS*ln(NIT)	A	**---**	**---**	**---**	**---**	**---**	**-.024(.003)**
	M	**---**	**---**	**---**	**---**	**---**	***-.027(.005)***
	S	**---**	**---**	**---**	**---**	**---**	***-.013(.005)***
OCB*ln(NIT)	A	**---**	**---**	**---**	**---**	**---**	.005(.003)
	M	**---**	**---**	**---**	**---**	**---**	*.005(.005)*
	S	**---**	**---**	**---**	**---**	**---**	*.002(.006)*
OCP*ln(IT)	A	**---**	**---**	**---**	**---**	**---**	.005(.003)
	M	**---**	**---**	**---**	**---**	**---**	*.001(.005)*
	S	**---**	**---**	**---**	**---**	**---**	*.000(.005)*
OCS*ln(IT)	A	**---**	**---**	**---**	**---**	**---**	**.006(.003)**
	M	**---**	**---**	**---**	**---**	**---**	***.010(.005)***
	S	**---**	**---**	**---**	**---**	**---**	*.003(.005)*
OCB*ln(IT)	A	**---**	**---**	**---**	**---**	**---**	**.007(.003)**
	M	**---**	**---**	**---**	**---**	**---**	*.001(.005)*
	S	**---**	**---**	**---**	**---**	**---**	***.011(.005)***
Constant	A	**9.825(.498)**	**9.994(.495)**	**9.988(.495)**	**9.981(.494)**	**9.972(.495)**	**9.912(.494)**
	M	***9.799(.084)***	***9.882(.082)***	***9.889(.082)***	***9.892(.082)***	***9.863(.089)***	***9.813(.094)***
	S	***9.914(.219)***	***10.263(.214)***	***10.250(.214)***	***10.259(.214)***	***10.206(.216)***	***10.152(.218)***
Sectors (NACE 3-digit)		Yes	Yes	Yes	Yes	Yes	Yes
Years (1994-2006)		Yes	Yes	Yes	Yes	Yes	Yes
Model Diagnostics							
Observations	A	32619	32619	32619	32619	32619	32619
	M	*15613*	*15613*	*15613*	*15613*	*15613*	*15613*
	S	*13698*	*13698*	*13698*	*13698*	*13698*	*13698*

Log Likelihood	A	-14085	-14074	-14061	-14054	-14043	-14013
	M	*-5838*	*-5830*	*-5827*	*-5822*	*-5824*	*-5802*
	S	*-6385*	*-6400*	*-6389*	*-6386*	*-6383*	*-6374*
Pseudo-R^2	A	0.295	0.303	0.304	0.305	0.303	0.307
	M	*0.291*	*0.295*	*0.296*	*0.298*	*0.296*	*0.300*
	S	*0.275*	*0.288*	*0.288*	*0.289*	*0.288*	*0.289*
Model LR Test		0.000	0.000	0.000	0.000	0.000	0.000

Samples: A (All), M (Manufacturing), S (Services). OCP, OCS, and OCB reflect process, structure and boundary changes respectively. OC is an overall indicator of organizational change without respect to its type. Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) and robust standard errors (in parentheses) are shown. Likelihood Ratio test is conducted for all model parameters.

Model (3) is estimated using both maximum likelihood estimator (MLE) and generalized least squares (GLS) estimator with robust standard errors corrected for heteroskedasticity of error terms and within-cluster correlations.[98] Regression (1) is the simplest specification with only two inputs: labor and capital. In regression (2) we break down the firm's capital to IT and non-IT parts. In regression (3), we also account for the direct contribution of OC to TFP, which is, in regression (4), separated in different types of OC. Regressions (5) and (6) include interaction terms between the capital and OC variables. In all these specifications, industry and year dummies are included.

We obtain a pseudo-R^2 of around 0.3 which is pretty good taking into account the high level of firm heterogeneity in the sample. The constant term denotes TFP, whose level moves around the value of 10.0. As regression (3) reports, we attain output elasticities of 0.12, 0.04 and 0.025 for non-IT, IT and OC respectively. These elasticities are comparable with those reported in some of the earlier studies (in similar settings) (e.g. see Brynjolfsson and Hitt 1996, 2003 and Sircar and Choi 2009 for the US and Hempell 2005 for Germany). It means that doubling the stock of IT and non-IT capital leads to 4% and 12% growth in labor productivity, ceteris paribus. The capital and organizational change elasticities are significantly (at 1% and 5% respectively) larger for the services. We employ a standard Chow test for this purpose to compare regression coefficients between the manufacturing and services subsamples. The relevant statistic is calculated as (Brame et al. 1998):

$$Z = \frac{b_1 - b_2}{\sqrt{{\sigma_{b_1}}^2 + {\sigma_{b_2}}^2}} \qquad (14)$$

b_1 and b_2 are the estimated coefficients associated with the two groups and ${\sigma_{b_1}}^2$ and ${\sigma_{b_2}}^2$ are the coefficient variances.

Turning the above output elasticities into marginal products (MP) reveals interesting results. The MP of an input equals to the increase in output due to an increase of one

[98] To correct for heteroskedasticity of error terms, the Huber-White Sandwich method was employed (White 1980). To correct for intra-cluster dependencies (i.e. observations of a single firm over time), the method of Froot (1989) was used.

unit of input, keeping quantities of all other inputs constant. As the law of diminishing returns suggests MP should be zero at the optimum level of output (providing that markets are perfectly competitive). Negative values of MP mean overinvestment in an input while positive values indicate that more of an input can be used productively.

$$MP_i = \frac{Y}{I}\varepsilon_i \qquad (15)$$

MP_i is the marginal productivity of input i , Y and I are the levels of output (value-added) and input and ε_i is the output elasticity of i. We calculate the MP of IT and non-IT as 4.029 and 0.503 respectively for the whole sample. This is equivalent to a gross rate of return of investment of IT capital of as much as 8 times of that of conventional types of capital. If we carefully look at the sectors, the above figures equal to 3.072 and 0.196 for the manufacturing and 5.081 and 0.864 for the services. These findings clearly demonstrate high potential for investment in information technologies compared with conventional types of capital (especially in the services sectors). The scale elasticity in our models amounts to around 0.85, 0.95, and 0.77 for the whole, manufacturing and services sample respectively. This means that we face decreasing returns-to-scale and that these are more dominant in services than in manufacturing. A scale elasticity of 0.85 means that a firm can roughly gain 80% increase in output (value-added) by doubling its capital-labor input mix (in a cumulative sense). A notable observation is that the results are pretty robust with respect to model specification, in terms of the scale and output elasticities and other key model parameters.

Regression (4) reveals a significant contribution to TFP from process and boundary but not from structure changes. This can be explained as structural changes are typically more painful, path-breaking and demanding than process or boundary changes and affect a wider range of organizational entities and actors. They require much longer time (compared to an average of 1.5 years observable in the panel) to become productive. In regression (5), interactions between OC and both IT and non-IT capitals are taken into account. We observe a significantly negative interaction between OC and non-IT capital. Conventional capital, such as fixed properties, physical structures and mechanical equipment, are generally inflexible to changing environments, less adaptable to new uses and only suitable for a limited array of functionalities (in contrast to IT as a general purpose technology). For example, facing certain organizational transformations, a firm’s options to redeploy its old plants and factory machinery in a new setting (such as a decentralized/flat organization), in a new way (that supports lean production) or in a new environment (where more operations are contracted out) are limited. In contrast, IT resources exhibit great deals of redeployability, adaptability and flexibility and are designed to function in a broad range of applications. The significantly positive interaction between OC and IT capital points to these complementary effects. For an average manufacturing firm, the output elasticity of IT capital is increased from 0.025 to 0.034 (i.e. 36% growth) and that of regular capital is decreased from 0.103 to 0.094 (i.e. 9% decline) when capital investments are coupled with organizational changes. For an average service firm, the growth in IT elasticity due to organizational changes is 22.5% (from 0.049 to 0.060) and the decline in non-IT elasticity is 12.5% (from 0.136 to 0.119).

Extending the analysis to different types of OC reveals interesting results. As regression (6) shows, there is evidence in favor of complementarity between the computer assets of the firm and its boundary-spanning (OCB*ln(IT)) or structural changes (OCS*ln(IT)). The complementarities with boundary-spanning initiatives are stronger for services while those with structure-breaking efforts are more prominent in the manufacturing sector. Unexpectedly, the analysis does not reveal significant complementarities between IT and process changes of the firm (OCP*ln(IT)). As we turn to conventional capital, some degrees of substitutability with OC exist. In particular, structural changes and process innovations (only in services firms) partly replace for the existing fixed capital of the firm by making old structures obsolete and promoting advanced, less capital-intensive routines for handling operational and/or administrative tasks.

Table 4: Replication of Regression (5) with Transformed Variables

Labor Productivity (SD Units)	Sample	Regression (7)
Employee (Mean centered)	A	**-.556(.010)**
	M	***-.315(.015)***
	S	***-.738(.013)***
Non-IT Capital (Mean centered)	A	**.226(.007)**
	M	***.184(.011)***
	S	***.244(.011)***
IT Capital (SD units)	A	**.108(.009)**
	M	***.077(.013)***
	S	***.152(.013)***
OC (Dummy variable)	A	**-.263(.065)**
	M	***-.146(.088)***
	S	***-.193(.102)***

OC*Non-IT (Mean centered)	A	**-.027(.006)**
	M	***-.016(.008)***
	S	***-.030(.009)***
OC*IT (SD units)	A	**.045(.009)**
	M	***.027(.014)***
	S	***.035(.014)***
Constant	A	**18.743(.881)**
	M	***18.992(.090)***
	S	***18.632(.357)***
Sectors (NACE 3-digit)		Yes
Years (1994-2006)		Yes
Model Diagnostics		
Observations	A	32619
	M	*15613*
	S	*13698*
Log Likelihood	A	-33028
	M	*-14911*
	S	*-14355*
Pseudo-R^2	A	0.303
	M	*0.296*
	S	*0.288*
Model LR Test		0.000

Samples: A (All), M (Manufacturing), S (Services). Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) and robust standard errors (in parentheses) are shown. Likelihood Ratio test is conducted for all model parameters.

Table 4 demonstrates the strong evidence for complementarity between IT and OC from a different perspective. Regression (7) is a replication of regression (5) with some differences. Labor productivity and IT capital are expressed in units of standard deviation (SD). Other explanatory variables are mean-centered. These changes allow us to plot the relationship between labor productivity and IT capital (in relative scales) at the average level of other explanatory variables and evaluate the role of OC therein. Figure 3 shows an interesting phenomenon. At relatively low levels of IT capital, the productivity level is lower if firms conduct organizational changes. This relates to situations when a company invests heavily in certain organizational changes but not sufficiently in enabling technologies that can support those changes and resulting new structures/processes. Under these conditions, OC efforts are not fruitful as they impose substantial costs, make (some of) the old routines, structures or professions ineffective/obsolete and create chaos and conflict. However, the slopes of the lines in figure 3 are higher in case of parallel investments in technology and change. As a result, at moderate or high levels of IT capital, firms gain productivity improvements by engaging in OC. As the analysis shows, the break-even point occurs somewhere around 1 SD unit below the average level of IT capital in the respective industry of the firm. This in fact provides a good benchmark for companies to have an idea about the required level of technology investments to support their related change initiatives.

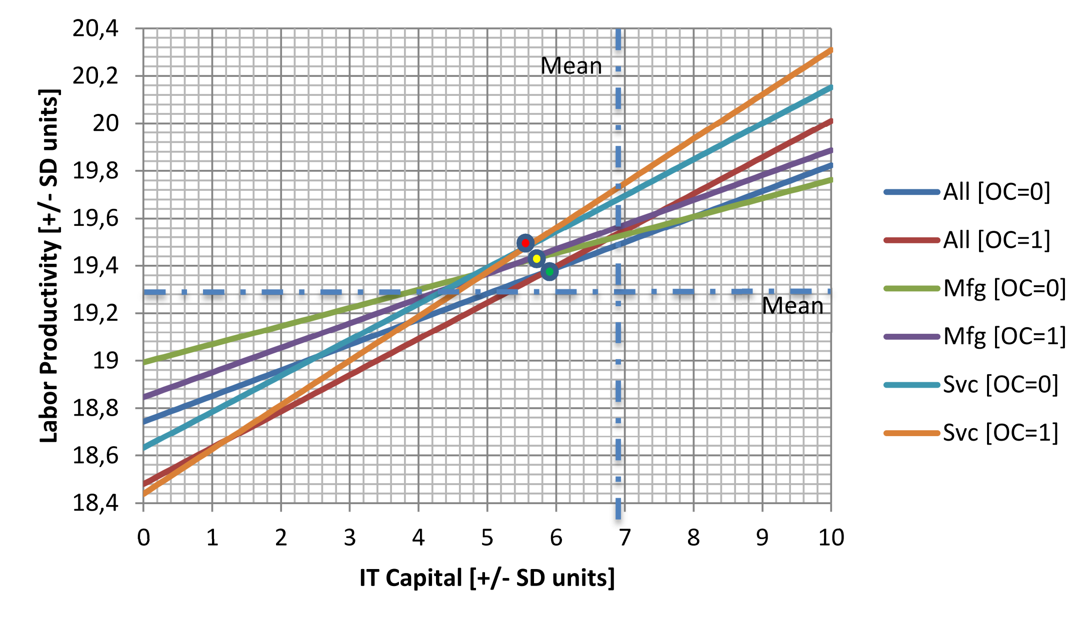

Figure 3: The Linear Relationship between Labor Productivity and IT Capital

Distinguishing between the sectors, manufacturing firms are more productive at low levels of IT while services are more productive at medium to high levels of IT. This highlights the increasingly important role of technology in services as evidenced by, among others, Brynjolfsson and Hitt (1995), Quinn et al. (1987) and Roach (1991). The line slopes (without respect to the presence or absence of OC) are higher in the services than in the manufacturing sector. One explanation is that services firms are in general more knowledge-intensive, heavily relying on their intangible assets such as internal human capital and external business interrelations with other firms. On the other hand, manufacturing firms rely more on fixed, physical assets for production.

The higher intensity and importance of knowledge in services makes computers a more important tool for processing of information, codifying, assimilating and creating knowledge and improving decision making. Besides, inter-organizational relationships seem to be a more vital element in the daily business of the services companies (compare the contribution of OCB to productivity between the services and manufacturing sample in regression (4)). In turn, IT systems play an essential role in facilitating inter-firm communication and coordination mechanisms and boosting customer satisfaction. Another explanation for why the (direct and complementary) effects of IT are stronger for the services sector relates to the mix of labor. Compared to manufacturing firms, services firms have on average a higher proportion of educated and technologically proficient workers, who are more likely to possess the required capability and specialized knowledge of how to properly use the advanced IT systems to improve organizational productivity (Melville et al. 2007). Previous research also highlights the importance of proper alignment between IT and the labor mix of the firm for generating productivity gains (Francalanci and Galal 1998). The third explanation attributes the difference in IT payoffs between the services and manufacturing sector to the nature of core value-adding activities and the role of innovation therein. The services sector mainly produces intangible outputs and can thus benefit more from the digital options enabled by IT. In this segment of the economy, business processes deal more with immaterial goods such as information and knowledge and less with physical goods. This provides more opportunities for IT to streamline and renovate the business processes of the firm. On the other hand, manufacturing firms rely more on traditional R&D-based innovation and face more limits in digitizing their bottom line activities. Furthermore, the common use of IT in manufacturing firms is to automate existing routines while real benefits lie on redesigning and restructuring business processes and transforming the organization (Hammer 1990). These transformation are though (usually) painful and complex, obscuring the actual productive effect of the underlying IT.

6.2. Systems approach

Table 5 reports the results of estimating model (4).

Table 5: Regression Results for Model (4)
Systems Approach: Maximum Likelihood Estimation

Log (Labor Productivity)	Sample	Fraction (% Sample)	Regression (8)	Regression (9)
ln(Employee)	A	---	**-.310(.005)**	**-.311(.005)**
	M	---	***-.175(.009)***	***-.176(.009)***
	S	---	***-.412(.008)***	***-.413(.008)***
ln(NIT)	A	---	**.117(.004)**	**.117(.004)**
	M	---	***.093(.006)***	***.093(.006)***
	S	---	***.128(.006)***	***.128(.006)***
ln(IT)	A	---	**.043(.003)**	**.043(.003)**
	M	---	***.033(.004)***	***.033(.004)***
	S	---	***.055(.004)***	***.055(.004)***
Cluster (00)	A	38.4	Reference	---
	M	*35.2*	Category	---
	S	*39.6*		---
Cluster (01)	A	21.9	**-.030(.008)**	---
	M	*18.1*	***-.026(.011)***	---
	S	*24.5*	***-.032(.012)***	---
Cluster (10)	A	25.4	.008(.006)	---
	M	*31.4*	*.012(.008)*	---
	S	*21.4*	*.011(.010)*	---
Cluster (11)	A	14.4	**.023(.009)**	---
	M	*15.3*	*.002(.012)*	---
	S	*14.5*	***.041(.014)***	---
Cluster (0000)	A	22.8	---	Reference
	M	*18.9*	---	Category
	S	*25.2*	---	
Cluster (0001)	A	13.0	---	**-.032(.009)**
	M	*9.8*	---	***-.024(.014)***
	S	*15.2*	---	***-.042(.014)***
Cluster (0010)	A	2.5	---	**.052(.014)**
	M	*2.7*	---	***.054(.019)***
	S	*2.4*	---	*.030(.023)*
Cluster (0011)	A	1.8	---	.004(.017)
	M	*1.7*	---	*-.022(.024)*
	S	*1.8*	---	*.013(.027)*
Cluster (0100)	A	6.3	---	-.002(.010)
	M	*5.2*	---	*-.005(.015)*
	S	*6.5*	---	***-.035(.015)***
Cluster (0101)	A	3.3	---	-.015(.014)
	M	*2.7*	---	*-.011(.021)*
	S	*3.8*	---	*-.033(.021)*
Cluster (0110)	A	5.2	---	.013(.011)
	M	*4.9*	---	*.000(.016)*
	S	*5.4*	---	*.012(.017)*
Cluster (01110	A	2.9	---	.017(.014)
	M	*2.8*	---	***-.041(.020)***
	S	*3.2*	---	***.053(.022)***

Cluster (1000)	A	6.7	---	.011(.010)
	M	*8.4*	---	*.007(.013)*
	S	*5.5*	---	*.018(.016)*
Cluster (1001)	A	3.8	---	-.016(.013)
	M	*3.9*	---	*-.016(.018)*
	S	*3.8*	---	*-.019(.020)*
Cluster (1010)	A	3.7	---	**.053(.012)**
	M	*5.4*	---	***.041(.015)***
	S	*2.4*	---	***.042(.023)***
Cluster (1011)	A	2.4	---	**.058(.015)**
	M	*2.9*	---	***.044(.020)***
	S	*2.1*	---	***.049(.026)***
Cluster (1100)	A	5.6	---	.004(.011)
	M	*6.6*	---	*.013(.014)*
	S	*5.1*	---	*.002(.017)*
Cluster (1101)	A	2.9	---	**.033(.014)**
	M	*3.1*	---	*.021(.019)*
	S	*3.0*	---	*.032(.022)*
Cluster (1110)	A	10.9	---	.008(.009)
	M	14.5	---	*.019(.012)*
	S	8.5	---	*.001(.015)*
Cluster (1111)	A	6.1	---	**.027(.011)**
	M	*6.5*	---	*.011(.016)*
	S	*6.1*	---	***.035(.018)***
Sectors		---		
(NACE 3-digit)		---	Yes	Yes

Years		---		
(1994-2006)		---	Yes	Yes

Model Diagnostics				
Observations	A	32619	32619	32619
	M	*15613*	*15613*	*15613*
	S	*13698*	*13698*	*13698*
Log Likelihood	A	---	-14047	-14028
	M	---	*-5824*	*-5811*
	S	---	*-6379*	*-6370*
Pseudo-R^2	A	---	0.303	0.305
	M	---	*0.295*	*0.297*
	S	---	*0.288*	*0.289*

Model LR Test		---	0.000	0.000

Samples: A (All), M (Manufacturing), S (Services). Cluster (abcd) denotes S_{abcd} in model (4) where *a*, *b*, *c*, and *d* indicate process OC, structure OC, boundary OC, and high IT intensity respectively. Similarly, cluster (xy) is constructed based on an overall OC indicator where *x* and *y* indicate organizational change and high IT intensity respectively. Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) and robust standard errors (in parentheses) are shown. Likelihood Ratio test is conducted for all model parameters.

We estimate model (4) using maximum likelihood estimator while the constant term is suppressed.[99] The obtained state coefficients (i.e. γ_{abcd}) are then compared against the set of conditions in (6) to determine complementary/substitutable practices. The proper method for the joint test of regression coefficients under multiple inequality constraints (and the corresponding Wald criteria) is introduced in Gourieroux et al. (1982), Kodde and Palm (1986), and Wolak (1989). On the basis of this method, we wrote a computer program in MATLAB that performs the Wald tests for us.[100]

The third column shows the relative distribution of different cluster types in the sample(s). In case of an overall OC indicator, it is more common among services firms to have overinvestments in IT (while no OC is accompanied) while the reverse (i.e. OC coupled with underinvestments in IT) is more recurrent among the manufacturing firms. Table 5 shows that the output elasticities of capital and labor are perfectly comparable to those produced by the interaction approach. Regression (8) includes three clusters whose effects on labor productivity are reported in reference to the base cluster. The base cluster refers to all those firms with no OC and a low level of IT intensity (i.e. below their industry average). The results endorse the idea of complementarity between IT and OC. Those firms that heavily invest in IT but fail to accommodate required organizational changes, face productivity decline. This finding reflects the idea of Milgrom and Roberts (1995) that partial or piecemeal implementation of organizational change might lead to negative outcomes. The only group of firms that manage to acquire productivity growth are those that jointly invest in both IT and OC (the effect is positive but insignificant for the manufacturing). Distinguishing between different types of OC, regression (9) shows that among the clusters with a high IT intensity only those which combine technology investments with a proper mix of organizational changes are contributing to firm productivity. When IT is not accompanied by OC, we observe a significantly negative effect on productivity (cluster (0001)). IT combined with all or certain pairs of OC variables demonstrates significantly positive contribution to productivity as well (clusters (1111), (1011), and (1101)). The effects are always significantly stronger in services. In case of the combination of high IT intensity and structure and boundary

[99] This is necessary to generate estimates for all the clusters in model (4).

[100] See Mohnen and Roller (2005) for an application of this method. The program can be made available upon request from the authors.

changes together, the effect is significantly negative in the manufacturing sector while positive in the services sector (cluster (0111)). Two surprising findings are the significantly positive contribution of joint process and boundary changes at low levels of IT (impact of cluster (1010)) and that of boundary changes alone in the manufacturing sector (cluster (0010)). These corroborate the importance of boundary-spanning, inter-firm developments to productivity of the firm, even when these developments are not necessarily IT-based.

Table 6: Complementarity and Substitutability Tests based on the Supermodularity Theory

	Practices / Sample	OC-IT	OCP-IT	OCS-IT	OCB-IT	OCP-OCS	OCP-OCB	OCS-OCB
H0: Complementarity	**A**	0.000	0.000	0.000	0.901	3.308	3.591	20.514
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	*(Indecisive)*	***(Reject H0)***
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	*(Indecisive)*	***(Reject H0)***
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Reject H0)***
	M	1.517	0.000	0.222	5.020	0.178	0.666	11.091
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Reject H0)***
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Reject H0)***
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*
	S	0.000	0.061	0.000	0.000	2.209	9.128	3.772
	10%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	***(Reject H0)***	*(Indecisive)*
	5%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Reject H0)***	*(Indecisive)*
	1%	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***
H0: Substitutability	**A**	24.259	9.062	13.930	2.957	2.468	2.622	0.000
	10%	***(Reject H0)***	***(Reject H0)***	***(Reject H0)***	*(Indecisive)*	*(Indecisive)*	*(Indecisive)*	***(Accept H0)***
	5%	***(Reject H0)***	***(Reject H0)***	***(Reject H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	1%	***(Reject H0)***	*(Indecisive)*	***(Reject H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	M	0.000	9.204	2.998	0.908	2.374	3.687	0.000
	10%	***(Accept H0)***	***(Reject H0)***	*(Indecisive)*	***(Accept H0)***	*(Indecisive)*	*(Indecisive)*	***(Accept H0)***
	5%	***(Accept H0)***	***(Reject H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***
	1%	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	S	18.218	1.139	10.315	3.383	2.321	0.126	1.044
	10%	***(Reject H0)***	***(Accept H0)***	***(Reject H0)***	*(Indecisive)*	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***
	5%	***(Reject H0)***	***(Accept H0)***	***(Reject H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***
	1%	***(Reject H0)***	***(Accept H0)***	*(Indecisive)*	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***	***(Accept H0)***

Samples: A (All), M (Manufacturing), S (Services). Wald test of inequality restrictions based on MLE estimates. Lower bound and upper bound critical values based on the Kodde-Palm method at different significance levels are:
10%: LB= 1.642, UB= 7.094; 5%: LB= 2.706, UB= 8.761; 1%: LB= 5.412; UB= 12.483.

The next step to complete the systems approach is to apply appropriate Wald tests to analytically examine the clustering patterns among different pairs of the practices under study. Table 6 reports the results of the tests against two alternative hypotheses. In the upper part of the table, the null hypothesis implies complementarity while in the lower part, it implies substitutability of practices. When both hypotheses are simultaneously accepted or rejected, the systems approach cannot provide a decisive answer with respect to the type of interaction between the pairs. The findings clearly indicate complementarity between IT and OCS in services, complementarity between IT and OCP in manufacturing, substitutability between OCS and OCB in manufacturing and substitutability between OCP and OCB in services. In case of interactions between IT and OCB or between OCS and OCP no clear-cut answer can be given based on the test results.

Complementarity between IT and OCS or OCP was expected. However, the lack of complementarity between IT and OCB is surprising. Apparently, boundary changes although an important contributor to output, do not necessarily need to be IT-enabled or IT-supported. This highlights the role of social and organizational elements when external connections of the firm are at stake; for inter-firm networking, there are more to consider than simply the technological aspects of the network. Furthermore, we observe patterns of substitutability between OCS and OCB and between OCP and OCB. For the first case, a relevant example is the decision of a firm under supply constraints to rely more on outsourcing/sub-contracting rather than changing its strategy and implementing relevant structural mechanisms to handle an exceeding demand in-house. As to the second case, we can mention the introduction of a knowledge management policy/system that partly relieves the firm from further reliance on external parties to acquire knowledge (that can simply be accessed within the boundaries of the firm itself, providing that it is managed properly).

6.3. Two-stage approach

We developed the two-stage method in response to endogeneity concerns in complementarity studies of IT-productivity. In the first stage and based on model (8), OC variables are estimated using a multivariate probit system of equations that accounts for inter-equation correlations. The system can be estimated by simulated maximum likelihood using the Geweke-Hajivassiliou-Keane (GHK) simulator (Train 2003).[101] Table 7 describes the results of this stage.[102]

Table 7: Regression Results for Model (7): ML Estimation based on GHK Simulator

1st-stage Model Probit/Triprobit	Sample	OC Regression (10)	OCS Regression (11)	OCP Regression (12)	OCB Regression (13)
ln(Employee)	A	**.476(.022)**	**.237(.008)**	**.294(.008)**	**.278(.007)**
	M	***.667(.037)***	***.301(.012)***	***.335(.012)***	***.353(.011)***
	S	***.326(.031)***	***.174(.011)***	***.245(.011)***	***.189(.010)***
ln(NIT)	A	**.098(.018)**	.007(.007)	**.055(.007)**	**.021(.007)**
	M	***.127(.029)***	*.007(.011)*	***.105(.011)***	***.044(.010)***
	S	***.069(.025)***	***-.019(.010)***	*.008(.011)*	*.000(.011)*
ln(IT)	A	**.109(.013)**	**.106(.006)**	**.083(.007)**	**.107(.006)**
	M	***.137(.020)***	***.118(.010)***	***.062(.010)***	***.140(.011)***
	S	***.085(.019)***	***.099(.009)***	***.088(.010)***	***.086(.009)***
Sectors (NACE 3-digit)	A, *M*, *S*	Yes	Yes	Yes	Yes
Years (1994-2006)	A, *M*, *S*	Yes	Yes	Yes	Yes
Model Diagnostics					
Observations	A	32619	32619		
	M	*15613*	*15613*		
	S	*13698*	*13698*		
Log Likelihood	A	-16081	-55521		
	M	*-7783*	*-27611*		
	S	*-6705*	*-22704*		
Rho (ρ)	A	ρ=0.678	ρ12=.356, ρ13=.443, ρ23=.643		
	M	*ρ=0.697*	*ρ12=.331, ρ13=.409, ρ23=.543*		
	S	*ρ=0.683*	*ρ12=.389, ρ13=.486, ρ23=.700*		
Model LR Test		0.000	0.000		

Samples: A (All), M (Manufacturing), S (Services). Estimations are based on a Triprobit system of simultaneous equations for OCS, OCP and OCB. In case of a single OC indicator, panel Tobit is used. Significant estimates (at least at 10%) and robust standard errors (in parentheses) are shown. Likelihood Ratio test is conducted for all model parameters.

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[101] Polder et al. (2010) used a similar approach in estimating their pseudo-CDM innovation functions. For relevant mathematical treatments, see their Appendix A.

[102] Due to space constraints, we only report the regression coefficients. Calculating the marginal effects (and their standard errors) in a triprobit system of equations follows a specific bootstrapping algorithm. The marginal effects lead us to exactly similar conclusions. The appropriate algorithm to calculate the marginal effects and the corresponding results are available upon request.

We see that IT capital significantly explains part of the variation in the probability of conducting organizational changes among firms. Putting it differently, firms with larger stocks of IT endowments are more likely to undergo organizational changes. The effect is also persistent over different categories of OC. The significant enabling effect of non-IT is in general weaker and even missing in some cases (especially in services industries). An interesting finding is the significantly negative impact of conventional capital on the probability of structural changes (in the services sector). We reached a similar conclusion earlier in section 6.1 (see the significantly negative interaction between NIT and OCS in regression (6)). Firms with extensive stocks of fixed assets face greater degrees of structural inflexibility, immobility of assets and internal resistances which discourages or hampers their structural change initiatives. These firms apparently do not face such severe inertia for changing their business processes or boundaries. Our findings also indicate that larger companies are more inclined to undergo organizational changes, as revealed by the positive coefficient of *ln(Employee)*.

Table 8: Regression Results for Model (9), Two-stage Approach: Maximum Likelihood based on Olley & Pakes Algorithm

2nd-stage Model MLE	Sample	Regression (14)	Regression (15)	Regression (16)	Regression (17)
Dependent Variable = log (Labor Productivity)					
ln(Employee)	A	**-.278(.006)**	**-.284(.006)**	**-.383(.009)**	**-.337(.011)**
	M	***-.093(.010)***	***-.104(.010)***	***-.240(.023)***	***-.275(.029)***
	S	***-.399(.008)***	***-.392(.008)***	***-.447(.012)***	***-.434(.015)***
ln(NIT)	A	**.130(.004)**	**.127(.004)**	**.114(.005)**	.005(.013)
	M	***.124(.006)***	***.123(.006)***	***.116(.023)***	*.108(.033)*
	S	***.134(.006)***	***.142(.006)***	***.125(.006)***	*.021(.018)*
ln(IT)	A	**.053(.002)**	**.071(.003)**	**-.013(.006)**	**.020(.010)**
	M	***.057(.004)***	***.062(.004)***	***-.022(.012)***	*-.041(.025)*
	S	***.060(.004)***	***.074(.005)***	***.020(.008)***	*.012(.012)*
1st-stage Model = Probit					
Pr(1)	A	**-.115(.009)**	**-.391(.039)**		
	M	***-.202(.011)***	***-.099(.051)***		
	S	***-.068(.017)***	***-.635(.066)***		
Pr(1)*ln(NIT)	A	---	**-.004(.002)**		
	M	---	***-.023(.003)***		
	S	---	***.026(.004)***		
P(1)*ln(IT)	A	---	.029(.002)		
	M	---	***.023(.003)***		
	S	---	***.016(.004)***		

		1st-stage Model = Triprobit	
Pr(0,0,1)	A	**-.887(.343)**	**9.881(2.228)**
	M	***-1.017(.538)***	*1.268(3.376)*
	S	***1.001(.550)***	*4.908(3.544)*
Pr(0,1,0)	A	**1.244(.229)**	**2.118(.954)**
	M	***1.818(.311)***	***5.403(1.464)***
	S	*.292(.527)*	*.517(1.945)*
Pr(0,1,1)	A	**1.883(.312)**	**-2.029(1.155)**
	M	*.853(.602)*	*.836(1.638)*
	S	***.788(.419)***	*-3.836(2.367)*
Pr(1,0,0)	A	-.016(.329)	**-16.677(1.644)**
	M	*-.715(.613)*	***-9.914(2.320)***
	S	***-1.218(.562)***	***-12.134(3.040)***
Pr(1,0,1)	A	**2.443(.201)**	-.044(1.167)
	M	***.904(.473)***	*-6.784(1.796)*
	S	***3.146(.421)***	***4.917(2.945)***
Pr(1,1,0)	A	**-1.922(.265)**	**-4.418(1.043)**
	M	*-.802(.520)*	***6.422(1.558)***
	S	***-1.924(.343)***	***-2.973(1.522)***
Pr(1,1,1)	A	**1.735(.157)**	**-1.471(.513)**
	M	***1.037(.365)***	*.341(.882)*
	S	***1.691(.253)***	*-.470(.885)*
Pr(0,0,1)*ln(NIT)	A	---	**-1.017(.118)**
	M	---	*-.151(.167)*
	S	---	***-.356(.190)***
Pr(0,1,0)*ln(NIT)	A	---	-.076(.051)
	M	---	*-.591(.088)*
	S	---	***-.206(.105)***
Pr(0,1,1)*ln(NIT)	A	---	**.465(.075)**
	M	---	*.-151(.112)*
	S	---	***.640(.152)***
Pr(1,0,0)*ln(NIT)	A	---	**1.383(.088)**
	M	---	***.623(.127)***
	S	---	***.818(.156)***
Pr(1,0,1)*ln(NIT)	A	---	.114(.076)
	M	---	*.464(.098)*
	S	---	*.025(.203)*
Pr(1,1,0)*ln(NIT)	A	---	**-.237(.061)**
	M	---	***-.240(.086)***
	S	---	*.072(.102)*
Pr(1,1,1)*ln(NIT)	A	---	**.148(.025)**
	M	---	*.045(.040)*
	S	---	*-.030(.044)*
Pr(0,0,1)*ln(IT)	A	---	**.531(.121)**
	M	---	*.313(.193)*
	S	---	*.090(.198)*
Pr(0,1,0)*ln(IT)	A	---	-.033(.061)
	M	---	*.168(.110)*
	S	---	*.159(.124)*
Pr(0,1,1)*ln(IT)	A	---	**-.197(.093)**
	M	---	*.194(.152)*
	S	---	***-.292(.166)***

Pr(1,0,0)*ln(IT)	A			---	**-.423(.083)**
	M			---	*-.054(.120)*
	S			---	*.012(.176)*
Pr(1,0,1)*ln(IT)	A			---	-.063(.088)
	M			---	*-.146(.129)*
	S			---	*-.235(.225)*
Pr(1,1,0)*ln(IT)	A			---	**.465(.073)**
	M			---	*-.119(.105)*
	S			---	*-.039(.126)*
Pr(1,1,1)*ln(IT)	A			---	-.002(.024)
	M			---	*.000(.037)*
	S			---	***.181(.049)***
Sectors (NACE 3-digit)		Yes	Yes	Yes	Yes
Years (1994-2006)		Yes	Yes	Yes	Yes
Model Diagnostics					
Observations	A	32619	32619	32619	32619
	M	*15613*	*15613*	*15613*	*15613*
	S	*13698*	*13698*	*13698*	*13698*
Log Likelihood	A	-14074	-13985	-13811	-13488
	M	*-5830*	*-5798*	*-5773*	*-5531*
	S	*-6400*	*-6360*	*-6356*	*-6294*
Pseudo-R^2	A	0.303	0.307	0.318	0.339
	M	*0.295*	*0.290*	*0.309*	*0.343*
	S	*0.288*	*0.293*	*0.291*	*0.301*
Model LR Test		0.000	0.000	0.000	0.000

Samples: A (All), M (Manufacturing), S (Services). Pr(w) indicates the predicted propensity of organizational change used in model (10). Pr(x,y,z) denotes the predicted propensity associated with the (x,y,z) configuration as in model (9) where x, y, and z indicate process OC, structure OC, and boundary OC respectively. Pr(0) and Pr(0,0,0) are the reference categories. Estimations are based on MLE for unbalanced panels. Significant estimates (at least at 10%) and robust standard errors (in parentheses) are shown. Likelihood Ratio test is conducted for all model parameters.

The second stage includes estimating model (9) and (10) based on the predicted propensities (to change) from the first stage. [103] Model (9) is estimated using the estimation algorithm by Olley and Pakes (1996) in order to control for the potential endogeneity of capital and labor (see Yasar 2008 for the corresponding STATA package). In model (10), instead of three OC measures we use an overall OC indicator.

[103] We wrote a MATLAB computer program for this purpose to calculate propensities and marginal effects. The program can be made available upon request from the authors.

Table 8 reports the results. In regression (14) and (15), the elasticity of non-IT and especially IT are greater than those reported in regression (3) and (5). As we turn to interactions of OC with capital stocks, we observe significantly negative interactions with non-IT (except for services) and positive interactions with IT. This implies that even when endogeneity of OC is corrected for, computer and ordinary capital develop different patterns of interaction with OC efforts of the firm (at least, in manufacturing industries). A related observation is the negative contribution of OC to labor productivity in regression (14). When interactions are included in the model, this negative contribution is radically intensified for the services while it becomes insignificant for the manufacturing.

A first finding from regression (16) is that IT elasticity turns to a negative value in manufacturing firms if the endogeneity of OC (and thereby the enabling impact of IT on OC) is accounted for. In the services sector, the elasticity of IT with respect to output keeps its positive sign but experiences a drastic reduction in magnitude of the coefficient (compare the elasticities obtained from the two-stage method with those from the interaction method). It seems that in manufacturing, IT contributes to productivity insofar as it enables the firm to change its internal structures, production processes and/or external boundaries. Beyond these change-stimulating effects, IT does not show productive effects in manufacturing. In services, however, IT effects are not limited to IT-induced change initiatives; only part of the productive impact of IT is transformed to the organization through the change channels. In line with our earlier findings, such an interaction that exists between IT and OC does not hold for non-IT. As a result, the output elasticity of NIT does not experience a tragic decline when endogeneity is accounted for through inclusion of OC propensities.

Among different configurations of change practices, structure changes alone (Pr(0,1,0)), combination of process and boundary changes (Pr(1,0,1)), and all changes together (Pr(1,1,1)) reveal a significantly positive impact on labor productivity in the manufacturing sector. In the service sector, boundary changes alone (Pr(0,0,1)), combinations of structure and boundary changes (Pr(0,1,1)) or process and boundary changes (Pr(1,0,1)), and all changes together (Pr(1,1,1)) exert a direct positive effect on labor productivity. In opposite, boundary changes alone (Pr(0,0,1)) in the manufacturing and process changes alone (Pr(1,0,0)) or their combination with structure changes (Pr(1,1,0)) in the services show a significantly negative effect. Apparently, different change configurations behave differently in the manufacturing and services sector with the exception of process and boundary changes (with or without structure changes) that produce significant positive effects on TFP.

Focusing on the interactions between capital inputs and different combinations of OC types, the results substantiate some of our previous findings. As in regression (17), conventional capital exhibits a substitutability relationship with most of OC arrangements, except when only process changes are present (Pr(1,0,0)*ln(NIT)) or when structure and boundary changes happen in combination (Pr(0,1,1)*ln(NIT)) (only in services). In other instances, the interactions are either negative or insignificant. In services, IT capital exhibits complementarity with a full combination of OCP, OCS and OCB (Pr(1,1,1)*ln(IT)) while shows substitutability with a combination of structure and boundary changes (Pr(0,1,1)*ln(IT)). In manufacturing, we cannot observe any significant interaction between IT and OC combinations.

In figure 4, we plot the output elasticity of IT against that of non-IT for the whole sample based on the results of regression (17) and depending on different groupings of OC variables. Only significant estimates (at least at 10%) are included in the graph. Apparently, in two different change situations the output elasticity of IT improves (in reference to the no-change situation): boundary changes or the combination of structure and process changes (see symbols (1) and (2) in the graph). This demonstrates complementary effects. Similarly, under two change conditions, the output elasticity of non-IT enhances: process changes or the combination of structure and boundary changes (see symbols (3) and (4) in the graph). It is remarkable that in the above situations, an improvement in the output elasticity of a type of capital comes at the expense of a reduction in the elasticity of the other type of capital. This sheds light on the fundamental differences between IT and non-IT capital in terms of how they behave/react under change conditions and interact with change initiatives of the firm.

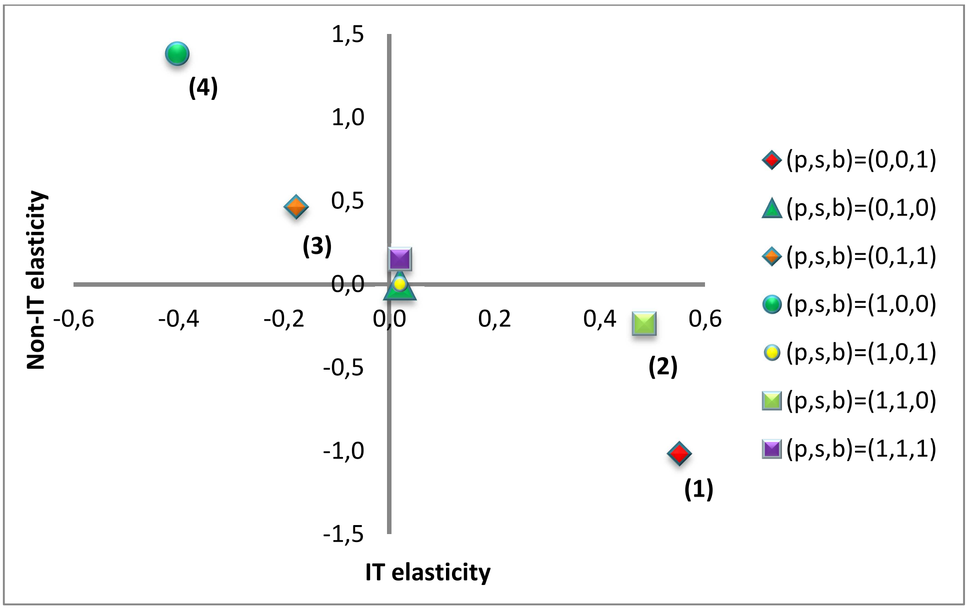

Figure 4: IT and Non-IT Elasticity based on Different Clusters of OC Constructs

There are considerable differences between the results of the two-stage method and those of the interaction and systems approach, specifically when IT capital is concerned. The pattern of complementarities and clustering is less straightforward when we explicitly account for endogeneity of organizational change in our estimations. This could mean that part of the productivity effects attributed to IT itself are indeed contributions from other practices and policies of the firm that are provoked by IT. This highlights the importance of mediating factors when examining IT payoffs. Our recent research recommends this line of reasoning by showing that the performance effects of IT significantly diminish or even disappear in the empirical models when IT-enabled product and process innovation are explicitly controlled for (Zand and van Beers 2010). The two-stage method allowed us to gain more insights into the underlying mechanisms leading to create business value from IT investments. Its findings underscore the salience of incorporation of endogeneity issues in the existing IT business value studies and warrants special attention from scholars in future empirical research in the field.

7. Discussion of the Results

7.1. Hypothesis 1: IT-OCP complementarity

Hypothesis H1 proposes a positive interaction between IT resources and process changes of the firm. The results of regression (6) in Table 3 show that we have to reject this hypothesis as the interaction between OCP and ln(IT) is found to be positive but statistically insignificant. Regression (9) in Table 5 does not support H1 as well since a negative (still insignificant) impact from cluster (1001) on labor productivity is observed. However, in the same regression, process changes become effective if they are simultaneously combined with IT and other types of organizational change. Combinations of process and boundary changes or process and structure changes together with high IT intensity lead to a positive contribution to productivity (cluster (1011) and (1101) respectively). The combination of all three types of change plus high IT intensity also leads to a positive impact; in case of manufacturing, though, the effect is insignificant. An explanation for this finding is that manufacturing firms rely more than services firms in their daily operations on physical materials, mechanical machineries and building structures, which are more physically bounded and rigid compared to human and knowledge capital. This makes the situation when all the aspects of the firm simultaneously change a relatively chaotic and less manageable and thus unfavorable situation for manufacturing firms.

The formal tests of complementarity and substitutability, although look at the pairwise relationships only, confirm significant complementarity between IT and OCP in the whole as well as the manufacturing sample. The results of the two-stage approach resemble these findings too. As regression (16) in Table 8 reports, IT-enabled process changes only lead to a positive productivity impact if they go together with boundary or boundary and structure changes (Pr(1,0,1) and Pr(1,1,1)); the effect of process changes alone is negative, especially in case of services (Pr(1,0,0)). If the interactions with the change initiatives are taken into account, as in regression (17), we observe a significantly positive interaction only when process changes are joined with structure changes (Pr(1,1,0)*ln(IT)) or with both structure and boundary changes at the same time (Pr(1,1,1)*ln(IT)) (only for services).

Putting all the findings together, we conclude that hypothesis H1 is rejected in its simplest form when process changes are the only type of occurring change in the firm. If process changes are combined with other types of change, the complementarities with IT become observable and hence the hypothesis is not anymore rejected. It is also remarkable that the act of combining process changes with other types of change in order to reveal positive interactions with IT, is a necessary condition more in case of the services than the manufacturing sector. One possible explanation for this finding might be related to how the OCP variable was constructed in this research. The variable has two dimensions: (1) changes in the production technologies or operational activities of the firm and (2) changes in the knowledge management policy or implementation of the firm. By definition, the first dimension is more relevant for the manufacturing sector. With regard to the second dimension, the data shows that knowledge management systems are by far more common in the services than manufacturing firms and thus the second dimension is a better distinguishing factor (between change adopters and non-adopters) in the manufacturing sector. Nevertheless, future research is necessary to shed more light on this issue.

7.2. Hypothesis 2: IT-OCS complementarity

Based on the results of the interaction method in regression (6), structural changes develop complementarity with IT capital of the firm (the effect is positive but insignificant in services). The clustering approach in regression (9) goes beyond simple pair-wise interactions and looks at more complex change configurations. There, we can observe that structural changes accompanied by high levels of IT intensity do not lead to a significantly positive impact unless they are combined with boundary changes (cluster (0111), for services), process changes (cluster (1101), the whole sample only), or process and boundary changes together (cluster (1111), for services). This finding is in line with our conclusion above that different dimensions of organizational change seem not to act independently but rather in coherent and connected sets of specific practices. An interesting finding in Table 5 is the significantly negative effect on productivity from the combination of structure and boundary changes and high IT (cluster (0111)) in the manufacturing sector. Exactly the same conclusion, yet from another perspective, can be made when one looks at the OCS-OCB column in Table 6. OCS and OCB demonstrate a substitutability relationship among the manufacturing (and not the services) firms.

Results of the formal tests following the systems approach in Table 6 lend support to a complementarity relationship between OCS and IT; distinguishing between the services and manufacturing sectors, the evidence for complementarity is sharper for the services. The two-stage approach in Table 8 reveals that IT-enabled structural changes contribute to productivity growth either alone (Pr(0,1,0), for manufacturing) or when they are combined with boundary changes (Pr(0,1,1), for services) or boundary and process changes (Pr(1,1,1), both manufacturing and services). As to the interactions in regression (17), no clear-cut conclusion can be derived. In the manufacturing sector, we cannot observe any significant interactions between IT and structure changes when the change-inducing effects of IT have already been accounted for. In services, we observe a negative interaction when structure and boundary changes coexist (Pr(0,1,1)*ln(IT)) and a positive one when process, structure and boundary changes occur simultaneously (Pr(1,1,1)*ln(IT)).

Overall, our findings support hypothesis H2. If structural changes are considered in isolation, the evidence is stronger for manufacturing and when they are analyzed collectively with other types of OC or when the enabling role of IT is explicitly taken into account, the evidence is more conclusive for services. Two possible explanations might be valid. First, major structural changes in the manufacturing sector seem to have a strong technological driver behind them while in the services sector other factors such as market or competitive forces seem to drive structural changes. Second, the less flexible and adaptable structure of manufacturing firms makes it harder for them to combine structural changes with other types of change and achieve performance improvements in the short term. Manufacturing firms might need much more time to be able to translate their complex change efforts to positive productivity effects. We leave this issue open for future investigation.

7.3. Hypothesis 3: IT-OCB complementarity

Hypothesis H3 extends the analysis of IT-OC interactions to external firm boundaries where issues such as inter-firm partnering, service outsourcing and marketing innovation play a role. Pair-wise interactions in regression (6) corroborate complementarity between IT and OCB in the whole sample as well as the services subsample of it. Looking at Table (5) tells us a similar story from another perspective. High investments in IT and changes in the boundary of the firm lead to productivity improvement when, in addition to boundary OC, structure changes are present (cluster (0111), for services), process changes are present (cluster (1011)) or both structure and process changes are present (cluster (1111), for services). However, the interactions between IT and OCB do not meet all the inequality restrictions required for a decisive test result in Table 6 (the complementarity evidence remains stronger for the services).

The findings in Table 8 also favor the IT-OCB complementarity. IT-enabled boundary changes lead to productivity growth in services without respect to the presence or absence of other change practices (Pr(0,0,1), Pr(0,1,1), Pr(1,0,1), and Pr(1,1,1)). In manufacturing, though, boundary changes need to be combined with either process or process and structure changes (Pr(1,0,1) and Pr(1,1,1), respectively); under other circumstances, the contribution of boundary changes to productivity is insignificant or negative (Pr(0,1,1) and Pr(0,0,1), respectively). Interactions with IT capital in regression (17) produce interesting results. Boundary changes increase the output elasticity of IT only when they occur alone or in combination with both process and structure changes (only services); when they are joined with either of process or structure changes, insignificant or negative effect on IT elasticity is observed (Pr(1,0,1)*ln(IT) and Pr(0,1,1)*ln(IT)). Overall, our findings support Hypothesis H3 under certain configurations of boundary changes with other types of OC. Moreover, the complementarities are stronger for the services than the manufacturing sectors of the economy. This might be due to higher importance of marketing innovation, service quality, and long-term relationship building in the services sector, where a bigger portion of the firms' revenues tend to come from satisfied, returning clients rather than new customers.

7.4. The dual role of IT: manufacturing vs. services

The results of the two-stage approach reveal a remarkable distinction between the manufacturing and services sector with regard to the dominant role of IT therein. In manufacturing, IT more plays the role of a change agent, initiating and stimulating change. In services, IT more plays the role of a change complement, supporting an effective change in the organization. What makes IT play rather different roles in different industrial contexts? One possible explanation that has recently received considerable attention form scholars relates to the nature of business processes and functional tasks that are more subject to change by IT in the manufacturing and services sectors (see e.g. Acemoglu and Autor 2010, Michaels et al. 2010).

Manufacturing firms are in general more labor-intensive than their services counterparts. Manufacturing operations are to a large extent characterized by routine and mechanizable tasks. These are typically procedural, codifiable and rule-based activities that are more vulnerable to automation and change by IT. Examples include assembly-line works, clerical tasks, and repetitive production and monitoring jobs. IT is a strong driving force behind altering or vanishing of these occupations and their associated processes and structures. On the opposite, services firms are generally more knowledge-intensive. Abstract, non-routine and analytical tasks to which computers are currently less suited are common in services. Computers do not directly compete with this type of tasks, where problem-solving, intuition, persuasion, and creativity play important roles. However, computer technology is complementary to these tasks, as they draw heavily on information and knowledge as an input. Professional, managerial, and technical occupations such as strategy and management consulting, law, medicine and health services, science and education, business and IT services and R&D are relevant examples.

7.5. Are multidimensional measures of OC useful?

Is an overall OC indicator as practical and meaningful as its multidimensional derivatives in empirical studies of complementarity? The results of this research reveals that an overall OC indicator tends to overstate the existence of complementarities. The overemphasis may lead to even more misleading results if one distinguishes between different economic sectors. For instance, regression (3) shows a significant direct contribution of OC to productivity while regression (4) attributes this positive impact to only process and boundary changes. Similarly, regression (5) reports significant interactions between IT and OC for both the manufacturing and services. By breaking down the OC variable into its three primary dimensions in regression (6), we can only report significant positive results for OCS and OCB in manufacturing and services sectors respectively. From a clustering perspective, the results of regression (8) indicate a negative contribution to productivity when high levels of IT investments are not accompanied with organizational changes. A positive impact is only observed when the technological investments are coupled with OC and that is valid only for services. Regression (9), although confirms a negative productivity effect when IT intensity is high and OC does not exist, shows that the reality is more complex. For example, the manufacturing sector can experience significant impacts under the following conditions: a positive impact if OCB and IT are joined with OCP (cluster (1011)) and a negative one if they are joined with OCS (cluster (0111)). In Table 6, we find that process and structure changes exhibit complementarity with IT in the manufacturing and services sectors respectively. Combining the OC indicators into a single measure, though, only confirms complementarity between OC and IT in the services (and not anymore in the manufacturing). We argue that combining different dimensions of change into a single OC indicator, as done in a number of previous studies, might result in aggregation problems and cannot capture a full account of the dynamics of different change practices, specifically if inter-sectoral differences are taken into account. Different configurations of change have divergent potential effects and a single OC measure can obscure the inefficiencies associated with certain configurations in specific sectors and hence may lead to misleading results.

7.6. Is there something special about IT capital?

Does IT capital possess particular characteristics or behave differently from other conventional type of capital with regard to interacting with the change practices of the organization? In section 7.1, 7.2, and 7.3 we explained how the empirical findings point to complementarity between IT and OC. Yet, is this phenomenon something specific to IT capital or do other types of capital also exhibit similar patterns of coexistence and interaction with the change initiatives of the firm? The answer is clear from Table 3. In contrast to the output elasticity of IT that significantly diminishes when OC (or its derivatives) is accounted for, that of NIT is almost unchanged (compare the coefficients of ln(NIT) in regression (2) with those in regression (3) and (4)). Even when pair-wise interactions are included in regression (5) and (6), elasticity of ordinary capital experiences an increase rather than a decrease. This is because non-IT capital exhibits substitutability with the change efforts (in particular, process and structure changes) of the firm. Otherwise stated, higher stocks of non-IT capital, characterized by (relative) immobility, non-adaptability, inflexibility, and weak redeployability resist or hinder organizational changes that aim at developing new processes and/or structures within the firm.

IT not only facilitates the change processes but also enables or stimulates them. This role originates from the capability of IT in digitizing business processes, integrating activity domains, handling information flows, and expanding knowledge assets of the firm. Ordinary capital is also required to initiate or support organizational changes but due to specific, routinized characteristics of this type of capital, it plays a weaker role. Table 7 clearly shows this fact. IT resources significantly increase the probability of different change practices in both manufacturing and services sectors (although the enabling effect is typically greater in manufacturing). On the opposite, conventional capital does not always lead to more changes. The effects, as reported in regression (11), (12) and (13), are in some cases insignificant or even negative. Even when an overall OC indicator is considered, the contribution of IT capital to likelihood of organizational change is always larger than that of non-IT capital (see regression (10)).

After the enabling effects of capital are corrected for, the patterns of interaction between IT or non-IT and OC reveal the story somehow differently. The elasticity of NIT in regression (16) is comparable to those in regression (2), (3), (4), (8), or (9). At the same time, the elasticity of IT significantly diminishes (for services) or even becomes negative (for manufacturing). This is a very interesting finding, which is further substantiated in regression (17). According to regression (5) or (6), we should predict a negative interaction between non-IT capital and OC and a positive one between IT and OC. However, regression (17) reports many instances where we observe an opposite relationship, i.e. a positive interaction for non-IT and a negative one for IT. Non-IT capital exhibits a positive interaction with a combination of structure and boundary changes in services (Pr(0,1,1)*ln(NIT)), with process changes alone (Pr(1,0,0)*ln(NIT)), and with all changes together in the whole sample (Pr(1,1,1)*ln(NIT)). In the same setting (i.e. regression (17)), there are fewer configurations where IT exposes a positive interaction. These findings made us wonder if the current state of the theories in use is satisfactory to explain all the relevant issues and phenomena surrounding organizational complementarities. Do we need a new theory or an extension of the existing theories to explicate the rather deviating and sometimes peculiar effects of organizational complementarities under different conditions or configurations? Appendix A provides more insights into why a theoretical extension is perhaps necessary and what considerations shall be preferably taken into account for this extension.

8. Conclusions and Recommendations

8.1. Conclusions and managerial implications

This paper examines the impact of complementarities and patterns of clustering between IT capital (hardware and software) and organizational change efforts of the firm on labor productivity. Three dimensions of organizational change are studied: (internal) process changes, (internal) structure changes and (external) boundary changes. Process changes relate to radical changes in the internal processes of the firm due to introduction of a new manufacturing or servicing method, support activity or knowledge management policy. Structure changes refer to fundamental changes in the internal structures of the firm due to introduction of a new management method, corporate strategy or reorganization policy. Boundary changes are associated with significant changes in the external boundaries of the firm due to outsourcing activities, interorganizational partnerships or marketing innovations. The study distinguishes between the manufacturing and services firms in response to the general argument that complementary relationships among the technological and non-technological aspects of the firm and the patterns of organizational change are influenced (if not determined) by the nature of firm processes and outputs.

The existing literature and theories supported us to formulate three hypotheses with respect to complementarities between IT and the three OC dimensions above. For the empirical analysis we developed a unique detailed and extensive panel dataset of 32,619 observations of firms in the Netherlands over the period 1994-2006. Three distinct methods and several model specifications were employed to test for complementarity and clustering patterns. The first one is the interaction approach which relies on the microeconomic theory of production and tests pair-wise interactions between the IT capital and change initiatives of the firm. Second, we use the systems approach which originates from the theory of supermodularity and examines the productivity contribution of different clusters of organizational practices. This approach is followed by formal tests of multiple systems of inequality conditions. Third, we develop a new approach to account for both complementarity as well as enabling roles of IT at the same time. This two-stage approach proved to be very enlightening. The results are very robust with regard to empirical model specifications and parameter values (such as growth rate, depreciation rate, price deflator, etc.) that were used to build the constructs.

The main findings of the research can be summarized as follow. First, IT exhibits a marginal productivity of as large as eight times that of ordinary capital. This means very promising investment potentials for computer hardware and software. Firms in the services sectors of the economy enjoy higher marginal products of IT (almost two times) than their manufacturing counterparts. These findings imply an important message for corporate managers, especially in service providing companies, when it comes to allocating their investment budgets to different asset classes. Second, organizational changes contribute to labor productivity of the firm if combined with proper levels of technology investments. As a supporting technology, IT facilitates the introduction and proliferation of new firm processes and structures both internally and externally. OC initiatives do not lead to performance improvements or even do lead to performance declines when they are not coupled with enough stocks (i.e. at the average level of the respective industry) of supporting technologies. This bears a very important message for managers who plan to initiate or govern a major change initiative inside their organization; they need to think about both the technological and non-technological elements of change at the same time. IT-OC complementarities are relatively stronger in services than the manufacturing sectors of the economy.

Third, the results show that structure changes are relatively more important for manufacturing firms while boundary changes are more relevant for services; process changes are of more or less comparable importance for both manufacturing and services firms. This should alert corporate managers in different sectors about specific types of organizational change that might matter more to their firm for gaining superior performance (and perhaps competitive advantage over the rivals). Fourth, we discover significantly negative interactions, in the form of substitutability relationships, between the conventional (non-IT) type of capital and OC efforts of the firm. This highlights the hampering or decelerating effects of conventional capitals that are typically characterized as (quasi-)fixed assets with low degrees of functional flexibility, structural adaptability, and reusability in diverse application domains. These hindering effects of non-IT capital are more evident in case of services firms and against structure or boundary changes (and less for process changes). This finding reminds managers, especially in dynamic and turbulent environments, on the consequences of their investments in fixed assets and the change-resisting effects they may encounter because of these assets in the future.

Fifth, in addition to complementing the change efforts of the firm, IT itself also stimulates or initiates certain types of change (in particular, structure and boundary changes). These subsequent changes and investments in organizational capital explain a major part of the performance effects of IT. This is an important issue of consideration for business managers who might think of IT spending as a static, self-fulfilling phenomenon. High levels of expenditure in IT without providing the right conditions, incentives or stimuli for initiating or accompanying proper organizational changes lead to extra costs without tangible effects on performance. Sixth, our analysis reveals that the primary role of IT depends on the nature of the firm. For manufacturing firms, IT plays more the role of a change originator while for services firms it mainly plays the role of a change complement. This suggests that different types of IT applications might be more productive depending on the degree of routinization and mechanization of common business processes and functional tasks in different industrial contexts. Finally, this research documents complex dynamics among different types of organizational change. IT-enabled process changes typically lead to performance improvements only when they are combined with structure, boundary, or both structure and boundary changes. Seemingly, technology-driven process changes do not lead to significant effects unless they also bring about fundamental changes in the (internal or external) structural elements of the firm. The necessity to combine different types of change at the same time to attain a positive outcome is more relevant for the services than the manufacturing sector. Another dynamic aspect of interrelations among different change dimensions relates to substitutability between structure and boundary changes, particularly in the manufacturing sector. It seems that it is not appropriate for manufacturers to alter their internal and external structural arrangements both at the same time (unless they combine them with proper process changes). These findings warrant managers not to simply focus on a single type of change in their organization but rather have a more complete picture of organizational change in mind when plan for or execute change.

8.2. Limitations and recommendations for future research

This research raised important questions each of which opens up new doors for further research in different directions. In this study, organizational change is specified through a multidimensional measure, encompassing the three primary dimensions of change. However, individual dimensions are measured through a set of dichotomous variables without respect to intensity or importance of them. Further information about the level of different types of change and/or relative importance of them for the firm can surely enhance our understanding of the relevant phenomena. Yet, it is very hard to measure such concepts as organizational change in an objective quantitative manner, especially when most of the effects and consequences of change have an intangible, qualitative nature. Perhaps, an estimate of the total amount of related (opportunity) costs associated with a change initiative over its life cycle or an estimate of the number of human agents that are directly or indirectly involved in implementing and sustaining a change can be considered as good candidates for quantifying OC.

As to another interesting avenue for future research, we need to analyze more thoroughly the underlying dynamics behind different types of technology-driven change inside or between companies of different activity type. What is specific about manufacturing or services firms that makes IT more an enabler or complement of change in them? Why process changes typically need to be combined with structure or boundary changes to result in performance improvements? Why structure changes are relatively more important for manufacturing while boundary changes for services firms? These questions can be even investigated at lower levels of aggregation with extended divisions of firms to explore intra-sector differences.

Some industries, most importantly the financial sector (including banking, insurance and pension funds) are absent in our database. With respect to the fact that the financial sector is one of the most service-innovative sectors of the economy and intensive users of IT, we expect that should we had this sector included in our analysis, we would have observed a sharper difference between the services and manufacturing sectors in terms of the level of IT payoffs and intensity of complementarities. Another challenging arena for future research concerns the study of time-lag effects. In this research, we observe an average time-lag of 12 months for capital stock and 18 months for organizational change. It deserves a separate study on how the complementarity and clustering patterns evolve over time. How do inter-dynamics among different dimensions of change as well as inter-plays between technological and non-technological aspects of the firm develop over longer periods of time? We expect that the level of payoffs and complementarities would increase (especially for slowly changing aspects of the firm), the higher the time-lag; but, are the time-lag differences more relevant for manufacturing or services firms? Do time-lags act similarly for different types of change?

Finally, we concluded earlier that there might be a need for an extension of the existing complementarity or configurational theories of the firm. The existing theories do not sufficiently oversee all the relevant phenomena and would have difficulty in predicting the outcomes of complex configurations, particularly when multiple forces interplay at the same time and technological and non-technological elements form complex constellations. We identified a major shortcoming by documenting significant differences in the level of IT payoffs and type of complementarities whether or not the enabling effects of technology is explicitly account for. Another relevant phenomenon is the enabling effects of OC in the process of IT value creation. There are instances where organizations implement a change and later realize that they need IT to support or strengthen their intended change. Another scenario is conceivable when IT leads to organizational change, which in itself creates needs for new IT, and so on (i.e. a virtuous circle). We leave it to future research to apply relevant extensions or suggest new organizational theories that can be used for better explanation or inference of complementarity phenomena.

References

Acemoglu, D., D. Autor. 2010. Skills, Tasks and Technologies: Implications for Employment and Earnings. in *Handbook of Labor Economics Volume 4*, O. Ashenfelter and D. E. Card (eds.). Elsevier, Amsterdam, the Netherlands.

Alavi, M., D. E. Leidner. 2001. Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS Quarterly* 25(1) 107-136.

Amit, R., P. Schoemaker. 1993. Strategic assets and organizational rent. *Strategic Management Journal* 14 33-46.

Anand, B. N., T. Khanna. 2000. Do firms learn to create value? The case of alliances. *Strategic Management Journal* 21 295-315.

Aral, S., E. Brynjolfsson, D. J. Wu. 2006. Which Came First, IT or Productivity? The Virtuous Cycle of Investment and Use in Enterprise Systems. *Proceedings of the 27th International Conference on Information Systems* 1-22. Milwaukee, WI.

Aral, S., P. Weill. 2007. IT assets, organizational capabilities, and firm performance: How resource allocations and organizational differences explain performance variation. *Organization Science* 18(5) 763-780.

Armbruster, H., A. Bikfalvi, S. Kinkel, G. Lay. 2008. Organizational innovation: The challenge of measuring non-technical innovation in large-scale surveys. *Technovation* 28 644–657.

Arora, A. 1996. Testing for complementarities in reduced-form regressions: a note. *Economic Letters* 50 51–55.

Arvanitis, S. 2005. Computerization, Workplace Organization, Skilled Labor and Firm Productivity: Evidence for the Swiss Business Sector. *Economics of Innovation and New Technology* 14(4) 225-249.

Athey, S., S. Stern. 1998. An empirical framework for testing theories about complementarity in organizational design. *NBER Working Papers*.

Bahrami, H. 1992. The emerging flexible organization: Perspectives from Silicon Valley. *California Management Rev*iew 34(4) 33-52.

Barrett, M., D. Grant, N. Wailes. 2006. ICT and organizational change: introduction to the special issue. *Journal of Applied Behavioral Science* 42(1) 6-22.

Bartel, A., C. Ichniowski, K. Shaw. 2007. How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills. *Quarterly Journal of Economics* 122(4) 1721-1758.

Barua, A., C. H. Kriebel, T. Mukhopadhyay. 1995. Information Technologies and Business Value-an Analytic and Empirical Investigation. *Information Systems Research* 6 3-23.

Beers, C. V., F. Zand. 2010. R&D Cooperation, Partner Diversity and Innovation Performance: An Empirical Analysis. *DRUID Working Papers Series*.

Benson, J., N. Ieronimo. 1996. Outsourcing decisions: evidence from Australia-based enterprises. *International Labor Review* 135 59–73.

Bertschek, I., U. Kaiser. 2004. Productivity Effects of Organizational Change: Microeconometric Evidence. *Management Science* 50(3) 394-404.

Bharadwaj, S. G., Bharadwaj, A. S., E. Bendoly. 2007. The Performance Effects of Complementarities Between Information Systems, Marketing, Manufacturing, and Supply Chain Processes. *Information Systems Research* 18(4) 437-453.

Bharadwaj, A. S., S. G. Bharadwaj, B. R. Konsynski. 1999. Information Technology Effects on Firm Performance as Measured by Tobin's q. *Management Science* 45(7) 1008-1024.

Black, J. K. Boal. 1994. Strategic resources: Traits, configurations and paths to sustainable competitive advantage. *Strategic Management Journal* 15 131-148.

Black, S. E., L. M. Lynch. 2001. How to compete: The impact of workplace practices and information technology on productivity. *Review of Economics and Statistics* 83 434-445.

Bocquet, R., O. Brossard, M. Sabatier. 2007. Complementarities in organizational design and the diffusion of information technologies: An empirical analysis. *Research Policy* 36 367–386.

Brame, R., R. Paternoster, P. Mazerolle, A. Piquero. 1998. Testing for the Equality of Maximum-Likelihood Regression Coefficients Between Two Independent Equations, *Journal of Quantitative Criminology* 14(3) 245-261.

Bresnahan, T. F., E. Brynjolfsson, L. M. Hitt. 2002. Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-level Evidence. *The Quarterly Journal of Economics* 117 339-376.

Broadbent, M., P. Weill, D. St. Claire. 1999. The implications of information technology infrastructure for business process redesign. *MIS Quarterly* 23(2) 159–182.

Brynjolfsson, E. 1993. The Productivity Paradox of Information Technology: Review and Assessment. *Communication of the ACM* 36(12) 67-77.

Brynjolfsson, E., L. M. Hitt. 1995. Information Technology as a Factor of Production: The Role of Differences among Firms. *Economics of Innovation and New Technology* 3(3–4) 183–99.

Brynjolfsson, E., L. M. Hitt. 1996. Paradox Lost? Firm-level Evidence on the Returns to Information Systems Spending. *Management Science* 42(4) 541-558.

Brynjolfsson, E., L. M. Hitt. 2000. Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives* 4 23-48.

Brynjolfsson, E. L. M. Hitt. 2003. Computing Productivity: Firm-Level Evidence, *Review of Economics and Statistics* 85(4) 793–808.

Brynjolfsson, E., L. M. Hitt, S. Yang. 2002. Intangible Assets: Computers and Organizational Capital. *Brookings Papers on Economic Activity* 1 137-198.

Brynjolfsson, E., T. W. Malone, V. Gurbaxani, A. Kambil. 1994. Does Information Technology Lead to Smaller Firms? *Management Science* 40(12) 1628-1644.

Brynjolfsson, E., H. Mendelson. 1993. Information systems and the organization of modern enterprise. *Journal of Organizational Computing* 3(3) 245-255.

Brynjolfsson, E., A. Renshaw, M. V. Alstyne. 1997. The Matrix of Change. *Sloan Management Review* 28(2) 37-54.

Brynjolfsson, E., A. Saunders. 2010. Wired for Innovation: How Information Technology is Reshaping the Economy. MIT Press, Cambridge, MA.

Caroli, E., J. Van Reenen. 2001. Skill-based organizational change? Evidence from a panel of British and French establishments. *Quarterly Journal of Economics* 116 1449-1492.

Carree, M., B. Lokshin, R. Belderbos. 2010. A note on testing for complementarity and substitutability in the case of multiple practices. *Journal of productivity Analysis* (forthcoming).

Chari, M. D. R., S. Devaraj, P. David. 2008. The Impact of Information Technology Investments and Diversification Strategies on Firm Performance. *Management Science* 54(1) 224-234.

Choi, B., S. K. Poon, J. G. Davis. 2008. Effects of knowledge management strategy on organizational performance: A complementarity theory-based approach. *Omega* 36 235–251.

Colombo, M. G., M. Delmastro. 2002. The Determinants of Organizational Change and Structural Inertia: Technological and Organizational Factors. *Journal of Economics & Management Strategy* 11(4) 595–635.

Dedrick, J., V. Gurbaxani, K. Kraemer. 2003. Information Technology and Economic Performance: A Critical Review of the Empirical Evidence. *ACM Computing Surveys* 35(1) 1–28.

Devanna, M. A., N. Tichy. 1990. Creating the Competitive Organization of the 21st Century: The Boundaryless Corporation. *Human Resource Management* 29 455-471.

Devaraj, S., R. Kohli. 2003. Performance Impacts of Information Technology: Is Actual Usage the Missing Link? *Management Science* 49(3) 273-289.

Davenport, T. 1993. Process Innovation: Reengineering Work Through Information Technology. Harvard Business School Press, Boston, MA.

Dewan, S., S. C. Michael, C. Min. 1998. Firm characteristics and investments in information technology: Scale and scope effects. *Information Systems Research* 9(3) 219–232.

Ennen, E., A. Richter. 2010. The whole is more than the sum of its parts or is it? A review of the empirical literature on complementarities in organizations. *Journal of Management* 36 207-233.

Fiedler, F. E. 1967. *A theory of leadership effectiveness*. McGraw-Hill, New York, NY.

Freeman, S. J., K. S. Cameron. 1993. Organizational downsizing: (A) convergence and reorientation framework. *Organization Science* 4(1) 10–29.

Faulkner, D. O. 1994. International strategic alliances: Co-operating to compete. McGraw-Hill, London, UK.

Francalanci, C., H. Galal. 1998. Information technology and worker composition: determinants of productivity in the life insurance industry. *MIS Quarterly* 22(2) 227-241.

Froot, K. A. 1989. Consistent covariance matrix estimation with cross-sectional dependence and heteroskedasticity in financial data. *Journal of Financial and Quantitative Analysis* 24 333–355.

Fulk, J., G. DeSanctis. 1995. Electronic communication and changing organizational forms. *Organization Science* 6 337–349.

Geroski, P. P. Gregg. 1994. Corporate restructuring in the UK during the recession. *Business Strategy Review* 5(2) 1–19.

Giuri, P., S. Torrisi, N. Zinovyeva. 2008. ICT, skills, and organizational change: evidence from Italian manufacturing firms. *Industrial and Corporate Change* 17(1) 29-64.

Gouriéroux, C., A. Holly, A. Monfort. 1982. Likelihood ratio test, Wald test, and Kuhn-Tucker test in linear models with inequality constraints on the regression parameters. *Econometrica* 50(1) 63-80.

Greenan, N. 2003. Organizational change, technology, employment and skills: an empirical study of French manufacturing. *Cambridge Journal of Economics* 27(2) 287-316.

Gulati R., D. Lavie, H. Singh. 2009. The nature of partnering experience and the gains from alliances. *Strategic Management Journal* 30(11) 1213-1233.

Hammer, M. 1990. Reengineering Work: Don't Automate, Obliterate. *Harvard Business Review* 68(4) 104-112.

Hammer, M., J. Champy. 1993. Re-Engineering the Corporation. Nicholas Brealey, London, UK.

Handy, C. 1992. Balancing corporate power: A new Federalist Paper. *Harvard Business Review* 70(6) 59–72.

Hedlund, G. 1994. A model of knowledge management and the N-Form corporation. *Strategic Management Journal* 15 73–90.

Hempell, T. 2005. What’s spurious, what’s real? Measuring the productivity impacts of ICT at the firm-level, *Empirical Economics* 30 427–464.

Hill, C. W. L., M. A. Hitt, R. E. Hoskisson. 1992. Cooperative versus competitive structures in related and unrelated diversified firms. *Organization Science* 3(4) 501–521.

Hitt, L. M. 1999. Information Technology and Firm Boundaries: Evidence from Panel Data. *Information Systems Research* 10(2) 134-149.

Hitt, L. M., E. Brynjolfsson. 1997. Information technology and internal firm organization: An exploratory analysis. *Journal of Management Information Systems* 14: 81-101.

Ichniowski, C., K. Shaw, G. Prennushi. 1997. The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines. *The American Economic Review* 87(3) 291-313.

Jarvenpaa, S., B. Ives. 1994. The global network organization of the future: Information management opportunities and challenges. *Journal of Management Information Systems* 10(4) 25-58.

Jeffers, P. I., W. A. Muhanna, B. R. Nault. 2008. Information Technology and Process Performance: An Empirical Investigation of the Interaction Between IT and Non-IT Resources. *Decision Sciences* 39(4) 703-735.

Kanter, R. M. 1991. Transcending Business Boundaries: 12,000 World Managers View Change. *Harvard Business Review* 69(3) 151-164.

Kast, F., J. Rosenzweig. 1973. *Contingency Views of Organization and Management*. Science Research Associates, Chicago, IL.

Kelley, M. R. 1994. Productivity and Information Technology: The Elusive Connection. *Management Science* 40(11) 1406-1425.

Ketchen, D. J. Jr., J. G. Combs, C. J. Russell, C. Shook, M. A. Dean, J. Runge, F. T. Lohrke, S. E. Naumann, D. Haptonstahl, R. Baker, B. A. Beckstein, C. Handler, H. Honig, S. Lamoureux. 1997. Organizational Configurations and Performance: A Meta-Analysis. *The Academy of Management Journal* 40(1) 223-240.

Kettinger, W. J., V. Grover, S. Guha, A. H. Segars. 1994. Strategic Information Systems Revisited. *MIS Quarterly* 18(1) 31-58.

Kodde, D., F. Palm. 1986. Wald criteria for jointly testing equality and inequality restrictions. *Econometrica* 54(5) 1243-1248.

Koellinger, P. 2008. The relationship between technology, innovation, and firm performance-Empirical evidence from e-business in Europe. *Research Policy* 37 1317-1328.

Lawler, E. D., S. A. Mohrman, E. Ledford Jr. 1998. Strategies for High Performance Organizations: Employee Involvement, TQM and Reengineering Programs in Fortune 1000 Corporations, Jossey-Bass, San Francisco, CA.

Lee, J. J.-Y. 2008. Complementary Effects of Information Technology Investment on Firm Profitability: The Functional Forms of the Complementarities. *Information Systems Management* 25 364–371.

Leonardi, P. M. 2007. Activating the Informational Capabilities of Information Technology for Organizational Change. *Organization Science* 18(5) 813–831.

Leonardi, P. M., D. E. Bailey. 2008. Transformational technologies and the creation of New Work practices: Making implicit knowledge explicit in task-based offshoring. *MIS Quarterly* 32(2) 411-436.

Levinthal, D. A. 1997. Adaptation on Rugged Landscapes. *Management Science* 43(7) 934-950.

Lokshin, B., M. Carree, R. Belderbos. 2004. Testing for complementarity and substitutability in case of multiple practices. *Research Memoranda* #2, Maastricht University.

Malone, T. W., S. A. Smith. 1988. Modeling the Performance of Organizational Structures. *Operations Research* 36(3) 421-436.

Malone, T. W., J. Yates, R. I. Benjamin. 1987. Electronic Markets and Electronic Hierarchies. *Communications of the ACM* 30(6) 484–97.

Markus, M. L., D. Robey. 1988. Information technology and organizational change: Casual structure in theory and research. *Management Science* 34(5) 583-598.

Martinsons, M. G. 1995. Radical Process Innovation Using Information Technology: The Theory, the Practice and the Future of Reengineering. *International Journal of Information Management* 15(4) 253-269.

Melville, N., V. Gurbaxani, K. Kraemer. 2007. The productivity impact of information technology across competitive regimes: The role of industry concentration and dynamism. *Decision Support Syst*ems 43 229-242.

Melville, N., K. Kraemer, V. Gurbaxani. 2004. Review: Information technology and organizational performance: An integrative model of IT business value. *MIS Quarterly* 28 283-322.

Merchant, H., D. Schendel. 2000. How do international joint ventures create shareholder value? *Strategic Management Journal* 21 723-737.

Meyer, A. D., A. S. Tsui, C. R. Hinings. 1993. Configurational approaches to organizational analysis. *Academy of Management Journal* 36(6) 1175–92.

Michaels, G., A. Natraj, J. Van Reenen. 2010. Has ICT Polarized Skill Demand? Evidence from 11 Countries Over 25 Years. *NBER Working Paper No. 16138*.

Miles, R. E., C. C. Snow, J. A. Mathews, H. J. Coleman. 1997. Organizing in the knowledge age: Anticipating the cellular form. Academy of Management Executive 11(4) 7–20.

Milgrom, P., Y. Qian, J. Roberts. 1991. Complementarities, momentum and the evolution of modern manufacturing. *American Economic Review* 81 84-88.

Milgrom, P., J. Roberts. 1990. The economics of modern manufacturing: Technology, strategy, and organization. *American Economic Review* 80 511-528.

Milgrom, P., J. Roberts. 1994. Complementarities and systems: Understanding Japanese economic organization. *Estudios Economicos* 9 3-42.

Milgrom, P., J. Roberts. 1995. Complementarities and fit: Strategy, structure, and organizational change in manufacturing. *Journal of Accounting and Economics* 19(2,3) 179-208.

Miller, D. 1987. The genesis of configuration. *Academy of Management Review* 12 686–701.

Miller, D. 1996. Configurations revisited. *Strategic Management Journal* 17(7) 505–12.

Miller, D., P. H. Friesen. 1984. *Organizations: A quantum view*. Prentice-Hall, Englewood Cliffs, NJ.

Mintzberg, H. 1979. *The structuring of organizations*. Prentice-Hall, Englewood Cliffs, NJ.

Mohnen, P., L.-H. Roller. 2005. Complementarities in innovation policy. *European Economic Review* 49 1431–1450.

Montoya, M. M., A. P. Massey, Y.-T.C. Hung, C. B. Crisp. Can you hear me now? Communication in virtual product development teams. *Journal of Product Innovation Management* 26(2) 139–155.

Mukhopadhyay, T., R. B. Cooper. 1993. A Microeconomic Production Assessment of the Business Value of Management Information Systems: The Case of Inventory Control. *Journal of Management Information Systems* 10 33-55.

Nohira, N., S. Ghoshal. 1997. The Differentiated Network. Jossey-Bass, San Francisco, CA.

Nonaka, I., H. Takeuchi. 1995. *The Knowledge-Creating Company*. Oxford University Press, Oxford, UK.

Olley, G. S., A. Pakes. 1996. The dynamics of productivity in the telecommunications equipment industry. *Econometrica* 64(6) 1263-1297.

Orlikowski, W. J., S. R. Barley. 2001. Technology and institutions: What information systems research and organization studies can learn from each other. *MIS Quarterly* 25 145-165.

Osterman, J. 1994. How common is workplace transformation and who adopts it? *Industrial &Labor Relations Reviews* 47(2) 173–188.

Otley, D. T. 1980. The contingency theory of management accounting: Achievement and prognosis. *Accounting, Organizations and Society* 5(4) 413-428.

Prahalad, C. K., G. Hamel. 1990. The core competence of the corporation. *Harvard Business Review* 68(3) 79–91.

Pickering, J. M., J. L. King. 1995. Hardwiring weak ties: Inter-organizational computer-mediated communication, occupational communities, and organizational change. *Organization Science* 6(4) 479-486.

Piva, M., E. Santarelli, M. Vivarelli. 2005. The skill bias effect of technological and organizational change: evidence and policy implications. *Research Policy* 34 141-157.

Polder, M., G. Van Leeuwen, P. Mohnen, W. Raymond. 2010. Product, process and organizational innovation: drivers, complementarity, and productivity effects. *UNU-MERIT Working Papers.*

Powell, T. C., A. Dent-Micallef. 1997. Information technology as competitive advantage: The role of human, business, and technology resources. *Strategic Management Journal* 18 375-405.

Quinn, J. B., J. J. Baruch, P. C. Paquette. 1987. Technology in Services. *Scientific American* 257(6).

Radner, R. 1993. The organization of decentralized information processing. *Econometrica* 62 1109–1146.

Rivkin, J. W. 2000. Imitation of Complex Strategies. *Management Science* 46 824-844.

Roach, S.S. 1991. Services under siege- The restructuring imperative, *Harvard Business Review* 69(5) 82-92.

Rockart, J. F., E. J. Short. 1989. IT in the 1990s: Managing Organizational Interdependence. *Sloan Management Review* 30(2), 7-17.

Sahaym, A., H. K. Steensma, M. A. Schilling. 2007. The Influence of Information Technology on the Use of Loosely Coupled Organizational Forms: An Industry-Level Analysis. *Organization Science* 18(5) 865-880.

Sankaranarayanan, R., A. Sundararajan. 2010. Electronic Markets, Search Costs, and Firm Boundaries. *Information systems Research* 21(1) 154-169.

Shah, R., P. T. Ward. 2007. Defining and developing measures of lean production. *Journal of Operations Management* 25(4) 785-805.

Siggelkow, N. 2002. Misperceiving Interactions among Complements and Substitutes: Organizational Consequences. *Management Science* 48(7) 900-916.

Sircar, S., J. Choi. 2009. A study of the impact of information technology on firm performance: a flexible production function approach. *Information Systems Journal* 19 313-339.

Sircar, S., J. L. Turnbow, B. Bondoloi. 2000. The impact of information technology investments on firm performance. *Journal of Management Information Systems* 16 69–97.

Solow, R. M. 1987. We'd better watch out. *New York Times* 36. Book Review July 12.

Statistics Canada. 2007. Depreciation Rates for the Productivity Accounts. *Research Paper: The Canadian Productivity Review*.

Tichy, N. M., S. Sherman. 1995. Control Your Destiny or Someone Else Will: How Jack Welch Is Making General Electric the World's Most Competitive Corporation. Harper Collins, New York, NY.

Train, K. 2003. *Discrete Choice Methods with Simulations*. Cambridge University Press, Cambridge, UK..

Triplett J. E. 1999. The Solow's productivity paradox: what do computers do to productivity? *Canadian Journal of Economics* 32(2) 309-334.

Venkatraman, N. 1991. IT-induced business reconfiguration. in *The Corporation of the 1990s: information technology and organizational transformation*, S. Morton (ed.), 122-158. Oxford University Press, New York, NY.

White, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica* 48 817–830.

White, R. E., J. N. Pearson, J. Wilson. 1999. JIT Manufacturing: A Survey of Implementations in Small and Large U.S. Manufacturers. *Management Science* 45(1) 1–15.

Whittington, R., A. Pettigrew, S. Peck, E. Fenton, M. Conyon. 1999. Change and complementarities in the new competitive landscape: a European Panel Study, 1992–1996. *Organization Science* 10 583–600.

Widaman, K. F. 1993. Common factor analysis versus principal components analysis: Differential bias in representing model parameters? *Multivariate Behavioral Research* 28 263-311.

Wolak, F. 1989. Testing inequality constraints in linear econometric models. *Journal of Econometrics* 41 205-235.

Yasar, M., R. Raciborski, B. Poi. 2008. Production function estimation in Stata using the Olley and Pakes method. *Stata Journal* 8(2) 221-231.

Zammuto, R. F., T. L. Griffith, A. Majchrzak, D. J. Dougherty, S. Faraj. 2007. Information Technology and the Changing Fabric of Organization. *Organization Science* 18(5) 749-762.

Zack, M. H. 1999. Developing a knowledge strategy. *California Management Review* 41(3) 125–145.

Zand, F., C. van Beers. 2010. Enterprise Systems Adoption and Firm Performance in Europe: The Role of Innovation. *DRUID Working Papers Series.*

Zeffane, R. 1992. Organizational structures: Design in the 1990s. Leadership & Organization Development Journal 13(6) 18–23.

Zell, D. 1997. Changing by Design: Organizational Innovation at Hewlett-Packard. Cornell University Press, Ithaca, NY.

Zenger, T. R., W. S. Hesterly. 1997. The disaggregation of corporations: Selective intervention, high-powered incentives and molecular units. *Organization. Science* 8(3) 209–222.

Zhu, K. 2004. The Complementarity of Information Technology Infrastructure and E-Commerce Capability: A Resource-Based Assessment of Their Business Value. *Journal of Management Information Systems* 21(1) 167–202.

Zornoza, C. C., R. L. Alcamí. 1999. The Enabling Role of Information Technologies on the Emergence of New Organizational Forms. *Management* 2(3), Special Issue: Organizational Downsizing 251-261.

Zuboff, S. 1988. In the Age of the Smart Machine: The Future of Work and Power. Basic Books, New York, NY.

Appendix A: Are the Existing Complementarity Theories Sufficient?

Do the configurational or supermodularity theories, in their current states, provide a complete picture of the complementarity phenomenon between the technological and non-technological aspects of the firm or they need necessary extensions? The interaction method, based on the microeconomic theory of production, is the basic standard approach to test for complementarities. The systems approach extends the study of complementarities on the ground that organizational practices behave in joint systems or clusters. Rather than analyzing multiple interactions in isolation, systems of practices offer a more complete picture. The behavior of certain practices may change providing the coexistence or shortfall of other practices. This research verified this argument. For instance, substitutability between non-IT capital and process or structure changes and at the same time complementarity between IT capital and structure or boundary changes of the firm are simple reflections on the results of Table (3). Table (5) and (6) demonstrate that the reality might be much more complex. As shown in regression (9) the pattern of interactions between IT and different OC configurations is diverse. IT exhibits complementarities with structure or boundary changes only if they are combined with each other and/or with process changes. The supermodularity theory in Table (6) imposes more restrictive conditions to confirm complementary relationships. Under these conditions, we can only accept, with confidence, complementarity between IT and OCP (in manufacturing) and between IT and OCS (in services). The evidence for IT-OCB complementarity is not decisive.

We proposed the two-stage method in response to concerns about endogeneity of OC. The results of Table (8) deviate from those of Table (5) and especially (3) in one main aspect. The output elasticity of IT is not anymore significantly positive. The exceptions are the elasticity of IT in regression (16) only for the services and in regression (17) only for the full sample (even then, the elasticity of IT is almost half of that in Table (3) or (5)). While IT elasticity experiences a drastic decline or sign shift, non-IT capital does not experience a similar phenomenon. This clearly highlights the substantial change-inducing effects of IT. It seems that part of the direct effects that are used to be attributed to IT, are in fact the result of change initiatives that are generated or facilitated by IT but not IT itself; when these enabling effects are explicitly accounted for, we face drastic drops in direct IT effects we observe.

From a methodological perspective, the two-stage approach might seem a remedy to deal with the endogeneity problem. However, more importantly, it extends the supermodularity theory from a conceptual perspective by suggesting new paths through which IT can create value for the firm. Considering the contributions of IT to OC practices in Table (7), elasticities of IT in Table (8) and patterns of positive interaction in Table (3) and (5) makes us also predict that the enabling effects are comparatively stronger in manufacturing while the complementary effects are more robust in services. This sheds light on the different patterns and objectives of technology use in the manufacturing versus the services sector. Manufactures typically use IT to initiate and push forward change in their organization while service providers normally get support from IT to accelerate or smooth their change initiatives. This conjecture shall be investigated in full details but nevertheless pushes the frontiers of research on complementarities further. Another interesting avenue for future research relates to the extent that different dimensions of change benefit from the two types of IT effects. Overall, our research suggests that the existing theories used to analyze complementarities need to be extended such that they capture the complementarities and enabling effects simultaneously.

If you would be a real seeker after truth, it is necessary that at least once in your life you doubt, as far as possible, all things. - *Rene Descartes*

OVERALL EVALUATION AND CONCLUDING REMARKS

This thesis is in essence a collection of theoretical and empirical studies analyzing the relationship between information technology (IT) assets and organizational performance of the firm with a focus on the role of innovation in the process of value creation from IT investments. Previous chapters explained how these studies were done, what results were found, and what conclusions can be made on the basis of these results. Now, it is only natural for the author to sit back and reflect upon findings of the research in order to come to a detached evaluation of the research as a whole. In this regard, the first section is devoted to some overall management implications of the research, while the second section provides some remarks about possibilities for future research.

1. Managerial Implications

The present thesis sheds light on the role of innovation in the process of value creation from IT investments. It focuses on the "how" and "why" aspects of IT business value. What makes some firms more successful than others in creating business value from their technology investments? How do successful IT adopters distinguish themselves from the pack? Why do similar IT resources lead to different outcomes in different organizational contexts? On the basis of firm- and sector-level studies, the findings of this thesis imply certain points of reference for corporate managers. Below, a few important ones are highlighted.

(A) *IT does matter for performance of the firm.*

If this thesis bears only one message that would be: "IT contributes to performance and market position of the firm, especially if (1) it is used to innovate and (2) it is accompanied by certain complementarities." Chapter 2 scrutinizes the process that links IT assets to IT-based capabilities and explains how this ultimately leads to generation of business value for the firm. It explores the diverse set of roles and functions that can be played by IT in the organization through a new process-oriented typology of IT roles. The analytical framework proposed in this chapter proved to be useful for managers. Chapter 3 shows that IT supports firms to diversify their alliance portfolios, from the perspectives of both the location and type of business partners. Diversity of partners enables the firm to produce and introduce more (whether incrementally or radically) new products and services to the market and consequently affects firm performance positively. In chapter 4, IT systems are found to be useful to cut costs, improve business processes, develop new services, create and disseminate knowledge, automate administrative tasks, coordinate groups and projects, integrate business domains and partners, and streamline operations. These effects permeate the entire organization and can be translated to higher efficiency, more sales, a better market position and even increased profits if the adopting firm differentiates itself from other adopters by using IT to develop new products and make fundamental changes to its organization. Chapter 5 further highlights the importance of change in the process of value creation of IT investments. Information technology was found to be a significant driving force behind organizational change (OC). Moreover, we found that when IT and OC are jointly adopted, their productive effects are usually amplified to higher levels that are not feasible with any of them alone.

The findings of this thesis corroborate the central idea that IT does matter, yet emphasize on the purpose and context of IT use. We argue that more important than what IT resources a specific firm has access to is how and where in its business it uses those resources. Here are a few important issues that managers need to be aware of: (a) why and for what specific purpose(s) they use IT, (b) what specific goals they intend to achieve by using IT, (c) how they put IT into use, and (d) whether or not they provide the necessary prerequisites and conditions for effectively using IT. Providing that the aim is clear and the context is ready, IT resources lead to substantially higher benefits compared to conventional or non-IT types of assets. In contrast to IT resources, non-IT assets are less flexible and less adaptable to different use contexts and can only be useful for certain purposes and in rather unchangeable conditions. As a result, the array of possible roles and functions of information and communication technologies in a firm is much broader than those of, for instance, construction, transportation or mechanical assets. Furthermore, non-IT types of assets are being invested in for centuries while IT resources have only been capitalized for a few (and mainly the last two) decades. This leaves a very substantial gap between the marginal productivity of IT capital compared to that of non-IT capital. For managers these mean great (and certain) return on investment (RIO) potentials for IT. They just need to translate these potentials to realized effects, which is, of course, the most difficult piece of the puzzle. In this thesis, we research this topic and try to provide managers with some guidelines. Another worthwhile characteristic of IT that sets it apart from other types of capital is its capacity to be combined or coupled with other firm practices, create emergent capabilities, and produce even larger marginal productivity effects. This should motivate corporate decision makers to invest in specific clusters of complementary practices (rather than solitary practices) to yield supernormal results. We advise managers to give special attention to co-investments in organizational capital in parallel with technological opportunities that they consider to capitalize.

At a higher level, the high investment potentials and productivity effects of IT should encourage policy makers to enact business incentives and regulations that promote advances in producing IT and growth in using it. Governments should focus on how they can support firms in stimulating creativity and further driving innovation through IT use. Through effective business-related policies and initiatives, governments should ensure that IT progress is appropriately transformed into long-lasting benefits for the citizens, businesses, and industries.

(B) *Innovation should be promoted to create more business value from IT investments.*

All studies in this thesis underscore the importance of innovation for creating more value from technology investments. In chapter 2, IT roles are introduced as intermediary mechanisms linking IT investments to emergent capabilities and performance measures of the firm. We also learn that the fundamental characteristics of these roles (whether they are intrinsic or interactive) enable us to group them in separate categories depending on their level of intricacy and convolution or in simple words their degree of innovativeness. Chapter 3 introduces innovation as an outcome of interorganizational collaborations that themselves are stimulated and supported by investments in information technologies. Chapters 4 and 5 highlight the essential roles of organizational innovation as mediating and moderating factors in the process of IT value creation. Enterprise systems were found to be effective to firm performance and position in the market to the extent that they enable the firm to innovate its business processes and/or introduce innovative products and services. Another factor we found critical for IT resources to be productive is whether or not the firm changes its internal structures and/or external boundaries in line with the requirements and objectives of the implemented technology.

Innovation for a firm means producing and selling new things, servicing customers in a new way, doing things differently and/or making its structures different from the past. Innovation is not only a driver of firm performance itself but also an influential factor determining how much value can be derived from technological investments of the firm. As a result, chief executive, innovation, information and technology officers as well as middle managers should not simply confine their attention to allocating budgets and investing in technology. On the opposite, they should give extra attention to track their technology spending, observe how, by whom and for what purpose(s) the technology is being used, and whether or not intermediary objectives and adoption criteria are satisfactorily met. One of the most important criteria for managers should be the extent of technology use by employees, in all levels of the organization, to innovate or extend/improve existing innovations. For this purpose, managers can design proper incentive and reward systems, cultivate an innovation culture inside the firm, develop internal support/advisory groups such as communities of practice (CoP), invest in human capital through training programs, motivate and empower employees to take up more decisions and responsibilities, and offer employees free time to spend on new ideas and participate in corporate-sponsored think tanks (like those at Google Inc.).

In addition to corporate managers, governments can also leverage technology investments by seeding and nurturing proper innovation incentives among firms through appropriate funding programs or intellectual property rights systems at a more macro level. The goal should be to improve incentives for innovation activities among firms, to provide them with better access to finance and business support services, and to encourage the innovative usage of ITs in all levels of the business and society.

(C) *Diversity should be promoted to create more business value from IT investments.*

Although chapter 3 specifically looks at the issue of diversity, there are indications of its importance in other chapters as well. We learned from chapter 3 that diversity of a firm's external partners is an influential factor to its innovation performance. A diverse alliance makes knowledge from a broad range of technical disciplines, areas of expertise, and cultural backgrounds accessible to the firm. It also leads to intake of divergent ideas, perspectives and mindsets to create innovative solutions. From chapter 4, we learned that diversity of business applications in a firm's IT portfolio is important to improve different aspects of performance. While some IT systems like KMS and SCM contribute to market share of the firm, others like CRM are more important to revenue and productivity growth. Chapter 5 also highlights the importance of diversity as it concludes that change initiatives are more influential when combined with each other rather than when acting in isolation. In other words, more diverse clusters of organizational practices are typically more productive. Yet, it is evident from all these studies that there is practically a limit to diversity, beyond which the firm's alliance portfolio becomes unmanageable, its application portfolio becomes too complex, or its change environment becomes such chaotic that the significant impact of diversity on performance starts to decline or even converse.

What do the above findings mean for corporate managers and possibly for policy makers? In simple words, diversity is a good thing and therefore should be promoted. However, the benefits of greater diversity normally come at the cost of greater complexity and need for coordination. To promote diversity, managers need to design and allocate proper incentives. They also need to make the relevant processes such those of inter-organizational collaboration, IT adoption or organizational change smoother and less risky for all employees of the firm to engage in, while maintaining the necessary coordination and control mechanisms. In this respect, the role of special subgroups of employees such as boundary spanners, knowledge brokers, communities of practice, lead users and change champions should not be ignored but strengthened. An important scheme to promote diversity is to invest in human capital through training and education programs that are meant to increase the level of knowledge and confidence of employees in working in diverse environments and dealing with diverse configurations.

From a policy perspective, governments should stimulate and incentivize diversity. For instance, subsidy grants should be designed and allocated such that firms are encouraged to participate in or establish more diverse collaboration networks. The gain then would be a higher innovation performance and productivity of firms that, under healthy market conditions, can be translated to higher quality, more diverse or cheaper products and ultimately to higher standards of living for the citizens.

(D) *Change should be promoted to create more business value from IT investments.*

Change has a close connotation with innovation. We call from chapter 5 that change entails organizational and/or marketing innovation. In chapter 4, when we suggest managers to use IT to innovate their products and processes, we mean that they need to (radically) change their work routines and service offerings before they can enjoy the benefits of their technology investments to a good extent. Even the topic of inter-firm collaboration and partner diversity in chapter 3 has a close connection to change. Interorganizational collaboration implies changing the policy, strategy and culture of the firm towards breaking down or at least fading firm boundaries in favor of more open approaches to business and competition. Engaging in a partnership or alliance is not achievable through simply opening up a firm's doors, but requires several changes in norms and routines, ex-ante and ex-post Partnering with a more diverse set of partners involves even more changes and challenges as the firm needs to prepare itself to communicate and work with different types of partners in different countries.

In chapters 3, 4 and 5, we found that moderate to high levels of change (being interorganizational collaboration, product innovation or organizational change) if accompanied with proper levels of investment in supportive technologies lead to performance and/or competitive improvements. This alone justifies why we argue that corporate leaders and, at a higher level, policy makers need to work on creating a change mindset and renovation culture. Big players in the market know this rule very well and act upon. According to Dell Inc. "improving IT productivity means change."[104] To this end, it is vital to build understanding of the change necessity in employees, to articulate effective change messages among them and to provide them with facilitating means. That is where IT can play the role of a powerful change agent itself.[105] Given the importance of change and innovation for economic growth, governments should improve incentives and provide guidelines to identify successful clusters of practices (that go well together) and then should facilitate the process of replication and dissemination of best practices among as many firms and industries as possible. This will have tremendous returns for the economy as well as the society.

The current pace and scope of scientific developments and industrial innovations is a good sign that advances in information and communication technologies will continue into the future with an ever-increasing speed. The main bottleneck for

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[104] For the article, see http://content.dell.com/us/en/enterprise/d/large-business/improving-it-productivity.aspx.

[105] See the Wal-Mart pressroom at: http://walmartstores.com/pressroom/news/9625.aspx for announcements of and discussions around a recent, large-scale change initiative throughout the whole organization. This is a good example of how a global role model of strategic IT adoption uses technology both for stimulating and communicating change as well as complementing and moderating change. In fact, these are the dual roles of IT discussed in length in chapter 5.

corporate managers and state officials will not be the ability or availability of IT. Instead, the bottleneck is to acquire a good understanding of why we use IT and how to use it. The greatest payoffs will go to those companies and countries which are able to widen this bottleneck and future research endeavors of us, as scholars, can help them in this regard.

2. Frontier Research Opportunities

The findings of this thesis allow us to identify a number of avenues with great promises for future research. The following is a list of potential research opportunities we propose:

- *Measuring intangibles*: Intangibles are very important for assessing the business value of IT, as they constitute a large part of IT effects. Measuring intangibles would allow us to gain a better understanding of the true nature and size of IT effects and dynamics both at the micro and macro level. IT leads to increases in the quality, ease-of-use and timeliness of products and services. IT results in better alignment and coordination among business processes. IT also affects customer satisfaction, customer-orientation of the firm and the quality of its relationships with business partners. These effects are all intangible, tacit and hard-to-measure aspects of products, processes and relations of the firm.

  One of the main obstacles faced in the course of this research was to measure intangibles. As an example, consider organizational roles of IT. We need to be able to measure IT roles before we can quantify the relationship between different application types and different roles or the contribution of any single role to formation of an IT-enabled capability. We also need to measure IT roles in order to assess and compare their individual impacts on performance of the firm and its IT-dependent initiatives. For the purpose of measuring intangibles, reliable and consistent scales, instruments and proxies shall be developed, tested, and standardized. Thereafter, primary data on intangibles, which is highly lacking, can be collected through surveys, interviews and case studies.

  Organizational change was another intangible concept that was dealt with in this thesis. Companies invest billions, if not trillions, of dollar every year changing their organizations. Governments also invest heavily in restructuring the economies under their control every year. However, these investments are usually treated as one-time expenditures and neglected from appearing in balance sheets and national accounts. Investments in organizational capital last for many years and lead to enduring productive assets. By failing to systematically document and measure these intangibles, we miss an essential part of organizational assets, underestimate the true effects of technology, and overlook the importance of complementarities in our cash flow and GDP calculations.

Measuring change by itself is a difficult task. Standard datasets typically do not contain detailed information about such intangible aspects as organizational change. We used secondary sources of data to measure change, while having access to primary data would have increased the precision and reliability of our measures. As an important avenue for future research, we suggest researchers develop proper instruments and proxies to measure intangibles. A related potential area concerns developing techniques or conducting studies that systematically account for intangibles, classify them based on their key characteristics (i.e. construct typologies) and assess their business effects and economic value through a mix of qualitative and quantitative methods. This can be considered as an important attempt to open up the black box of organizations and to better understand how they function and how they evolve over time. As an example, Brynjolfsson (2005) argues that "Seven practices characterize highly productive companies turning them into 'digital organizations.' IT is the catalyst, but organizational capital provides the context."[106] These practices can be combined into a composite indicator or compound index that can be later used as a measure of organizational capital in empirical studies.

- *The black box of innovation:* We learned from this thesis that innovation plays an indisputable role in creating value from technological investments. At the same time, we realized that different types of innovation exhibit a complex interplay among themselves. Not every type of innovation works in every context. Successful adoption of some technologies depends heavily on process innovation while others are more dependent on introduction of new products

[106] For details, see: "VII Pillars of Productivity" published in *Optimize* (May 2005, Issue 22), accessible at: http://ebusiness.mit.edu/erik/Seven Pillars of Productivity.pdf

and services. In some cases, structural innovations are more relevant to optimize IT investments while there are other circumstances where marketing innovations play a more prominent role. A more complex situation is encountered when there are synergistic effects or counter forces among different types of innovation. For example, our findings suggest that the combination of product and process innovations typically lead to super-additive effects while structural and marketing innovations may hardly fit together.

Future research has the potential to more meticulously examine the role, nature and impact of innovation under diverse use contexts and organizational conditions. This research direction will shed more light on the black box of innovation to understand how workers and managers combine their daily use(s) of technology with the innovative aspects of their tasks and responsibilities. In this regard, specific qualitative approaches such as in-depth case studies as well as quantitative studies at lower levels of organization like at individual, group or task level seem very much supporting.

- *Disentangling IT:* We argued that different types of IT systems play different roles in the organization depending on the nature of processes they handle and the level of change they generate. We further learned that different IT applications have varied effects on different dimensions of firm performance. Different technologies are developed with different a priori objectives in the mind of their developers. Similarly, different technologies are adopted for different purposes. While some technologies target inter-firm aspects of business through facilitating networking and partnering, others focus on intra-firm aspects through making processes more efficient and workers more productive. Some applications support the firm to internally cut costs while others create more sales opportunities and thus modify its market position. IT infrastructure builds the information and communication backbone of the company, whilst more advanced, business software are installed on top of it and create strategic value for the firm. When comparing IT with non-IT resources, this is specifically a unique characteristic of IT that makes it applicable in and adaptable to a wide array of application domains and functional areas. After all, IT is a GPT.

Following the above line of reasoning, aggregating the IT capital of the firm into a single, unified measure results in a simplified representation of the potential role of technology and would deprive us from understanding fine-grained details about the black box of IT. However, as a strong barrier, detailed and objective information about different types of IT systems, specifically over time and for representative groups of companies or sectors, is currently very scarce and also cumbersome to collect. Future endeavors can alleviate this shortcoming once they engage in gathering reliable and representative data about a broader spectrum of IT applications in a systematic and persistent manner. A first step is to define general classes of IT types that can be easily and unequivocally incorporated into standard IT statistics and surveys. Research on the more qualitative aspects of computer hardware and software allows us to develop widely-accepted typologies and taxonomies that can be further used in the process of data collection. The typological model proposed in chapter 2 of this thesis can be considered as a first attempt in this direction. Yet, we still consider this as a promising open area for future works in the field.

- *Cross-sectoral differences:* In multiple parts of this thesis, we understood that considerable differences between manufacturing and services firms exist with respect to their pattern(s) of technology adoption, the type and size of effects they encounter, and the contextual conditions under which these effects are maximized (or optimized). The operational routines, core activities and nature of primary outputs differ significantly between manufacturing and services firms. As a result, they adopt technology for different purposes and use it rather differently. In addition to different business needs, manufacturing and services companies follow rather different patterns of innovation, organizational change and alliance formation. In simple words, they are not equally inclined towards these phenomena. These structural, behavioral, and contextual differences lead to more diversified effects of technology in these two broad sectors of the economy.

  The significant differences above dictate us to conduct sector-specific as well as cross-sector studies to better understand the process of IT value creation in our contemporary economy. We even push forward the research limits one step further by suggesting IT business value studies at the level of sub- or sub-sub-sectors of the manufacturing and services. We expect that there would be remarkable differences between firms in the wholesale and the financial sector with respect to how they use IT and what type of benefits they observe. Similarly, IT is expected to play largely different roles in a high-tech manufacturing sector like aerospace engineering compared to a low-tech one like footwear and apparel. As a high potential avenue for future research with great promises for advancement of our understanding of organizations and their use of IT, cross-sectoral studies at different layers of the economy help us to open up many black boxes: *the black box of IT*, *the black box of innovation*, and *the black box of organization*.

Summary

There is an essential quest in the literature to open up the "black box" of Information Technology (IT) by identifying and explaining how and why IT creates value for the firm. The present dissertation is an attempt to clarify the role of innovation in the process of value creation from IT investments. It belongs to the mainstream of "IT business value" research. After an introduction of the topic in the first chapter, the second chapter identifies the six primary roles of IT as a general purpose technology. These roles, in the order of strategic value for the firm, are: (1) Transformation, (2) Integration, (3) Coordination, (4) Automation, (5) Communication, and (6) Information. The proposed descriptive IT typology in this chapter is evaluated through two rounds of in-depth problem-centered, qualitative interviews with a panel of 54 senior IT managers and consultants. The third chapter studies one of the many ways through which IT improves the performance of product innovating firms. IT is found to be a significant determinant of the diversity of a firm's R&D alliances. In return, partner diversity significantly contributes to innovation performance, yet through a sigmoid pattern. The chapter relies on a representative sample of 12,811 innovating firms in the Netherlands over the period 1994-2006 and concludes that stakeholder diversity of R&D partners is more important to radical innovations of the firm while the geographic diversity is mainly important to incremental innovations. The fourth chapter focuses on the performance effects of a specific class of IT assets, i.e. enterprise systems. Four aspects of firm performance are analyzed: (1) productivity, (2) turnover, (3) market share, and (4) profitability. Using a sample of 33,442 enterprises in 29 European countries in the period 2003-2007, the analysis of this chapter sheds light on the significant mediating role of product and process innovation in creating value from enterprise systems. The results also imply that less complex and more domain-specific systems are easier to understand, learn, adjust and use by employees and hence more likely to result in successful implementations. Chapter five studies complementarity effects and clustering patterns between IT and three dimensions of organizational innovation: (1) process changes, (2) structure changes, and (3) boundary changes. The findings, on the basis of a panel of 32,619 firms in the Netherland during 1994-2006, imply significant complementarities such that organizational change initiatives of the firm do not lead to productivity improvement or even result in productivity decline if they are not combined with appropriate levels of IT capital stocks. These clustering patters are found to be stronger in services than in manufacturing firms. The proposed method in this chapter is an attempt to mitigate endogeneity concerns that are dominant in IT business value research and allows us to conclude that a significant part of the productivity enhancements normally attributed to IT are rather contributions from the firm's change initiatives that are initiated or provoked by IT. The dissertation concludes with managerial implications of the research and recommends several areas with promising potential for future research.

Keywords: Information Technology, Firm Performance, Innovation Performance, IT Business Value, IT Roles, R&D Alliances, Partner Diversity, Enterprise Systems Adoption, Organizational Change, Organizational Complementarities

Samenvatting

In de Informatie Technologie literatuur bestaat een sterke tendens de zogenaamde 'black box' van Informatie Technologie (IT) te onderzoeken door te analyseren hoe en waarom IT voor de onderneming waarde creëert. Dit proefschrift is een bijdrage de rol van innovatie in het proces van waardevorming door IT-investeringen te onderzoeken. Het behoort tot de zogeheten 'IT business value research'. Na de inleiding van het centrale onderzoeksthema in het eerste hoofdstuk, worden in het tweede hoofdstuk zes primaire rollen van IT als een 'general purpose technology' bediscussieerd. Deze rollen -in volgorde van strategische waarde voor de onderneming zijn: (1) Transformatie, (2) Integratie, (3) Coördinatie, (4) Automatisering, (5) Communicatie, en (6) Informatie. De voorgestelde IT-typologie in hoofdstuk 2 is gevalideerd door middel van twee rondes diepgaande probleemgerichte interviews met een panel van 54 senior IT-managers en consultants. Het derde hoofdstuk bestudeert een van de mogelijkheden van prestatieverbeteringen van het product innoverende bedrijven ten gevolge van IT. Laatstgenoemde is een belangrijke factor voor de diversiteit R & D samenwerkingsverbanden. Het verband tussen partner diversiteit en innovatie prestaties van bedrijven laat een S-vormige relatie zien. Hoofdstuk 3 is gebaseerd op een representatieve steekproef van 12.811 innoverende bedrijven in Nederland gedurende de periode 1994-2006 en concludeert dat 'stakeholder' diversiteit van R & D-partners belangrijk is voor radicale innovaties van de onderneming, terwijl de geografische diversiteit vooral belangrijk is voor incrementele innovaties. Het vierde hoofdstuk richt zich op de invloed van een specifiek onderdeel van IT namelijk 'Enterprise Systems' op de prestaties van bedrijven: (1) productiviteit, (2) omzet, (3) marktaandeel, en (4) winstgevendheid. Met behulp van een steekproef van 33.442 bedrijven in 29 Europese landen in de periode 2003-2007, werpt de analyse van dit hoofdstuk licht op de bemiddelende rol van product- en procesinnovatie in het creëren van waarde door de ondernemingssystemen. De resultaten laten zien dat minder complex en domein-specifieke systemen eenvoudiger te begrijpen zijn, te leren, aan te passen, en te gebruiken door werknemers. Zij zullen met grote waarschijnlijkheid resulteren in succesvolle implementaties van deze systemen. Hoofdstuk 5 bestudeert complementariteiten en clustering patronen tussen IT en drie organisatorische innovatie dimensies: verandering in (1) het proces, (2) de structuur, en (3) de grenzen van het bedrijf. De bevindingen, op basis van een panel van 32.619 ondernemingen in Nederland tussen 1994-2006, laat een significante rol van complementariteit op de productiviteit van bedrijven zien, waarbij de organisatorische veranderingen in de onderneming niet tot productiviteitsverbetering leiden en zelfs resulteren in productiviteitsvermindering als ze niet gecombineerd worden met een passend niveau van IT kapitaal. Deze clustering patronen lijken sterker te zijn in de dienstensector dan in de industrie sector. De voorgestelde schattingsmethode in dit hoofdstuk is een poging om endogeniteitsproblemen te beperken. Het blijkt dat een aanzienlijk deel van de productiviteit verbeteringen die normaal gesproken toegeschreven worden aan IT, worden veroorzaakt door de verandering van de onderneming en eigenlijk indirect zijn gestart of uitgelokt door IT. Het proefschrift sluit af met het management implicaties van het onderzoek en suggereert verschillende gebieden met veelbelovende mogelijkheden voor het toekomstig onderzoek.

To avoid situations in which you might make mistakes may be the biggest mistake of all.

-- Peter McWilliams