# GROWTH OF INTANGIBLE INVESTMENTS AND ITS EFFECT ON THE ECONOMY

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# Executive Summary

The OECD countries have realised low business investment levels and productivity growth since 2000. Economists have attempted to explain the declining growth by pointing to a potential mismeasurement of economic growth due to the increased concentration of business investment towards intangible assets. It is puzzling that the Tobin's Q (which is the ratio of the stock market value of firms and the their replacement value) is exceptionally high for firms, although the tangible investments have decreased in the recent years. Hence, it is important to investigate the overall rise of intangible investments and understand their effect on economic growth especially for the recent time period. This study takes up this task for the USA, USA, the UK, the EU, Germany and the Netherlands during 1996-2015.

The study is relevant to the "Management of Technology (MOT)" course at Delft University of Technology as economic growth and business investments go hand-in-hand. Investments are necessary for firms to expand their production capacities which also benefit the society in improving the economic condition of a nation through job opportunities, increased tax revenues and so on. The knowledge of business investments, labour productivity and economic growth also benefit businesses in better strategizing for emerging threats or opportunities in an ever-changing world. For example, during the COVID-19 pandemic, not only governments had to find ways to prevent an economic meltdown, but businesses had to implement new ways of doing businesses to stay afloat. This study help managers and entrepreneurs to understand the changing trends of investments and innovation, as well as to realise the effect of intangible investment on labour productivity and economic growth.

The intangible assets are different and have unique properties: appropriability, non-rivalry, sunkness and scalability which make them beneficial to gain competitive advantage for the businesses. The literature also discusses the relationship and the differentiation between intangible assets and tangible assets. However, intangibles are a recent, contemporary phenomenon and have only recently been identified by the System of National Accounts (SNA). The definitions and categorisation are yet not complete. The industry standard of estimations of intangibles are not fully built, hence there is every reason to think that intangible assets and their effects have not (yet) been appropriately measured.

The growth accounting model, utilised as a standard for almost 60 years now for calculations related to economic growth and technological progress, does not directly evaluate the intangible assets contribution to economic growth. Although the residual factor i.e. Total Factor Productivity (TFP) understood as technological progress for the country partially fulfil the gaps like these. Through this methodology, this study has empirically estimated the impact of intangible investment on GDP or growth output as well as the effects of other components i.e. TFP, labour productivity and economic growth in the advanced countries including the USA, the UK, the EU, Germany and the Netherlands during 1996-2015.

The growth accounting analysis uses two different data bases, one by the OECD and the other, the EU KLEMS economic database, to estimate the growth of intangible assets (comprising of intellectual properties, research and development and literary and artistry items is realised) in comparison to tangible assets. The growth in Information and Computer Technology (ICT) shares is also analysed for these countries as the literature discusses the growth of ICT shares in recent years which partially comprises of intangible assets in the form of computer databases and software for IT and telecommunication industry. Although the growth of intangible investments is increasing, the quantitative contribution of these assets to GDP growth are still relatively small.

A different analytical framework to estimate the contribution of intangible capital formation to economic growth has been proposed by Corrado, Hulten and Sichel (CHS) and applied to the US economy. CHS showcase the importance of additional intangible assets like brand-equity and firm specific resources, and their approach is interesting for further research. While many researchers use the CHS framework for calculation of economic growth based on intangible investments along with other components like labour and capital, it was not possible to do this in this thesis – because the cost of buying the data needed in the CHS approach was prohibitively high.

Further research and study is required to get a clearer picture of intangible investments and their impacts on economic growth discussed in this study. Also, the role of economic institutions, industry financial reporting and auditing committees and governments is important in building policies for right estimations and utilising the positive potential impact of intangible assets for overall societal and economic growth.

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# Chapter 1: Introduction

## 1.1 The problem statement

Business investments are depressed in most of the OECD countries (Bean, 2016 as cited in Haskel & Westlake, 2018a), and productivity growth in advanced countries has been much weaker since 2000 than in the 1990s (OECD, 2016). The secular stagnation of investment and productivity growth is puzzling for most of the economists:

- Corporate profits are at a constant high and this should have elevated animal spirits and raised business investments (Haskel & Westlake, 2018a).
- There is an increased spread of profits and growth for highly- productive firms versus other firms (OECD, 2016).
- It is not only lower productivity growth but the technological aspect of growth known as total factor productivity is declining as well (Haskel & Westlake, 2018a)

Economists have attempted to explain the observed secular stagnation of growth and declining labour productivity growth. Notable explanations of secular stagnation include the following:

1. There is a dearth of general-purpose inventions, similar to the major breakthroughs for innovation in the 20th century, and hence productivity growth is on a declining trend (Haskel & Westlake, 2018a).
2. Investment and long-term productivity growth are held back by the growth of Too-Big-To-Fail banks, excessive leverage of non-financial corporations and an increase in non-performing loans (OECD, 2016).
3. Corporations have been investing more in intangible investments as compared to tangibles and these intangible investments are not showing up in higher productivity growth, also because of measurement problems (OECD, 2021).

There is a dearth of studies on the effect of (rising) intangible investment on productivity and economic growth. The aim of this thesis is to resolve this puzzle and understand the contribution of intangible business investment on growth output and productivity in the USA, the UK, EU, Germany and the Netherlands (1996-2015).

## 1.2 Background & Literature Review

According to the literature, tangible investments made by the firms have stagnated in recent years, which has been one of the reasons for the observed slowdown of productivity (and TFP) growth. The reason is that the new capital goods (machines) embody the latest technologies – and therefore, the installation of new capital goods brings with it technological progress and productivity growth. However, the decline in tangible (fixed) business investment has coincided with an increase in intangible investments by firms (Stehrer, 2019).

The main purpose of an investment is to contribute to the production process and generate income for the firm. Moreover, investments lead to the accumulation of (tangible and intangible) assets (Vosselman, 1998a).

The contribution of investment to productivity growth is generally estimated using the so-called Growth Accounting Model (Brynjolfsson et al., 2018). According to this model, labour productivity growth depends on (a) Total Factor Productivity (TFP) growth, which stands for the rate of exogenous technological progress; and (b) the contribution of capital deepening, which is defined as the increase in capital stock per hour of work. Firms that have more capital per hour of work will have a higher level of labour productivity than firms with fewer capital goods per hour of work.

In principle, the amount of 'capital' per hour of work includes both tangible (fixed) capital and intangible capital. But because intangible assets are more difficult to measure than tangible capital goods (machines; trucks; buildings; etc.), most Growth Accounting studies fail to (completely) account for the impact of rising intangible assets on productivity growth.

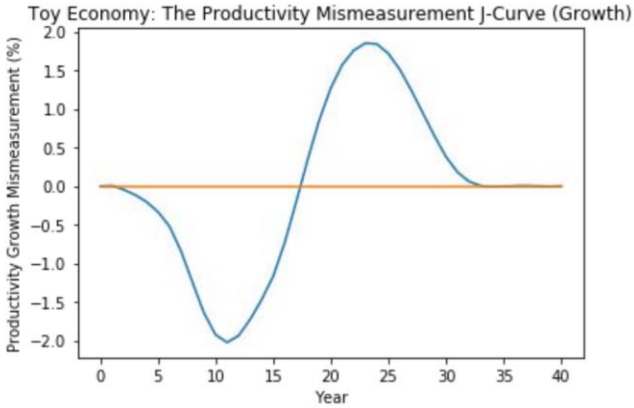
In this context, Corrado, Hulten and Sichel associate the reason for declining labour productivity growth to the inaccuracy of calculating business intangibles in the national accounting framework (Corrado et al., 2012). Similarly, Eberly and Crouzet indicate that 50% of the decrease in US productivity growth or TFP growth during the early 2000s is due to rising markup values and the mismeasurement of intangible capital.

Van Ark, de Vries and Erumban (2021) indicate that there is a puzzle: investments in ICT and digital services have increased, but without contributing to an increase in labour productivity growth. Haskel and Westlake realise there are other factors which establish the growth of intangible assets and labour productivity. The spillovers and synergies through knowledge-sharing between the firms is a common aspect of intangibles which can act as an advantage for leading firms as compared to laggard firms. However, it can lead to slower growth in intangible assets and TFP in return (Haskel & Westlake, 2018).

Brynjolfsson et al., 2018 explain the stagnation as part of innovation in form of the GPT. "General purpose technologies (GPTs) are engines for growth. They are pervasive, improve over time, and lead to complementary innovation (Bresnahan and Trajtenberg 1995)." They are crucial innovations of their times and carry the huge potential to radically change the economic environment over the time. However, realizing that potential requires unmeasured investments and a major shift in the fundamentals of production itself. Hence, the measurement of productivity growth as a residual in growth accounting for input changes in the production function falls short when the technology changes the production function itself (Brynjolfsson et al., 2018).

The problem is that intangible investments are not readily counted on a balance sheet, which leads to mismeasurement of productivity as discussed before. Brynjolfsson et al (2018) discuss the importance of GPTs and argue that these technologies not only transform existing capital goods (in qualitative terms) but also create entirely new asset classes (including intangible assets). However, these transformations of the production process do not occur instantaneously. This (in their argument) leads to the Productivity Paradox, or the fact that measured productivity growth is not (yet) increasing, when the economy is undergoing a fundamental technological transformation. A historical example of the Productivity Paradox concerns the technologies based on the British industrial revolution which led to "Engels' Pause": a long period of capital accumulation, industrial innovation, and wage stagnation (Allen 2009; Acemoglu and Robinson 2013 as cited in Brynjolfsson et al., 2018).

Figure 1: Productivity J-curve




Source: (Brynjolfsson et al., 2018)

Figure 2 is helpful in explaining the Productivity Paradox. As firms adopt a new GPT, TFP will be underestimated initially because capital and labour are utilized to accumulate intangible capitals. In future, TFP growth will be overestimated, once the intangible capital goods begin to generate measurable output. Therefore, Brynjolfsson et al. (2018) argue that the error in the measurement of TFP growth follows a J-curve, initially dipping while the investment rate in unmeasured capital is larger than the investment rate in other types of capital, and then increasing as intangibles begin to affect measured production. In the long run, as investment quantities and capital reach a steady state, mismeasurement disappears even if the intangible investments do not. They argue that such mismeasurement occurs in the case of new promising GPTs such as Artificial Intelligence (AI), and a subfield of AI, i.e., machine learning (ML) (Brynjolfsson et al., 2018). According to Brynjolfsson et al. (2018) a similar mismeasurement (of intangible assets) can be observed when considering the ratio called Tobin's Q. The Q ratio was introduced by James Tobin in 1970. Tobin's Q is defined as the market value of an asset/firm divided by its asset/firm replacement cost. Ideally this ratio should be around 1 (Naastepad & Storm, 2021).

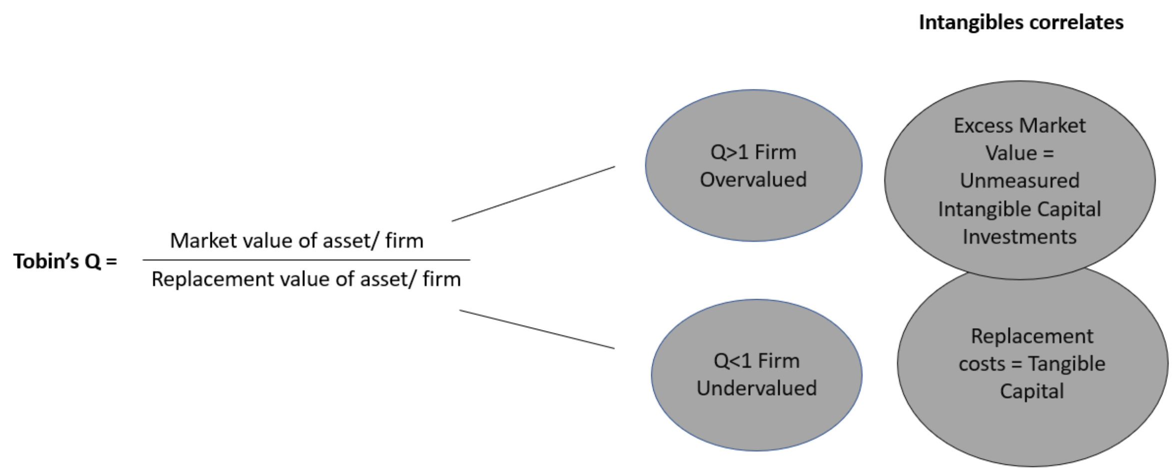
- if Tobin's Q< 1: the stock market undervalues these firms, because the market value of the firm is less than its replacement value. (It therefore makes sense to buy up this firm, because the value of installed capital goods is larger than the stock market value.)
- If Tobin's Q>1: the stock market overvalues these firms, because the market value is more than the replacement value.

Figure 2: U.S. Equity Valuation: Q-Ratio


Source: https://thefelderreport.com/portfolio/tobins-q/

It can be seen that Tobin's Q for US firms has steadily increased to values much higher than 1 during the 1990s and during 2010-2021 (see Figure X). Brynjolfsson et al. (2018) argue that the high Tobin's Q (Market to Book Value) is attributable to unmeasured intangible capital (and is not necessarily caused by excess valuation of the shares of these corporations).

Figure 3: Q Ratio




Source: Author's Interpretation

When a firm's market value rises more than the observed investment, it can be inferred that the difference is reflecting the value of intangible capital investments that can be correlated to the tangible investment. The authors call these correlated intangible investments "intangible correlates" (Brynjolfsson et al., 2018).

The preceding argument can be illustrated using the following example. Consider a company that wants to become more “data-driven” and shift its production processes and utilize new ML prediction technologies. This firm needs to modify its labour mix; it will need a software development team to develop software, and support and a marketing team to teach its customers on how to order products online instead of in person. While the company builds online ordering applications and business processes for that purpose, it is not using those investments to produce more inventory of final goods. Also, software knowledge of the company, hiring practices, organizational expertise and customer training to use digital systems are left unmeasured on the balance sheet in comparison to the tangible capital assets of the firm. However, the (present-discounted and risk-adjusted) value of these unmeasured assets matches the costs incurred to produce them. But during the period in which that output is forgone, the firm’s traditionally measured productivity will deteriorate substantially, as output per worker will have gone down. However, in the future, when these hidden intangible investments will start to generate growth, a shift occurs and this will show as an increase in output per worker. “Therefore, in early investment periods productivity is understated, whereas the opposite is true later when investment levels taper off.” (Brynjolfsson et al., 2018, p. 15).

And, a similar J-curve exists for productivity growth rates as well. Early in GPT diffusion-adoption process, intangible investment growth is larger than intangible capital growth. Due to unmeasured output growth, measured TFP growth is lower than true TFP growth. Later in the future, investment growth reduces below the growth rate of the installed intangible capital. Also eventually, the growth rate equalizes and productivity mismeasurement disappears (Brynjolfsson et al., 2018).

## 1.3 Research Objective and Research Questions

As seen, the puzzling situation of declining productivity and economic growth in most of the countries is the biggest concern nowadays. But is it actually the ‘mismeasurement’ (of intangible capital formation) and if so, to what extent this conundrum be solved? A lot of economists, and researchers have been trying to decode the reason for secular stagnation and declining economic growth in spite of enormous business and industrial efforts and investments made in new technologies (GPTs) such as AI, as mentioned before. The study of intangible investments and their impact on economic growth is a small step toward solving this issue. As a student of ‘The Technical University of Delft, Management of Technology ‘MOT’’, the objective of this thesis is

*Analyse the nature of the business investments in the USA, the UK, the EU, Switzerland, Germany and the Netherlands (during 1995-2021). Also, understand the effects of these investments (intangible) on growth output, labour productivity and total factor productivity (and hence for economic growth) in the USA, the UK, EU, Germany and the Netherlands based on the consolidated data (from EU KLEMS and OECD) for the time period 1996-2015.*

It is essential to remember that the business investment and the economy always go hand in hand. The productivity and value add at the economical level, actually starts at the firm and industrial level. Investment is nothing but firms buying capital goods to expand their production capacities and eventually improve the overall production process. Hence, increased productivity using investments or capital intensity (in economic terms) allows businesses to produce more goods and services per unit of input. This ultimately aids economic growth with increased profitability, more tax revenues and employment for the country. Therefore, the starting point of this study is to understand these investments (both tangible and intangible) and their importance for the growth of businesses and industries.

The study is relevant to the MOT course as businesses need to advance and analyse emerging threats or opportunities in an ever-changing world. Businesses do strategise as per the economic situation not only in terms of purchase and resource allocation, but also via product research and development, investment opportunities, marketing and many other tactical decision-making strategies. This study will make us aware of these changing trends of investments as well as its effect on economic growth.

The above discussion brings us to the main research question and the sub-questions of this thesis:

*What has been the impact of intangible investment on growth output, total factor productivity, labour productivity and economic growth in the USA, the UK, the EU, Germany and the Netherlands during 1996-2015?*

As discussed in the previous section, many OECD countries are observing consistent low tangible business investment which has contributed to declining output, productivity (and TFP) growth in recent years. As researchers argue the growth of intangible investments has led to this decline. The focus of this thesis is to do an empirical analysis of growth output, TFP and labour productivity based on intangible investments for the mentioned countries during the discussed peak of intangible assets.

However, it is necessary to understand that economic analysis doesn't directly measure or utilize intangible assets to understand their act on economic growth. Intangible investments have very recently been included in economic growth estimations after observing their growing importance at the firm level. Hence, the following sub-questions will help in achieving the key to the main RQ.

**Sub-Research Questions**

The definition of intangible assets isn't very clear in the literature. Also, the similarities and differences between intangible to tangible assets are important in understanding the assets in depth. The business perspective of businesses in adapting these intangible assets is also significant to comprehend this change in trend:

*What is intangible capital and why is it important for business and economic performance? Why has intangible capital become more important over time?*

After having clarity on intangible assets and their types, it becomes easier to determine the measurement techniques of intangible assets. As iterated earlier, the information for intangible assets flows from the firm level to the industrial level which is finally utilised for economic growth. Hence, the measurement and estimation of intangible assets is equally important:

*How can one measure intangible capital? Which measurement techniques already exist at the firm or industry level as well as economical level for intangible investment?*

Once, the overall picture of intangible investments is clear, it becomes easier to examine the data sources available at the economical level for the intangible investments for the advanced countries and hence, draw an empirical analysis of intangible investment growth and its impact on the economy:

*What has been the empirical contribution of intangible capital on growth output, labour productivity and TFP growth in the USA, the UK, the EU, Germany and the Netherlands during 1996-2015? What has been the empirical contribution of intangible capital, TFP to growth output based on the growth-accounting model[1]?*

It is interesting to note that the research questions pose three below mentioned hypotheses which we will try to assess throughout this report.

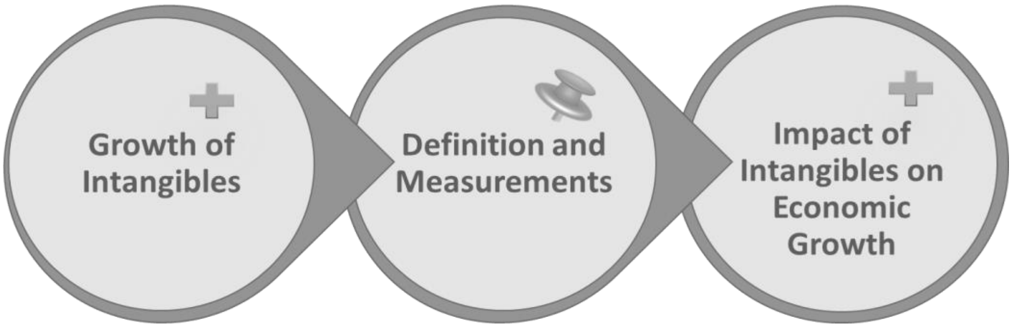
1. There is positive growth of intangible investments in the advanced countries.
   *As discussed, the researchers have established the reasoning of declining labour productivity and economic growth on positive growth of intangible investments by the firms. This gives us the first idea to examine if there is definite growth of intangible investments by the firms and we will examine for the advanced economies such as the USA, the UK, the EU, Germany and the Netherlands.*

2. The intangibles are clearly defined and measured.
   *If we infer the growth of intangible investments throughout the businesses and industries for these economies, the important question arises if the definition and categorization of intangibles is in place for businesses, industries and analysts at economical level to evaluate and measure the growth and impact of intangibles overall.* In this thesis, we will identify information and guidelines set by financial reporting and auditing institutes for businesses and industries. We will also recognise the information, data and methodology covered by economic institutes and databases such as EU KLEMS, OECD and CHS.

[1] Growth accounting model is the traditional method used by economists to understand the amount of economic growth based on three important key factors: capital, labour and technological advancement (TFP) (Kenton, 2021a).

3. Intangible investments have positive effect on economic growth.
   *Lastly, based on the previous two hypothesis including the background and the literature of intangibles, the idea is to identify the impact of growth of intangible investments on economic growth. Also, alongside it is important to estimate their impact on Total Factor Productivity (TFP), the technological aspect of economic growth.*

Figure 4: Hypotheses




Source: Author's Interpretation

## 1.4 Method of the thesis

The nature of (rising) intangible investment, the reasons why firms are increasingly investing in intangibles, and the quantitative importance of intangible assets for businesses is done using literature review. Also, the methods by which intangible assets are measured and their limitations are analysed and discussed using the literature published in Google Scholar (GS).

Then, the data collection and consolidation for growth outputs, labour productivity and capital (intangible) is done through EU KLEMS and OECD. This helps in performing the comparative study of the impact of the rise of intangible investment in the USA, the UK, the EU, Germany and the Netherlands. Then, using Growth Accounting model the contribution of intangible capital formation to growth output is estimated. using the Growth Accounting Model. The OLS regression analysis performed in Excel, will be used to calculate the shares of the variables, necessary for estimating the intangible investment contribution to growth output. CHS framework discussed in the background and literature review of this chapter will also be analysed to understand if its viable to use the framework in the calculation of intangible assets in economic growth in the future.

## 1.5 Structure of the thesis

As this chapter, Chapter 1 covers problem statement, background, thesis objective and research objectives. The next chapters elaborate and find answers to the sub-questions and eventually resolves the main RQ.

Chapter 2 gives an overview of intangible assets and their differences from tangible assets. It also discusses the categorization of intangible assets and realise their definition and meaning throughout the literature.

Chapter 3 discusses the measurement tools already used for estimating intangible assets. It covers quantitative and qualitative techniques utilised by the industry

Chapter 4 explains the growth accounting model and the background behind this tool which is important for understanding the significance and relevance of the model to economic growth analysis

Chapter 5 discusses the data sources and methodology used for the calculation of growth outputs, growth inputs (capital, labour). It showcases the variables recognised for performing the empirical analysis of TFP, growth output and labour productivity.

Chapter 6 shows the results and discusses the interpretation of the findings in terms of the growth of intangible investments, and its contribution to growth output for the different countries during 1996-2015 (mainly).

Chapter 7 concludes and draw important policy recommendations for the research and study of intangible investments and its utilisation in the economy at the length. It also addresses the limitations and reflections of the study from the author’s point of view.

# Chapter 2: What are Intangible assets and why are they important?

## 2.1 Introduction

Capital formation, or investment, concerns the acquisition of new or existing fixed assets by the business sector which are used to replace and/or expand the capital stock of firms. These fixed assets are called ‘capital goods’ and firms use them to produce goods and services over a period of time (which is generally the economic life-time of those capital goods). Investments are thus made by firms to be able to expand their production capacities so as to meet their potential future demands. Firms will invest and expand their productive capacity if they expect that these investments will pay off in the future (Hayes 2021). If the expected rate of return on the planned investment is considered too low, firms will postpone or cancel their investment plans – and investment in the economy will go down.

Business investment affects the economy in the short run as well as in the long run. In the short run, business investment directly adds to the aggregate demand for goods and service and contributes to gross domestic product (GDP). As more physical capital is produced and sold, GDP increases. However, business investment is a relatively volatile component of demand and is likely to fluctuate considerably from quarter to quarter. In the long run, increased physical capital stock not only increases the firm’s but also the economy’s overall productive capacity, allowing more production of goods and services with the same amount of labour as well as other resources.

Firms’ investments can be classified into two broad categories: investments in tangible assets, such as machines, trucks, buildings and robots; and investments in intangible assets including R&D, software, organisational improvements and human capital. In recent times, tangible business investment has been declining (relative to GDP) in most OECD economies, whereas intangible investment (as a percentage of GDP) has been rising. Businesses are, in other words, at least partly purchasing ‘intangible assets’ instead of ‘tangible assets’. This trend may reflect a transformation of activities at the firm level as well as structural change in the economy as a whole towards a more knowledge-based economy.

The next section will look into main differences between (old-fashioned) tangible assets and (modern) intangible assets.

## 2.2 Tangible assets versus intangible assets

Tangible assets are physical and measurable assets applied in a firm’s production operations. Assets such as land, factory buildings, trucks, inventory and machines & equipment are tangible assets. Tangible assets provide the means for a firm to produce its goods and services. Tangible assets do wear off eventually and they need regular maintenance (Murphy, 2022). The two main types of tangible assets are:

1. Current Assets: These are short-term assets of a firm that are expected to be consumed, sold or exhausted within a year. Cash, inventory of materials and liquid investments in marketable securities like short-term Treasury bills or bonds are current assets. They are essential to take care of ongoing operations expenses, including paying for wages and materials (Murphy, 2022).
2. Fixed (Non-Current) Assets: Long-term assets of a firm that are expected to last, be consumed, or be converted into cash after at least a year. Property (land and real estate), plant and equipment (PP&E) are fixed assets. They are essential to run the business continuously. They depreciate in value due to 'wear and tear' and their (depreciating) values are calculated in the balance sheet consequently (Murphy, 2022).

In the national accounts, investment in fixed assets is called gross fixed capital formation (Young, 1998). According to OECD (2022), gross fixed capital formation (GFCF) or investment, is defined as "the acquisition of produced assets (including purchases of second-hand assets), including the production of such assets by producers for their own use, minus disposals. These include relevant assets that are intended to be used in the production of other goods and services for a period of more than a year" (OECD Data, 2022a). GFCF accounts for spending done by public as well as private sector on new machines, buildings, transport equipment, computer hardware and so on. Also, it accounts for expenses made to improve existing setups like buildings, structures such as roads by both the sectors. Table 1 describes the fixed assets included in GFCF estimate. However, land and natural resources are not included in this list as GFCF only accounts for expenditure on produced assets i.e. assets that exist only as a result of production process.

Table 1: A typology of tangible (fixed ) assets

| **Published Asset** | **Includes** | **Definition** | **Examples (N.B. not exhaustive)** |
|---|---|---|---|
| Dwellings | Dwellings | Dwellings are buildings, or designated parts of buildings, that are used entirely or primarily as residences, including any associated structures, such as garages, and all permanent fixtures customarily installed in residences | Houses, mobile homes and caravans. However, it should be noted that dwellings do not include prisons, boarding schools or hospitals |
| Transport | Transport equipment | Transport equipment consists of any equipment used to move people and objects. | Motor vehicles, trailers, ships, trains, trams, aircraft, motorcycles, and bicycles |
| Other buildings and structures and transfer costs | Other buildings | Other buildings are buildings that are not dwellings, industrial buildings, commercial buildings, educational buildings and health buildings. | Schools, hospitals, prisons, religious, sport, amusement and community buildings |
| | Transfer costs | Transfer costs, sometimes known as cost of ownership transfer, are the costs associated with buying or selling an asset | Transportation costs, legal fees and stamp duty. |

| | | | |
|---|---|---|---|
| Information and communication technology equipment (ICT) and other machinery and equipment | ICT | This mainly consists of computer hardware and telecommunications equipment such as computers and mobile phones | Computers, laptops, mobile phones and gaming consoles |
| | Other machinery and equipment including weapons | Other machinery and equipment consists of all equipment and machinery that is for general or special use. General use machinery includes engines, turbines, ovens, etc. Special use machinery includes machinery for mining, domestic appliances, agricultural equipment, etc | Typically large electronic equipment (e.g. equipment used in the production of goods and services) |
| | Cultivated | Cultivated assets are livestock for breeding (including fish and poultry) | Livestock not for slaughter, orchards, vineyards, dairy draught |

Source: Office for National Statistics (2022)

Intangible assets are different: these assets are non-physical, often regarded as ‘intellectual’ or knowledge-based assets that carry long-term value for a firm. Patents, trademarks, service contracts, brand equity and copyrights are a few examples of intangible assets (Murphy, 2022). The following Table draws a basic comparison between tangible assets and intangible assets to illustrate the key differences.

Table 2: Tangible vs Intangible assets: key differences

| Tangible Assets | Intangible Assets |
|---|---|
| Physical existence | No physical existence |
| Rivalrous | Non-rivalrous |
| Exclusive | Partially exclusive as spill overs in terms of knowledge and information is possible |
| Relatively easy to measure | Relatively hard to measure |
| Wear outs- depreciates slowly or quickly depending on the asset | No damages but generally has a life span |
| Easy to liquidate due to their physical presence | Not easy to liquidate and sell in the market |
| Cost can be easily determined or evaluated e.g.: damage to the machine | Cost is much harder to determine e.g.: customer dissatisfaction, harm to brand reputation |
| Directly utilized for the firm’s operation | More substantial in terms of the firm’s overall growth and performance |
| Property, Plant, Equipment, Furniture, Inventory, Securities like Cash, Stock, Bonds etc | Patent, Trademarks, Franchises, Licensing agreements, Service contracts, R&D, Computer software, Blueprints, Trade secrets etc |

Source: Murphy (2022)

One difficulty related to intangible assets is that these assets are relatively heterogeneous and therefore difficult to define (in a generalised manner). The literature discusses the lack of one single definition of intangible assets. Experts interpret and define intangibles generally according to the research purpose (Parshakov & Zavertiaeva, 2017a). Early researchers Stewart (1997); Edvinsson and Malone (1997); construed intangibles as intellectual properties as they are nothing but an extension of knowledge, experience, and intellect that encompasses value-creation and competitive advantage for the firms (Kristandl & Bontis, 2007; Parshakov & Zavertiaeva, 2017). Barney (1991) proposed a model, called VRIN and based on value creation, rarity, imitability and substitutability, to define knowledge, invisible, absorptive capability assets, now kknown as intangible assets (Sánchez et al., 2000).

The common terminologies used in the literature related to intangibles are intellectual property, intangible assets, intellectual capital, intellectual assets, knowledge capital, and knowledge-based assets (Kristandl & Bontis, 2007). Also, experts define intangibles based on categorization and taxonomy of intangibles like human capital, structural capital and relational capital describing the categories of intellectual capital here. Good-will included as an intangible asset in balance sheet points the same situation. In fact, only some items of good-will are recognized and comply with the term "intangibles" as per regulations (WGARIA, 2005 as cited in Kristandl & Bontis, 2007). According to IFRS [2], it is difficult to distinguish the cost of maintaining or enhancing the entity's operations or goodwill making it difficult to calculate the cost of generating intangible assets internally. Hence, internally produced brands, mastheads, publishing titles, and customer lists are not recognized as intangible assets (IFRS, 2022).

The lack of definition and of information throughout the system makes it difficult to evaluate and measure 'intangible investment'. Hence, authors like Riley and Robinson (2011) understand and define intangibles based on their economic nature. According to them, 'intangible assets are those inputs into the production process for which there is little traceable evidence in a standard accounting sense' (Rico & Cabrer-Borrás, 2019). However, Marrocu et al. (2012) indicate that elements, such as software, R&D expenditure, patents, economic competencies, and employee training should be included under the definition of intangible assets (Rico & Cabrer-Borrás, 2019). However, according to IFRS, R&D activities are classified as expenses or capital accumulation based on whether activities/costs arise in the research phase or the development phase. Research-based costs are recognized as an expense, whereas costs involved in the development phase are recognized as the cost of an intangible asset (IFRS, 2022).

The literature widely recognizes the contribution of R&D and investments in R&D to analyse productivity growth and actual economic growth. Moreover, experts have already added human capital as one of the factors in the growth accounting model, understanding the importance of

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[2] International Financial Reporting Standards (IFRS) are accounting standards and practices issued International Accounting Standards Board (IASB) for companies throughout the world. IAS are the old standards replaced by IFRS in 2001, but IAS remains valid, if not replaced by a new IFRS. It is widely accepted by auditors, investors, government regulators and other parties.
GAAP (Generally Accepted Accounting Principles) are also accounting standards issued by rival board i.e. Financial Standards Accounting Board (FSAB) and Government Accounting Standards Board (GASB) followed by public corporations instead (Palmer, 2021)

skills and competencies contributing the technological progress, innovation and competitive advantage for company productivity (Rico & Cabrer-Borrás, 2019).

The System of National Accounts 2008 (SNA 2008) defines intangibles as assets based on four categories of 'intellectual property products': 'research and development', 'mineral exploration and evaluation', 'computer software and databases' and 'entertainment, literary or artistic originals'. OECD (2018), like other economic organisations argues that these categories do not fully cover the extent of intangible assets as there are other aspects where firms are investing to create value such as brands, human or organisational capital. But the challenge remains where it is difficult to put a value on these assets and hence, incorporate them in the growth accounting model (Alsamawi et al., 2020). Also, OECD (2018) discusses cases where intangibles are unpatented or unbranded categorized as hard-to-value intangibles.

(Thum-Thysen et al., 2017.) refer to intangibles as NA (national accounts) intangibles and non-NA intangibles. According to them, NA intangibles are accounted as 'investment' in the System of National Accounts (SNA), whereas non-NA are accounted as intermediate consumption which nonetheless are 'investment' and should be included in the productivity analysis. Non-NA intangibles include economic competencies, new products, and designs. Similarly, (Corrado et al., 2012) elaborate business investments reflecting intangible capital extend from R&D and computerized databases, softwares to design, brand equity, firm-specific training, and organizational structure.

It is reasonable to conclude that there is no established definition of intangible investment/assets in the extant literature and no agreement of which items to include under the heading of 'intangible investment'. This lack of agreement is partly due to the fact that intangible investments are a relatively recent economic phenomenon and to the fact that (ICT) technologies are developing so fast that research and accounting are behind the curve as it concerns measuring intangible assets.

However, even if there is no universally accepted definition of intangible assets, there is a growing consensus that intangible assets do play an important role in the economy and do exhibit common (structural) features. I will now turn to a discussion of the major features of intangible assets.

## 2.3 Complementarities and Spill-overs

Haskel & Westlake (2018) establish synergy (referred as complementarities in most of the literature) and spillovers (strongly related to complementarities) as an important characteristics of intangibles in addition to sunkeness and scalability (these two characteristics will be discussed below). Intangibles are closely connected with other intangibles as well as with tangible assets. They are considered to be highly valuable when combined with other assets. For example, the success of an iPhone not only depends on its design but also on R&D and the following (intangible) features:

1. The organizational design of Appstore (Intangible)
2. The use of iOS (Intangible)
3. The use of Apple supply chains (intangible)
4. Sale channel via exclusive platforms i.e. Apple Stores (tangible) and
5. The connection to Apple's overall brand name (intangible)

(Haskel & Westlake, 2018a).

Tangible assets definitely have synergies (e.g., machines and properties (plants), train and train station, etc.), but as explained by Haskel and Westlake, (2017) intangible assets exhibit even larger synergies, because "the scope of different ideas to interact and the fact that ideas are not expended when they are combined, makes the potential synergies bigger" (Haskel and Westlake, 2017; Thum-Thysen et al., 2021). Basu & Waymire, (2008) argue that it is impossible to account for the productivity effects of individual knowledge-based intangibles because intangibles are inseparable from tangible assets and other intangibles, when not owned by a single entity. Ideas are built on other ideas, which are never owned by an individual firm.

An empirical study by Thum-Thysen et al. (2021) highlights complementarities between different asset types: 1. the broad categories of tangibles and intangibles 2. ICT (including hardware) and various intangible assets (training or organizational capital), intellectual property (R&D or patents) and other intangible assets and 3. R&D asset categories and its positive effects on productivity and economic growth. Brynjolfsson and Hit (2000) and (Corrado et al., 2017a) also confirm that investments in intangible capital such as organizational and human capital are complementary to ICT. AI is one of the major technologies of ICT which specifically requires growth of complementary intangible assets like databases, skills and competencies referring to human capital and organizational capital (see Brynjolfsson et al. (2017)).

In the literature, an increase in overall intangible investments is associated with a reduction in tangible investments across the firm and industry level (Roth, 2019a). However, it is important to understand the complementarity involved with both the assets. Tangible and intangible assets complement each other. Hence, making stand-alone valuations of intangibles is difficult (Basu & Waymire, 2008). Intangibles create new requirements for physical capital and infrastructure (Young, 1998, Hazan et al., 2021). For example, an increase in e-commerce websites based on the demand for virtual shopping by customers accelerates the increase in demand for improved electrical equipment, electronics, IT and telecommunication technology and its setup. Moreover, the opposite is true as well. Investment in tangibles may require investments in intangibles. The following table exemplifies the complementarity of tangibles and intangibles for the production of goods and services:

Table 3: Complementarity between tangible and intangible assets

| Type of firm investing | Tangible Investment | Intangible Investment |
|---|---|---|
| Producing investment goods | Computer firms buying welding equipment | R&D to design paper mill;<br>Market research before launching a new computer model |
| Producing other goods | Pulp and paper company buys paper mill | Training staff to use the new paper mill;<br>Introducing quality circles in a refrigerator manufacturing company |
| Producing investment services | R&D lab buying computer<br>Software or service firm buying computer | R&D lab buying packaged software for its activities<br>R&D to design entirely new network software |
| Producing other services | New POS (Point-of-sale) equipment for supermarket<br>New plant for newspaper publisher | Training cashiers for new equipment in supermarkets<br>Reorganisation of office process and procedures in an insurance firm |

Source: (Young, 1998)

On the other hand, there are also opportunities for substitution for the two classes of assets if seen at the firm level while considering investment budgets from the shareholder and management point of view (Thum-Thysen et al., 2021). Also, there is a possibility of intangibles replacing tangible assets in some cases. However, there is a lack of literature to showcase the reduction of not only tangibles but also effort, time and money with the advancement of technology and innovation due to intangible investments. For example, digitalisation of support services across the IT sector where chatbots (automated software which provides first-level troubleshooting steps to customers through conversation channels) are reducing the support staff for resolving the issues of the end user. For example, if Amazon needed 100 employees in 9 hour shift to resolve day-to-day support tickets of the end customers, with the help of chatbot it may only need 70 employees for the same task. Hence, it reduces the effort and time of 30 employees which can be utilized for other projects. Also, it can be accounted as costs savings for support team where they longer spend $81k amount on labour for this task. This doesn't yet include the resources like computers and infrastructure used by the 30 employees which are spare to consume.

Costs Saving per month for support team = 30(employee reduction)*20(working days)*9(working hours)*15$(assumed salary of an employee/hr) = $ 81,000

Crouzet et al., (2022) go back to the basics of intangibles lacking physical existence while considering the relationship with tangible assets. They point out that intangible assets require tangibles as a storage medium. For example, patents are stored in writings and diagrams on the documents. The following table shows more such examples.

Table 4: Intangible and their storage medium

| Intangibles | Storage |
|---|---|
| Patents | Patent application |
| Software | Computers |
| Video and Audio material | Audio visual media |
| Franchise agreements | Contract |
| Consumer Lists | Digital media, contracts, or in Labour |
| Organization capital | Key talent, manuals |
| Brands | Consumers, Trademark media |

Source: Crouzet et al., (2022)

In fact, sometimes tangibles are conflated with intangibles while considering their value. For example, the value of a book is not only based on its paper or binding but rather on the information it holds (Crouzet et al., (2022).

Haskel & Westlake (2018a) and Wong (2018) suggest that all intangible investments are likely to have spillovers but leading firms are far more skilled at appropriating the spillovers of other firms' investments as part of open innovation. The reason is that appropriability is a function of intellectual properties such as patents, trademarks and copyrights that hold legal protection for the (large) firms which own these right (Basu & Waymire, 2008). Hence, collaboration or synergy here acts as a counterforce to spillover effects. Intangible-intensive industries like tech [3]and pharmaceuticals carry an ability to acquire or imitate ideas, knowledge, and inventions developed by start-ups or their fellow competitors (Haskel & Westlake, 2018a). An extensive literature suggests spillovers in innovation and intangible investments corresponding to the R&D sector. Hall et al. (2009), and Griliches (1973) confirm that as a result of (positive spillover effects) social returns likely exceed private returns for R&D-related investments (Goodridge et al., 2017). An empirical study by Elnasri & Fox (2017) shows significant R&D spillovers within the public sector (research and higher educational institutes) with possible gains in terms of productivity.

The lack of appropriability (and the presence of significant spillover effects) may make it unattractive for firms to invest in intangible assets. The introduction of intellectual property rights in intangible assets makes it possible for firms to appropriate the returns from their investment in intangibles. Because larger (oligopolistic) firms tend to be better placed to claim these intellectual property rights than smaller firms, the investments in intangibles assets are dominated by larger firms.

[3] The technology industry includes firms that either design, manufacture, or distribute electronic devices like computers, computer-related equipment, computer services, software, scientific instruments or any other electronic products or components

## 2.4 Non-Rivalry, Exclusivity, Scalability, Sunkeness

The literature (Basu & Waymire, 2008; Crouzet et al., 2022; Thum-Thysen et al., 2021) discusses their non-rivalrous nature as an important feature of intangibles. Intangibles are 'non-rivalrous in use', because these intangibles can be stored and used in multiple places at zero marginal cost simultaneously. (Crouzet et al., 2022) refer to this property as "non-rivalry in use", as opposed to non-rivalry simply, in order to stress that intangibles are production inputs. For example, an algorithm stored in multiple places can be copied and used multiple times by different developers to produce different outcomes. Organisational structure can be used in multiple instances in different parts of the same organization or across firms around the world. The non-rivalrous nature of intangibles does not make them public goods as partial exclusivity still exists, if not complete exclusivity, which is mostly valid in case of intellectual properties (Basu & Waymire, 2008).

The other two important features of intangibles are scalability and sunkeness (Haskel & Westlake, 2018a). Intangibles can scale over their operations more readily than tangibles. For example, Uber can serve more customers with their application and existing software, whereas local taxi owner 'John' needs to buy more cars to scale. Uber needs no or minimal resources to improve or expand its software to more cities whereas John Taxis will have to invest in terms of cars, parking spots as well as hire employees to be able to operate in more cities. John Taxis would also require marketing channels to advertise profoundly about the expansion of its business to draw more customers. Hence, tangible-based business models need continuous investment to grow and produce more products that cannot be sold more than once. On the other hand, intangibles can generate continuous returns based on initial investment without acquiring new resources to make additional units (Lamb & Munro, 2020). However, Lamb & Munro (2020) show concern over extreme first-mover advantages and winner-take-all dynamics involved with this feature. Also, scalability raises questions about the distribution of opportunities from an employment perspective. Intangibles-based firms have the capability to grow so quickly with minimal labour needs and costs which might lead to fewer opportunities for workers in the labour market.

The properties of intangibles may make them seem special and unique. But intangible investments are still seen as risky investments. Once the investment has been made, they are hard to recover; this is recognized as the 'sunkeness' feature of intangibles. Intangibles like data, brands, recipes, and firm-specific knowledge are difficult to sell especially when they are not intellectual properties. Whereas, tangibles such as inventories, properties, machines etc. can be relatively easily sold or used as collateral for financing. Intangibles can easily become obsolete irrespective of their existence and timeline (Lamb & Munro, 2020). Data for customers based on its entertainment provided by Netflix shows lose their relevance in no time as a new products/shows can become more popular and/ or consumers altogether change their streaming service i.e. from Netflix to Amazon Prime.

Intangibles have high fixed costs but these are generally one-time costs with very low marginal costs of production (Basu & Waymire, 2008). Intangibles are to be used again with existing resources and infrastructure (Thum-Thysen et al., 2017).

Table 5: Features per asset type

| | *Appropriability excludability separability transferability* | *Non-rivalry scalability network-exter-nalities* | *Spill-overs* | *Risks, sunk costs, un-certainty* | *Synergies, comple-mentarity* |
|---|---|---|---|---|---|
| **Computer software** | partly excludable, transferable | fully non-rival, scalable, network-external | high (codified) | high | potentially high |
| **Computerised databases** | partly excludable, transferable | fully non-rival, scalable, network-external | high (codified) | high | potentially high |
| **Scientific R&D** | partly excludable, separable / trans-fer e.g. as patents | fully non-rival, scalable, network-external | for 'pub-lished' re-sults high; partly otherwise | very high | high |
| **Copyrights and creative property** | partly excludable (depending on IPR), transferable | fully non-rival scalable | high (codified) | high | potentially high |
| **Design** | low excludability for 'visible' items, transferable (IPR) | fully non-rival scalable | high for 'visible' products; partly oth-erwise | potentially high | potentially high |
| **Brand equity** | high excludability, non separable, trans-fer via M&A | largely rival scalable | low / firm-spe-cific | high | potentially high |
| **Firm-specific human capital** | high excludability, non separable, trans-fer through staff mo-bility | largely rival scalable | partly, large if high staff mobil-ity | very high | very high |
| **Organisational capital** | partly excludable, non-separable, transfer | largely non-rival, scalable | partly | high | potentially high |
| **Market re-search** | high excludability (if non-disclosure), separable, trans-fer | fully non-rival, scalable | partly | high | high |

Source: Thum-Thysen et al., 2017

## 2.5 Industry specific importance

As argued in the previous sections, intangibles are extensively linked to ICT in the literature. Brynjolfsson et al. (2017) discuss AI to be a promising general-purpose technology which is an integral part of ICT industry and research. ICT holds separate consideration in major databases including the EU KLEMS database and OECD database, as experts understand that the major accumulation of intangible capital has been done in ICT sector. Corrado et al. (2012) also confirm that those intangible investments done by ICT sector have higher productivity. (Gambardella & McGahan, 2010) highlights ICT industry having the largest Tobin's Q. According to them, the market value for ICT sector is nearly ten times higher than book value. The difference between the market value (which includes an appreciation of intangible assets) and the book value may be due to the fact that the intangible (knowledge) assets of firms have grown over time.

However, it should be realised that different types of intangibles hold different importance throughout the sectors. In the manufacturing industry, R&D constitutes the main intangible assets. In contrast, many service sectors rely on intangible organisational capital to bring performance and productivity growth (Mahony, 2022). Intangible types show different results for productivity growth across the sectors. R&D and productivity are, in general, positively correlated in in many industries, particularly for mining and quarrying, and high-technology manufacturing sector; but in low technology manufacturing sector ( wood or textiles) where R&D is not as substantial, intangible organizational capital has been found to be of importance. Similarly, IT capital provides positive effects across all sectors (Riley and Robinson, 2011 as cited by Mahony, 2022).

Hazan et al., (2021) and Gambardella & McGahan, (2010) stress the importance of intangibles understood by leading firms. As per their study, leading firms in innovation-driven sectors invested 5.2 times more than laggard firms in intangible assets to their revenue as of 2019 (Hazan et al., (2021) . Also, spillovers and synergies are seen to be more advantageous for leaders as compared to laggards (Haskel & Westlake, 2018a).

## 2.6 Categorisations of Intangible Assets

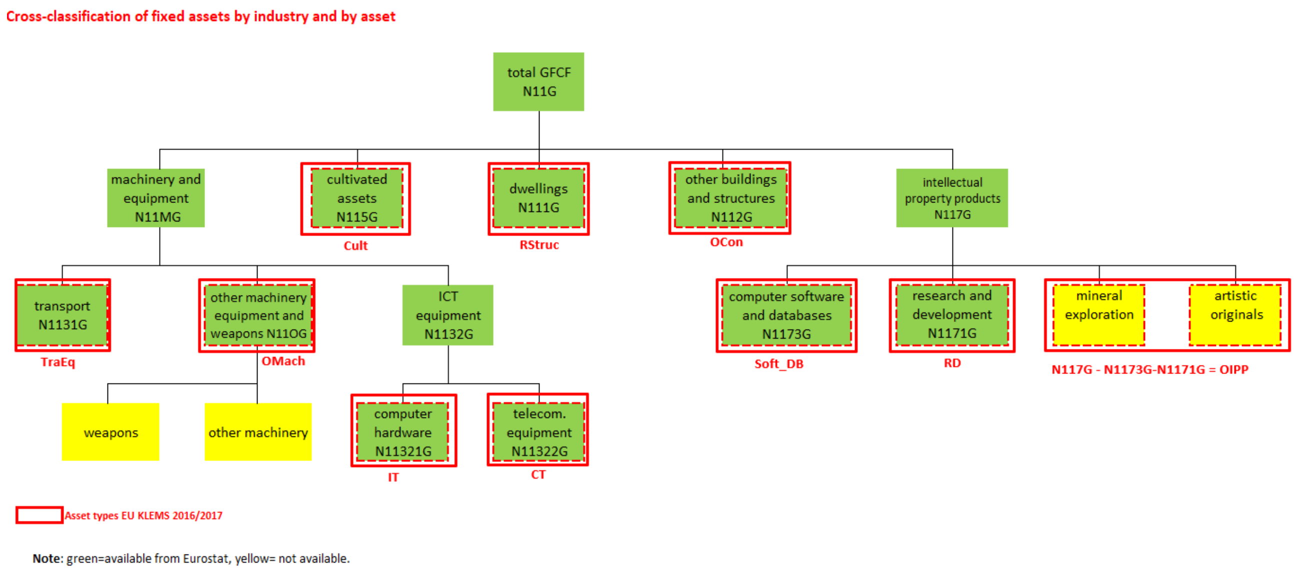
The treatment of intangible assets in the widely used System of National Accounts (SNA) differs from approaches used by academic researchers. The System of National Accounts (SNA) 1993 guidelines suggest that artistic originals, computer software and mineral exploration costs be treated as fixed (tangible) investments. In 2008, SNA added R&D to fixed capital formation.

The OECD and EU-KLEMS database include six different asset types (see Figure 5):

1. Dwellings (excluding land);
2. Other buildings and structures (roads, bridges, airfields, dams, etc.);
3. Transport equipment (ships, trains, aircraft, etc.);
4. Cultivated biological resources (managed forests, livestock raised for milk production, etc.);
5. Intellectual property products (such as R&D, mineral exploration, software and databases, and literary and artistic originals, etc.); and

6. Information and Communication Technology (ICT) equipment (computer software and databases, telecommunications equipment and computer hardware).

Figure 5: EU KLEMS Categorisation of Assets (Tangible and Intangible)




Source: EU KLEMS, 2022

Corrado, Hulten and Sichel (henceforth: CHS) have designed a classification of intangible assets that is widely used in the literature. CHS (Corrado et al., 2012, p 12) "list attempted to include all other costs of developing and launching new products and services, including market research and all costs of improving production processes (including services delivery systems) beyond outlays on conventionally defined ICT and R&D." The CHS classification distinguished between three main categories of intangibles:

(1) computerized information;

(2) innovative property; and

(3) economic competencies.

These categories consist of total of nine types (see Figure 6). We call these assets 'CHS assets'. The comprehensive list holds importance for competition agencies considering the valuation of a firm during a merger or acquisition. Hence, these categories have become part of modern business realities and value assets (Corrado et al., 2012).

With CHS, the authors have included both product and process R&D as part of R&D. It includes

1. The non-technological costs of design (industrial and non-industrial); services innovation costs (including investments by financial services firms not captured by R&D surveys)

2. The costs of marketing and launching new products, including ongoing investments made to maintain the value of a brand,

3. The costs of organization and human capital management innovations.

Figure 6: Intangible Assets inclusion in SNA

| Intangible Capital Asset Types | |
|---|---|
| **Asset type** | **Included in National Accounts?** |
| *Computerized information* | |
| 1. Software | Yes |
| 2. Databases | ?[1] |
| *Innovative property* | |
| 3. Mineral exploration | Yes |
| 4. R&D (scientific) | Satellite for some[2] |
| 5. Entertainment and artistic originals | EU-yes, US-no[3] |
| 6. New product/systems in financial services | No |
| 7. Design and other new product/systems | No |
| *Economic competencies* | |
| 8. Brand equity | |
| a. Advertising | No |
| b. Market research | No |
| 9. Firm-specific resources | |
| a. Employer-provided training | No |
| b. Organizational structure | No |

[4]

Source: Corrado et al., (2012)

Corrado et al., (2012) realise that they have not included venture investments, and especially seed and first-stage investments in CHS intangible assets. They think these funds are associated with marketing and product development and there are measurement difficulties, own-account design and market research lacking with venture investments.

One final problem concerning the measurement of intangible assets including, R&D and other new CHS assets is the risk of double-counting. The primary reason for double-counting is that there is no fixed definition of intangible and its types (Vosselman, 1998a). Also, while accounting for intangibles it is necessary to exclude those that were already counted before. For example, the design costs should be excluded if already added in equipment costs (Corrado et al., 2012). Research and development phases should be seen differently as discussed before. Research-based activities are recognized as an expense whereas development-based activities form the part of intangible assets as per IFRS guidelines for businesses (IFRS, 2022). Additionally, during the purchase of an intangible investment, both the service production costs and purchasing price is accounted, where in double-counting might happen twice. For example, development costs for a software producing firm and the value of software sales to the customers (when the development of software was not done in-house) lead to the counting of software development costs done twice, as from buyer and seller-side. For tangibles, the production of investment goods is not capitalised by the producing firm, but instead is added to the stock of finished goods

[4] Although SNA 1993 recommended capitalizing databases, they are yet not included. 2. R&D satellite accounts are under preparation for many countries. Databases include R&D satellite data for Finland, Netherlands, United Kingdom, and the United States. 3. The US BEA includes entertainment and artistic originals and R&D as an investment under a revision made in 2013 (Corrado et al., 2012).

hence this problem does not occur (Vosselman, 1998a). As discussed earlier, because intangibles sometimes exist in combination with tangible assets, there is a risk of double counting the cost of intangible investment (which may have been included in the tangible investment already).

## 2.7 Contribution of Intangible assets in businesses

The literature discusses the importance of intangibles based on the value adds they bring to the businesses. These invisible assets are not readily accounted for in the balance sheet or the national accounts but lately been analysed as a major reason for bringing competitive advantage and market power to the firms. We analyse the benefits of intangible assets for the businesses across the sector below:

1. The labour productivity growth increases the production capacity of firms. More intangible investments by top growers, is deduced to have increased the productivity gap with the low growers of the same industry (Hazan et al., 2021). Wherefore, intangibles like human capital, and organisational capital play a crucial role in producing more goods and services for the firm as compared to their competitors with the same amount of inputs (Hallenstein, 2020).
   Also, the positive features like scalability and non-rivalrous provide long-term value to the owners where they can utilize these intangible assets not only in multiple instances but re-use them commercially in different ways.
2. Intangible investment is a constructive element for innovation and market differentiation. As, a broad range of intangible assets constitutes national innovation (Corrado & Hulten, 2014). Intangibles like intellectual properties can lay foundations for market leaders in a particular sector at the early stage of the adoption and diffusion of the technology. Early entrants, develop and adopt production processes that can't be copied by their competitors or are too expensive to imitate, gain the edge and tend to become market leaders for new technology. Also, intangibles like brand reputation play a significant role for companies to sustain and grow in the market. Firms definitely interest customers not only based on their products and their unique features but also based on their marketing and advertising strategies (Inusa Milala et al., 2021).
3. The general purpose technologies like AI associated with ICT-sector is the part of digitalisation and technological change which majorly depends on intangible assets. It's not only important from a perspective of the knowledge economy but also from a perspective of computerized intangibles like software, databases etc (Brynjolfsson, 2020). Hence, firms understanding this paradigm shift are focussing more on intangible assets as compared to tangibles now.
4. Situations like the pandemic, not only force governments to find ways to prevent the economic meltdown, but force businesses firms to find sustainable ways of doing business to stay afloat. R & D, human capital, organisational capital and other such intangibles contribute to firm's sustenance in uncertainty.

## 2.8 Conclusion

In recent times, tangible business investment has been declining (relative to GDP) in most OECD economies, whereas intangible investment (as a percentage of GDP) has been rising. Businesses are, in other words, at least partly purchasing 'intangible assets' instead of 'tangible assets'. This trend may reflect a transformation of activities at the firm level as well as structural change in the economy as a whole towards a more knowledge-based economy.

Intangible investments are not (yet) widely discussed and analysed, because:

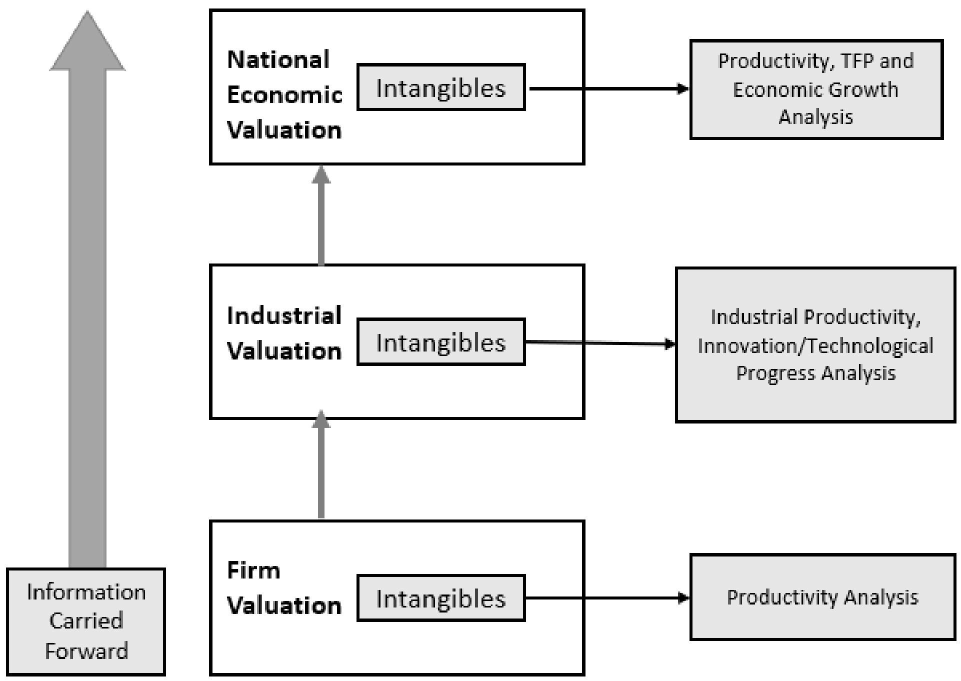
- Intangible asset and its types are not clearly defined or classified for analytical purposes as discussed in this chapter.
- The economic impacts of these investments are likely to be insignificant in the short run, but to be important for the longer-run performance of firms; this gives rise to the innovation-productivity paradox (Fragkandreas, 2021; )
- Economic growth may be mismeasured because the existing models of estimating Gross Domestic Product and measures of productivity growth may fail to fully incorporate the effects of the growth of intangible capital in past few years (Crafts, 2018).

# Chapter 3: Valuation of the Intangible assets.

## 3.1. Introduction

The market value of the firms is inexplicable and hence researchers are focusing on intangibles to explain the gap. As discussed in the previous chapter, intangibles are seen as the key contributors to value creation and competitive advantage for the firms. However, there is a lack of information on intangible investments and their potential returns on the financial statements of the firms. This may result in less-informed decisions by shareholders, investors and the management team (Ajao & Theophilus, 2016). Though firms' higher market value as compared to book value someway reinforces the accumulation of intangible assets and market growth for the firms; it doesn't amount to a certainty or the fixed value attached to it (Rodov & Leliaert, 2002; Parshakov & Zavertiaeva, 2017). The misinformation of investments and assets is carried forward during the analysis of productivity and economic growth at the industrial, regional as well as national levels. As it is obvious that intangibles' role in the global economy is only going to increase in the future, the valuation and accounting of intangibles become considerably important (Powell, 2010).

Figure 7: Financial information shared at different levels




Source: Author's Interpretation

## 3.2. IASB guidelines (IAS 38)

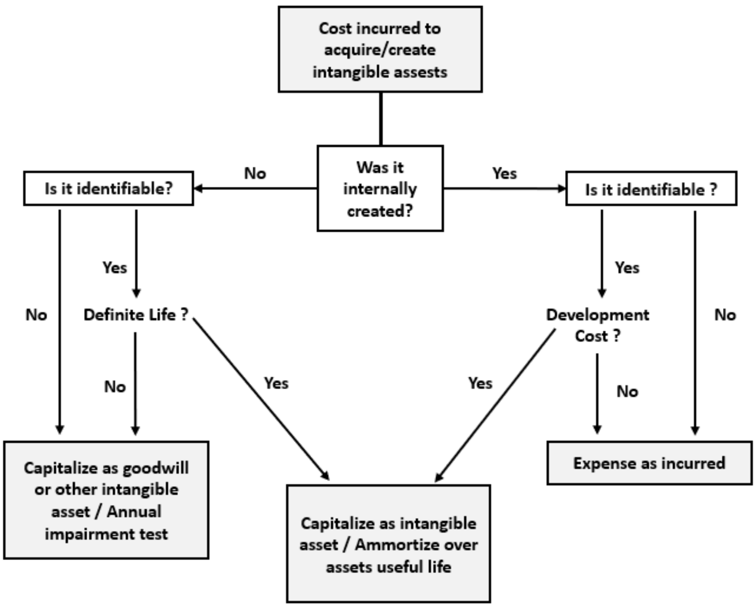
The International Accounting Standards Board (IASB) set guidelines for companies to consolidate financial statements that are adopted by countries i.e. Australia, Canada, France, Germany, Japan, New Zealand, UK and USA. The strong association of corporate entities and stock exchange regulators (particularly as part of the International Organization of Securities Commissions IOSCO, 2002) makes it possible to accept uniform accounting standards across the countries (Powell, 2010).

The criteria issued by IASB under 'recognition of intangible assets- IAS 38' is fulfilled if the intangible asset':

- **Cost can be measured reliably** (if not explicit in case of self-created/internal intangible)
- **Carries potential economic benefits expected to flow in the future**

IASB realises intangible assets are either **self created** in research or development phase or **purchased/ acquired s**eparately or in business combination i.e. during merger/acquisitions. The research phase intangibles are expensed whereas development phase intangibles are capitalised when the above-mentioned two conditions are fulfilled. IAS acknowledges research phase as initial stage where activities are done to discover new product or process. Whereas development phase is a step further into the planning or designing stage as positive outcome for research activities which may result in patents or copyrights. In case of separately purchased intangibles, valuation is done the same as tangibles where cost is readily available. Whereas, in case of merger, intangibles are treated as good will which equals difference between purchased (acquired) company costs and net value of identifiable (tangible) assets (IAS, 2022; Powell, 2010).

Figure 8: IAS Recognition and Capitalisation of Intangible Asset




Source:
https://www.bwl1.ovgu.de/bwl1_media/pdf/financial_accounting/WS+18_19/FinAcc_8.pdf

The measurement allowed corresponding to acquisition are: Cost model and Revaluation model.

**Cost model**- An asset is valued at the initial recognition cost minus any accumulated amortization and impairment losses.

**Revaluation model** – An asset based on its revalued amount minus any accumulated amortization and impairment losses. The revaluation model is only allowed if an active market for the intangible exists.

The life of intangibles decide if they get amortised[5] or not. The intangibles having indefinite life are expected to generate net cash inflows for an unforeseeable period whereas when intangibles have definite life, they are expected to benefit for a limited period, value needs to be reviewed annually based on the amortisation rule (IAS, 2022; Powell, 2010).

Although the intangibles have been recognized and identified as a separate class of assets by IASB there are issues highlighted by experts in the literature (Ajao & Theophilus, 2016). The following theories discuss these issues in detail:

1. Imperfect measurement theory
   According to this theory, goodwill is only discussed when the economic and performance growth of a firm can't be explained. The 'unrecorded asset concept' is a failure of accounting to measure these assets which can be both tangible or intangible and can lead to undervaluing or overvaluing of these assets.
2. Market value theory
   The difference in market and book value of the firm which is greater than one due to overvaluation of firms' is goodwill. The firms already consider this value as goodwill (for both internal and merger situation) while analysing the market capitalization.
3. Fair value theory
   According to IFRS, fair value is the price that would be received to sell an asset or transfer liability between participants at the measurement date. Fair value is a market-based measurement and not category specific measurement. A fair value can be revalued based on the active market. "If an intangible asset is revalued, all assets within that class of intangible is revalued" (Ajao & Theophilus, 2016 p 3). Hence, firms make assumptions if intangible doesn't belong to the active market and make changes to its values now and then in case revalued.

Based on these theories consolidated by authors (Ajao & Theophilus, 2016) it can be understood that intangibles are treated as nothing but a cumulative entity i.e. goodwill which does justify the gap in market and book value but is inefficient in covering the concept and the role intangibles in productivity growth at a firm or industrial level. As discussed in the previous chapter there is no one definition of intangibles and their categories which does make them difficult to measure yet separately. But, recognition and measurement of intangibles using IASB guidelines are not complete and fair. Intangibles are different and cannot be treated or used in an organized market

[5] Rules for Impairment loss and amortization can be further referred at https://www.iasplus.com/en/standards/ias/ias36

like tangible assets (Ajao & Theophilus, 2016). The following conditions should exist for an active market of assets:

1. Abundant buyers and sellers are available, hence transactions can happen at any time
2. Prices are open and readily available to the public
3. Entities are homogenous in nature

These conditions make sense for tangible assets but are unable to value intangibles reasonably due to their basic characteristics. Hence, IASB should originally focus on defining intangibles and its different types and then make progress in finding ways to evaluate and inculcate them in the financial statement of the firms.

## 3.3. Intangible Asset Valuation- IVS 210

Intangible Asset Valuation issued by International Valuation Standards Council (IVSC[6]) according to IVS 210

IVS considers intangible as intangible asset if it falls into one of the following categories:

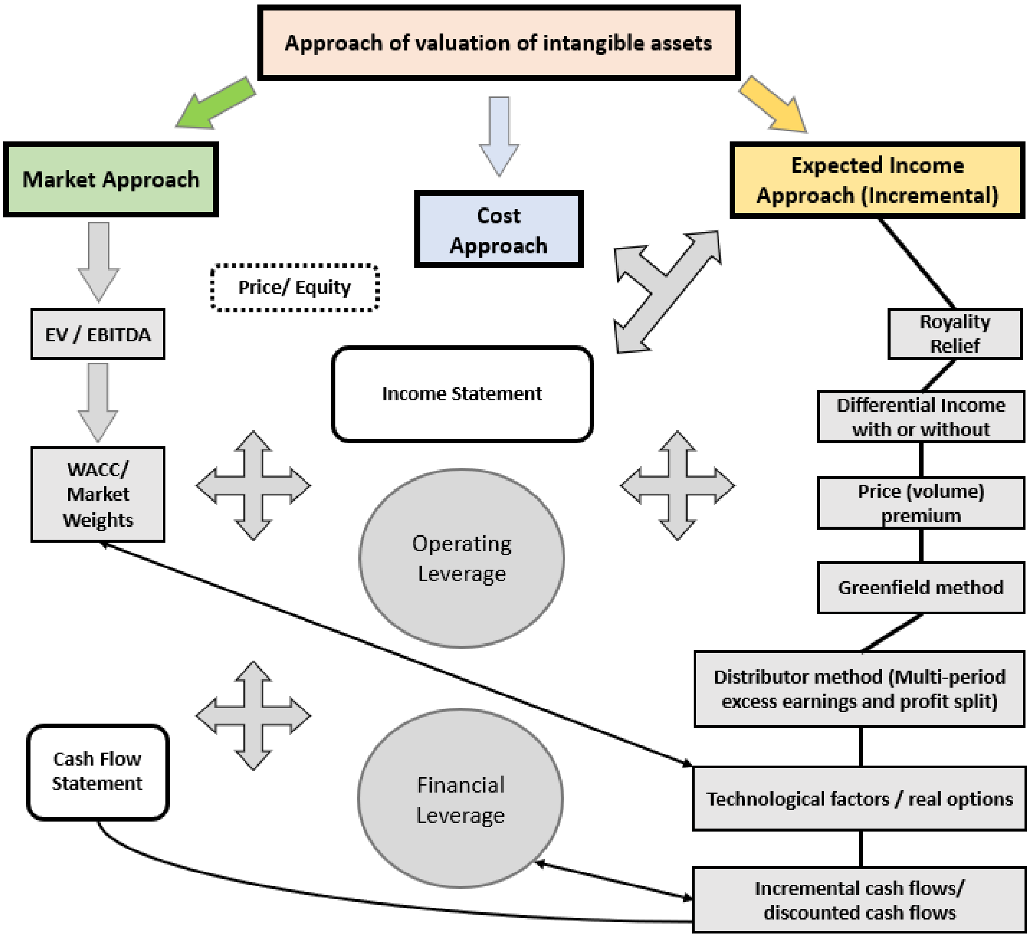
- Marketing-related: Marketing or promotion-related products or services like trademarks, trade names, unique trade design, and internet domain names
- Customer-related: Customer-related information like customer lists, backlog, customer contracts, customer relationship
- Artistic-related: Artistic-related work causing benefits like royalities from books, music, movies or any artistic piece with copyright protection
- Contract-related: Contractual agreements providing licensing, royalty agreements, service or supply contracts, lease agreements, permits, broadcast rights, servicing contracts, non-competition agreements, and natural resource rights
- Technology-based: Technology-related products or services from contractual or non-contractual rights to utilise patented or unpatented technology, databases, formulae, designs, software, processes, or recipes
- Good-will

The three principal valuation approaches suggested in IVS105 for intangibles individually or in a complementary way are:

1. The market approach
2. The cost approach (reconstruction or replacement capital)
3. The (incremental) income approach.

[6] The International Valuation Standards Council (IVSC) is a renowned international standard setter for valuation situated in UK. IVSC and IFRS Foundation announced collaboration between the two boards in 2014. Both committees exchange views and inform each other about the emerging and divergent practice issues and research in determining fair value for the purposes of financial reporting for the companies which is utilised by investors, stakeholders and other parties (Deloitte IVSC, 2022).

Figure 9: IVS Valuation Approaches




Source: Visconti (2019)

The valuation of an intangible asset can be done by any of these valuation approaches. Experts should consider the characteristics of intangibles and the nature of its benefits in the future for not only its owner but for the end user and the reference market while deciding on the valuation approach. The accessibility and reliability of the information related to intangibles should also be kept in mind before making the choice of valuation.

1. Cost Approach - The cost approach is a method where intangibles are estimated based on the amount it would incur to replace the service capacity of an existing intangible asset. Hence, it needs to assess the costs to develop an equivalent intangible asset. *According to the cost approach, the value of an intangible asset is determined by the sum of the capitalized costs, incurred for the realization of the intangible or to be incurred to reproduce it (restoration of rights and brand accreditation represented, in general, by advertising, promotional and distribution network investments (*Visconti, 2019 p 48*)*
   The costs of developing an intangible is not easy to estimate due to intangible assets' basic nature. Also, if the intangible asset was developed years ago and was not capitalised then, it becomes impossible to make this valuation.
   The two main approaches that are part of the cost approach valuation are the replacement cost and the reproduction cost. Since intangibles are not physical assets they are difficult to

reproduce. Software can be an exception where they can be replicated based on its function but not exact lines of code. The replacement cost approach is most commonly used fo the valuation of intangible assets.

Replacement cost approach assumes that a buyer will not pay more than the cost it would incur to replace the intangible asset with a substitute having comparable functionality. The replacement cost includes the cost to develop an intangible asset at current prices at the date of analysis with the comparable utility/ functionality using modern resources, production standards, design, layout and quality standards" (Reilly and Schweihs 2016 as cited in Visconti, 2019). The replacement cost is then adjusted for a factor relative to the intangible asset.

2. Income/Financial Approach - It is based on past and future economic benefits in terms of license revenues (royalties) and incremental revenues linked to an intangible. It is based on discounted cash flow which converts the future cash flows into the present discounted value. The future revenue is estimated from the perspective of market participant instead of of the entity. Therefore, it needs the understanding of how market participant would assess the benefits of an intangible asset from the time it owns the asset (Visconti, 2019). The various methods of income/financial approach are:

Table 6: Income Approaches

| **Methods** | **Description** | **Applied for** |
|---|---|---|
| **Relief from Royalty Method** | It is based on the royalty payments that would be saved by owning the asset rather than licensing; Owning an intangible asset means the underlying entity doesn't have to pay for the privilege of deploying that asset | Value domain names, trademarks, licensed computer software, and in-progress R&D that can be tied to a specific revenue stream and data on royalty and license fees from other market transactions is available |
| **With and Without Method (WWM)** | It is used to calculate the difference in two discounted cash flows to know the economic advantage for firm with the tangible asset in place with another firm without it | Used to value noncompete agreements |
| **Multiperiod Excess Earnings Method (MPEEM)** | It is applied when a primary intangible asset is the driver of a firm's value and the related cash flows can be isolated from the overall cash flows. It is similar to DCF but instead of focusing on the whole entity, this approach isolates cash flows from a single intangible asset or multi-intangible asset (asset and its complementary asset) | Early stage enterprises, technology firms, and firms having assets like computer software and customer relationship which generate frequent cash flows |
| **Real Option Pricing** | It is based on time-value component of intangible where intangible asset under development having potential future cash flows with option characteristics can be assessed. The cost of developing | undeveloped patent and undeveloped natural resource |

| | | |
|---|---|---|
| | the patent, the present value of the cash flows from introducing the drug now, intangible/patent life, return rate, expected cost of delay needs to be observed. | |
| **Distributor Method** | It is used to estimate the excess revenues linked to customer-related intangible assets. As distributors mostly perform functions like distribution of products to customers rather than the development of intellectual property or manufacturing, the profit margins earned based on customer information and relationships by distributors is valued as intangible asset. | Customer- related intangibles |
| **Discounting of differential (incremental) income or cash flow** | It is used the estimate the specific economic benefit of the intangible asset compared to "normal" situations, i.e., products not marked or covered by a patent. It is obtained by subtracting the revenues from costs relating to the intangible asset minus the extraneous income components then discounting it to obtain the present value of specific intangible | All intangible except patented products |

Source: (Puca, 2019; Visconti 2019)

3. Market Approach
   Many intangible assets are "context-specific" and there is little or no value for estimation as it is hard to compare them with other similar intangibles(Haskel and Westlake 2017). The brands, newspaper mastheads, music and film publishing rights, patents or trademarks are unique which makes them special but it is also a weakness as it makes their estimation impossible. When applicable, the market approach is based on comparison with similar assets, in terms of income or incremental assets, or based on an analysis of comparable transactions and market multipliers. The limitation of this approach remains the asymmetry of information as they are mostly hidden. Hence, makes the information necessary to compare even more difficult to find (Visconti, 2019). Complementary or multiple assets are also difficult to evaluate based on an empirical approach. The main market approaches are:
   a. Empirical approach: The income linked to the given intangible asset is multiplied by a coefficient of the strategic strength of the asset which depends on aspects like leader-ship, loyalty, market power, trends, marketing investments, internationality, and legal protection. It varies

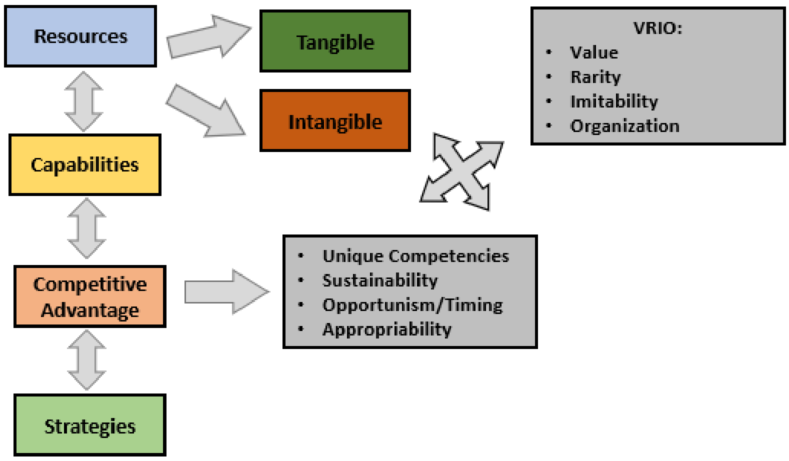
b. Valuation of the differential (incremental) assets using Tobin's Q where the surplus of market to book value is considered as implicit goodwill which may or may not account for intangibles on the whole.

## 3.4. Qualitative Valuation of Intangible assets- Examples

The examples of qualitative valuation of intangibles assets are:

1. Resource based view
   Resource-based view (RBV) is based on the important characteristics of intangibles which make them rare, complex and difficult to imitate. The internal variables such as organization and human capital is recognised by RBV model. The higher competitive advantage of the firm is evaluated as possession of rare and difficult to imitate resources. The company is seen as a portfolio of skills and value-added creations. As discussed in the previous chapter, intangibles are a depiction of knowledge and innovation. Intangibles carry supplies of customer information, corporate identity, customer loyalty, relations with stakeholders, and much more. RBV model is an innovative approach to measure company's performance beyond the traditional method (Visconti, 2019).

Figure 10: RBV Framework

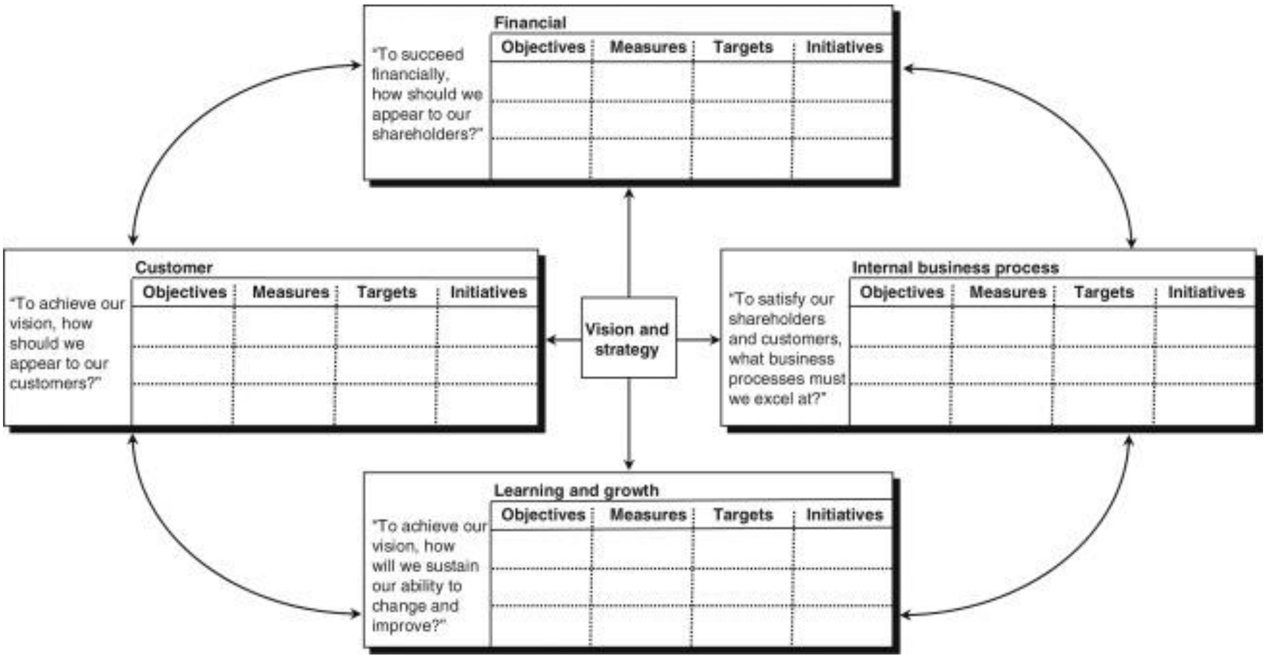



Source: Visconti (2019)

2. Balanced scorecard
   Balanced scorecard is similar to RBV method where the competitive advantage showcasing the accumulation of intangible assets is used to determine company's performance and its future potential in the industry. The "scorecard" is review based on the fundamental financial and non-financial indicators. Although, financial performance is not the primary focus as the company's overall performance, the evaluation is based on its strategic objectives (Visconti, 2019). The balanced score-card as shown below identifies goals and measures within four areas: the financial perspective, the customer

perspective, the internal business perspective, and the innovation and learning perspective (Rodov & Leliaert, 2002).

Figure 11: Balanced Scorecard




Source: (Kaplan, 2009)

Other methods for valuation of intangible assets or intellectual capital consolidated are described in Appendix (Appendix 1)

## 3.5. Conclusion

However, researchers and standard committees have suggested qualitative and quantitative methods to evaluate the intangibles, but there are still gaps. No standard definition of intangibles and its types is the first and foremost reason for the discrepancy. Other major reasons can be analysing intangibles from tangible perspective. As we discussed earlier the drawback of not able to perform financial reporting and valuation at firm gets carried forward at industrial and national level. Hence, inspite of lot of investments and technological advancement we see no productivity and economic growth.

# Chapter 4: Measuring the effects of intangible investments on labour productivity

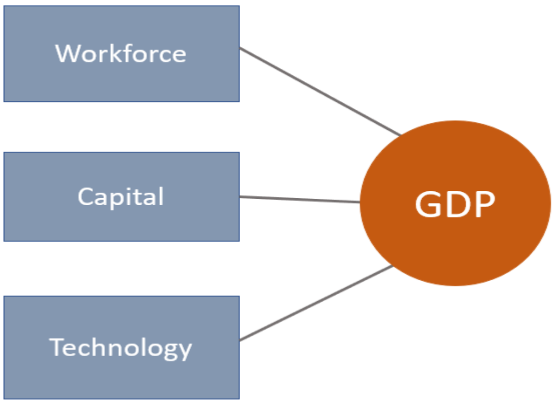
## 4.1. Introduction

After analysing the business aspect of intangible investments and its growth throughout businesses and industries, the next step is to understand its trickle-down effect on the economy corresponding to its unmapped labour productivity.

Long-term economic growth primarily depends on labour productivity (Greenlaw & Shaprio, 2022). Therefore, a nation's ability to advance its standard of living is dependent upon its ability to raise the output per worker. This ultimately depends on the firm's ability to increase productivity at its end which also reflects on productivity increase at the industrial level. For a firm, productivity quantifies the efficiency of the production process, i.e. the total number of units produced per hour worked or net sales per hour worked (Kenton, 2021b).

Labour productivity at the national level is estimated as the gross domestic product (GDP) per total hours worked by employees. To analyse productivity and economic growth, it is necessary to start with a production function. A production function specifies the technical relationship between economic inputs like labour, capital and technology inputs (in terms of goods and services). A microeconomic production function comes from a firm's or industry's inputs and outputs. Whereas for macroeconomics, an aggregate production function takes into account inputs to outputs for the entire economy (Greenlaw & Shaprio, 2022).

Figure 12: Components of the Aggregate Production Function




Source: Author's Interpretation

We will discuss the theoretical aspect of economic growth and describe the growth models already used by economists to evaluate the economic health of the nation. It is easier to understand the short and long run impact of capital deepening (capital per unit of labour) and technology on economic growth based on the growth model. Readers can move to the next chapter as this part of the report is not directly connected to the research questions. But it may help readers in understanding how economies work and how the variables used for empirical analysis impact the economic growth.

## 4.2. Solow Residual & Growth Accounting Model

The growth accounting concept was introduced by Robert Solow in 1957. Before 1957, economists focused on the impacts of labour and capital investments to analyse economic growth. With the growth accounting model, Solow brought light to the technological part being another contributor to GDP. Hence this technological aspect as well as the concept is referred to as Solow residual (Kenton, 2021a).

The Solow Growth Model is based on neoclassical macroeconomics where the factors of production i.e. capital K, and labour L, change as a result of investment and population growth respectively. Investment is financed out of savings (Storm & Naastepad, 2020a). The production factors, i.e K and L, are endogenous variables whereas savings rate, population growth and technological progress are treated as exogenous variables. The market is assumed to be perfectly competitive. The Solow growth model is also called as an exogenous growth model as the savings rate is taken as an exogenous factor (Schilirò, 2017).

As discussed earlier, labour productivity growth and economic growth estimation start with the production function. Solow considered the neoclassical production function to calculate outputs based on capital and labour inputs (Barro et al., 1998).

$Y = F(K, L)$ Aggregate Production Function

Where $Y$= output, $L$ =labour input, $K$ = capital stock and $A$ = a technological constant

$Y/L = F(K/L)$, and

$y = f(k)$

Where $y$ = output per capita and $k$ = capital stock per capita

In the case of a closed economy where there is no government sector or international trade, output equals consumption and investment:

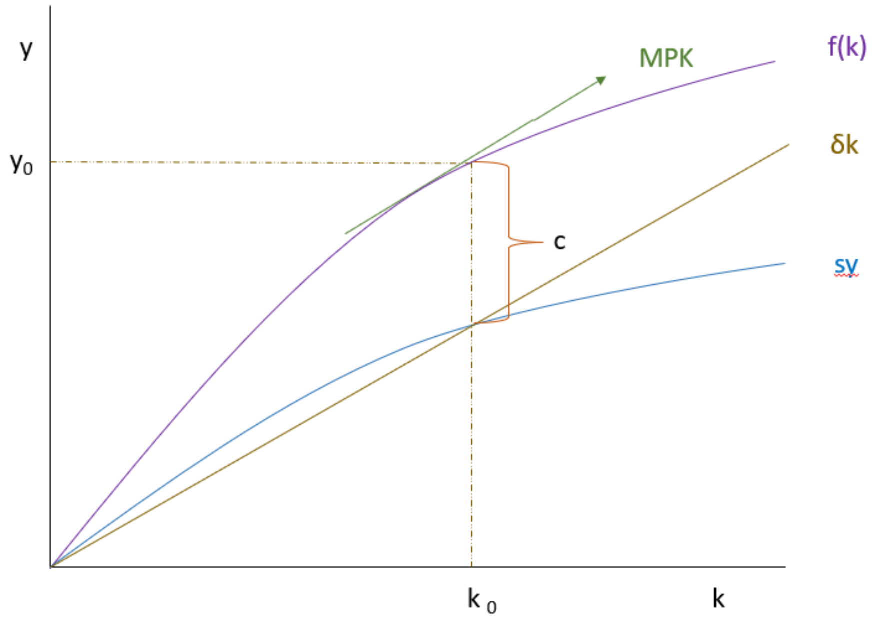
$Y = C + I$

Savings are based on the output achieved per year. In other words, we can say if citizens/consumers do not consume a part of their income they save, therefore savings ($S$) = $sY$ where $0 < s < 1$

And we already discussed, investment equals savings so $I = sY$. Hence consumption $C = Y - sY$.

Figure 13 illustrates a graphical representation of the production function for a closed economy.

Figure 13: Neoclassical Production Function




Source: Author's Interpretation

Solow identified capital stock to depreciate at an exogenous rate δ every year and consequently, a segment of investment done in a year was utilised to re-establish depreciated stock. Therefore, capital stock in year t+1 equals the capital stock and investments made in year t after deducting the depreciated stock (Hayward, 2020).

$K_{t+1} = K_t + I_t - \delta K_t$

$\frac{dK_t}{dt} = I_t - \delta K_t$

$\frac{dK_t}{dt} = sY - \delta K_t$

In terms of per capita, $\frac{dk_t}{dt} = sy - \delta k_t$, which is also known as the Law of Motion of Capital.

## 4.2.1. Convergence Dynamics

Solow suggests the economy tends to converge towards a steady state of the capital where the stock of capital remains constant i.e. $K_{t+1} = K_t$ (Whelan, 2014).

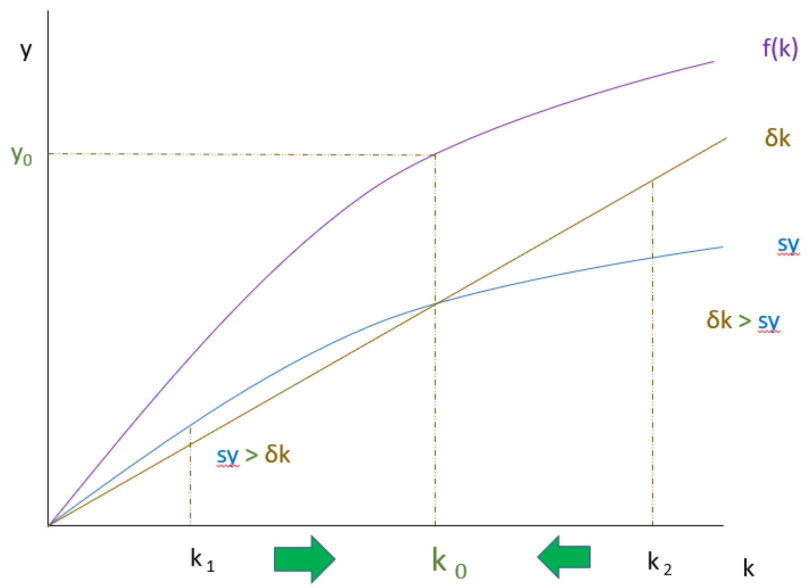
Hence, in the steady (long-run) state, we have: $\frac{dK_t}{dt} = 0 = sY - \delta K_t$

$\frac{K_0}{Y_0} = \frac{s}{\delta}$

Therefore, steady state (equilibrium) is a state where investment is equal to depreciation and no new capital is being created as all the new investments are being used to recover the depreciated capital. Capital to output ratio in steady state equals savings rate to depreciation rate. The change in savings or depreciation rate will generate a new steady state.

If capital-output ratio is lower than the capital-output ratio in the steady state, then capital stock will be increasing until it reaches its steady-state value and if it is higher than the steady state level, it will be decreasing. Hence, if the savings rate, depreciation rate, production inputs i.e. technological progress growth rate and labour input, are constant, there will be a defined steady-state of capital. And no matter where the capital stock starts, it will converge over time towards this level and produce a constant amount of output.

Figure 14: Steady State of Capital

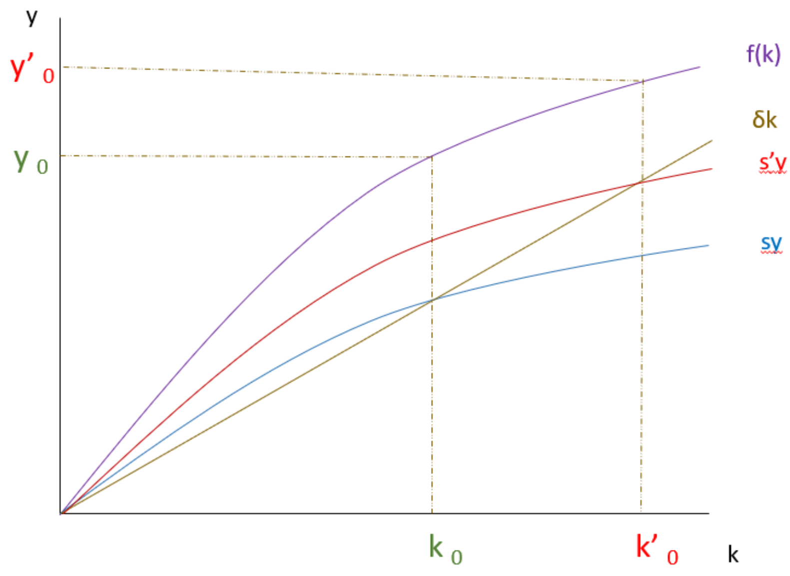



Source: Author's Interpretation

## 4.2.2. Short-run Economic Growth

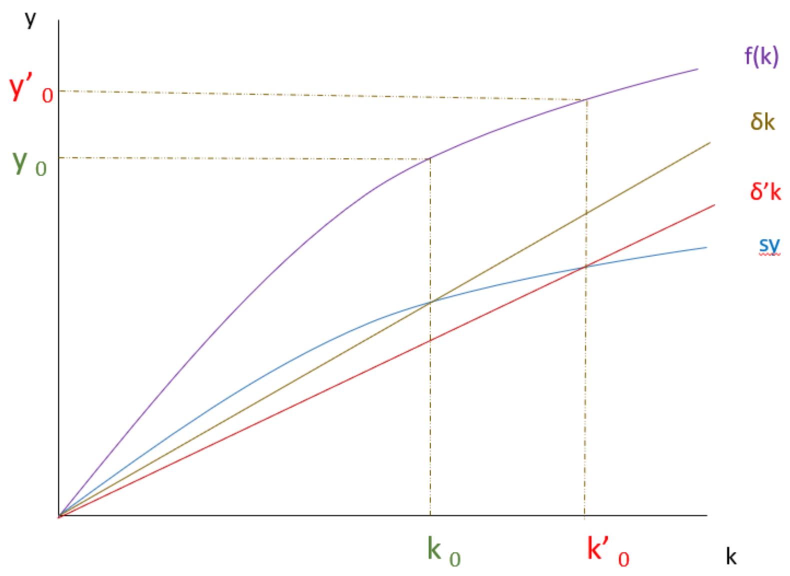
If the savings rate increases, the investment curve moves upward and a new steady state is achieved. The capital stock starts to increase and economic growth output improves. Similar effects are seen if the depreciation rate is decreased.

Figure 15: New steady state with change in savings rate




Source: Author's Interpretation

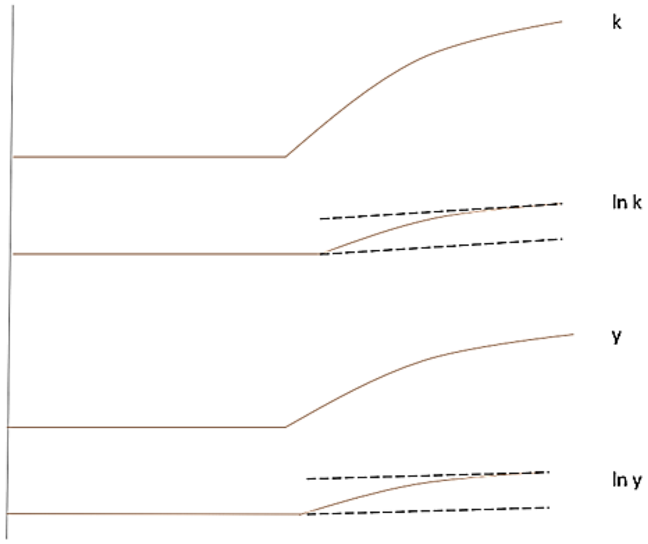
Figure 16: New steady state with change in depreciation rate




Source: Author's Interpretation

However, Solow indicated that economies achieve only a short-run boost due to one-time increase in the savings rate. Countries need to keep raising the savings rate if they want to sustain economic growth permanently, which is not possible as only a fraction of output can be allocated to savings or investment. Also, savings decisions are made by private individuals in a capitalist economy and hence these cannot be controlled by the government. Similarly, the depreciation rate is exogenous in nature. Therefore, it is a temporary transition (Whelan, 2014).

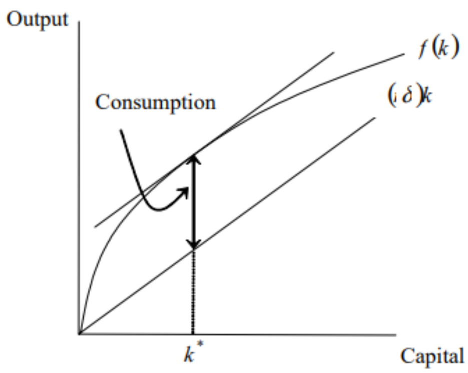
Figure 17: Transition in the short-run




Source: Author’s Interpretation

The amount of savings which maximises consumption over time is called the ‘Golden Rule’ capital-labour ratio (Hayward, 2020). The figure illustrates that consumption or distance between production function and depreciation line is maximised when the slope of the production function is equal to the depreciation rate . The tangent drawn to the production function is the marginal product of capital (MPK[7]) which can be easily determined.

Figure 18: Consumption in Solow's Model

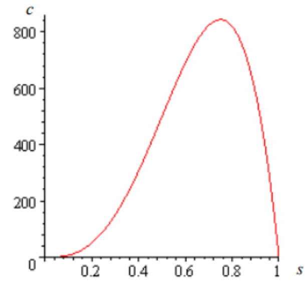



Source: (Myles, 2009)

[7] Marginal Product of Capital is the change in the output produced when an additional unit of capital is added. The labour and technological progress inputs are kept constant. It plays an important role to determine if its worth to introduce new capital in the business or economy. After a certain point of time, due to diminishing marginal returns of capital, level of production starts decreasing than increasing with each additional capital (Thakur, 2022).

The following figure shows the effect of an increase in the savings rate on consumption. It can be seen that after a point i.e. Golden Rule savings rate, consumption has rather decreased.

Figure 19: Golden's Rule

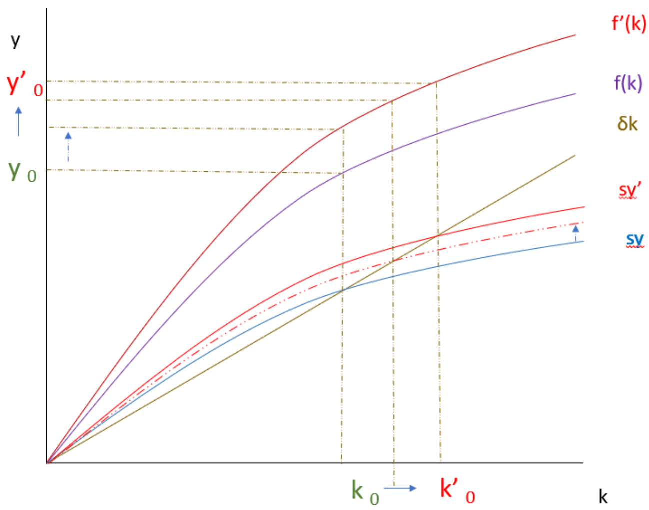



Source: (Myles, 2009)

## 4.2.3. Long-run Economic Growth

When technological efficiency increases, a new production function is obtained, which leads to new capital and output levels.

Figure 20: Changes based on technological advancement



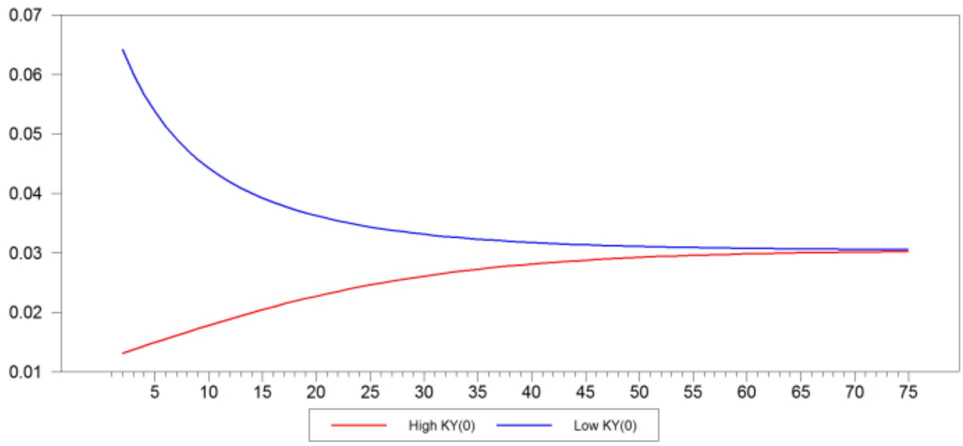

Source: Author's Interpretation

The Solow model predicts that although increased capital accumulation will tail off over time producing a one-time increase in output per worker, whereas increased TFP or technological progress growth rate will lead to a sustained higher growth rate of output per worker (Whelan, 2014).

Researchers used the Solow model to explain the economic performance of Japan and Germany post-World War II. The USA having similar institutions and culture didn't show the same growth during the 1960s. However, these war-impacted countries having the same steady states of output showed different results altogether as compared to the USA. It is important to understand that due to the war, these countries were suffering economically and lot of their past accumulated capital was destroyed. Hence, they were observed far behind their potential i.e. steady state in the production function. When the investments were made to re-develop the assets and GDP of the country. The investments led to capital stock accumulation as the depreciation of capital was almost negligible or low. In other words, there wasn't much assets like roads, bridges etc to depreciate. Therefore initial investments of these countries led to serious increase in output. The convergence towards the steady state was steep showcasing higher economic growth for Germany and Japan. However, the USA was already in a steady state, all new investments were getting used to maintain the existing capital, hence no growth in capital stock and output was seen (Valdes, 2003).

The following figure showcases the convergence dynamics for two countries having the same economic setup but different conditions at one point will eventually move towards the steady state where growth and productivity will be same for both these countries at time t; given their economic setup (institutions, labour policies and regulations etc) doesn't change.

Figure 21: Convergence Dynamics




Source: (Whelan, 2014)

The Solow model was further utilised to derive a growth-accounting framework, based on the Cobb Douglas production function (Bavre, 2005).

Y = F(K,L)

Y = $a \times L^a \times K^{(1-b)}$ ; $0<a,b<1$

To do so, it assumed that the Cobb Douglas production function exhibits constant rates of scale, or: a+b =1, i.e. for an increase in both labour and capital by x%, output will increase by x% as well[8].

Y = $a \times L^{\alpha} \times K^{(1-\alpha)}$ *Cobb Douglas Equation*

Y/L = $a \times (K/L)^{(1-\alpha)}$

$\lambda = a \times k^{(1-\alpha)}$

[8] For constant returns of scale Y = F(xK, xL) => Y = x F(K,L) x ≥0

Labour productivity (economic output per capita or real gross domestic product per labour hour) (λ) depends on technological progress (a), capital deepening or capital intensity or the capital to labour ratio (k) and the technical coefficient of return to scale (α) as shown in the equation above.

The Cobb-Douglas production function can be expressed in terms of growth rates as follows. Differentiating the equation with respect to time:

$dY = L^{\alpha} K^{(1-\alpha)} dA + (1-\alpha) A L^{\alpha} K^{-\alpha} dK + \alpha A L^{(\alpha-1)} K^{(1-\alpha)} dL$

Dividing by A $L^{\alpha} K^{(1-\alpha)}$

$$\frac{dY}{Y} = \frac{dA}{A} + (1-\alpha)\frac{dK}{K} + \alpha\frac{dL}{L}$$

$G_Y = G_a + 1\text{-}\alpha\ G_K + \alpha\ G_L$ (Whelan, 2021)

where $\alpha = P_L L/Y$ (Share of labour, $S_L$) and $1-\alpha = P_K K/Y$ (Share of capital, $S_K$), $P_L$ = Price of labour (wage) and $P_K$ = Cost of machine or Price of capital. GY, Ga and GL growth rate of output, growth rate of the technology and growth rate of labour.
Ga is Total Factor Productivity (TFP) also known as Solow's residual (Storm, 2020).

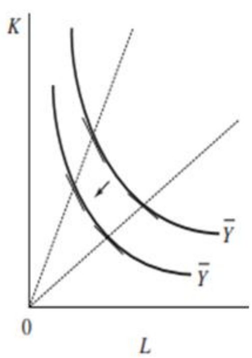
## 4.3. Technological Progress and Growth Accounting Equation

As we have seen in the earlier section, the Solow growth model identifies technological progress to have sustainable and long-run economic growth. Technological progress can be defined as a continuous process which increases the efficiency of the production process with the same quantities of inputs i.e., capital and labour. The possible effects of technology in the production process described in literature are as follows:

- Hicks-neutral – Technological progress saves both capital and labour inputs to raise output. The ratio of marginal products remains constant for the given K-L ratio (Ozak, 2022). The capital-labour ratio remains unchanged.

  Y = F (K, L, A) = A F (K, L)

Figure 22: Hick's Neutral

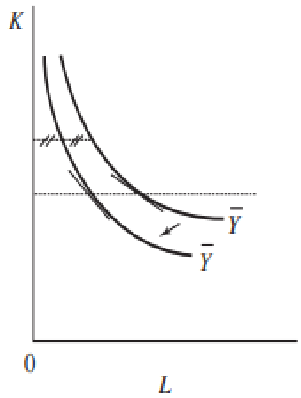



Source: Ozak, 2022

- Harrod-neutral – Technological progress augments labour input. The relative input share of the capital-output ratio changes (Cameron & Hall, 2004).

  F (K, L, A) = F (K , A (L ))

Figure 23: Harrod Neutral

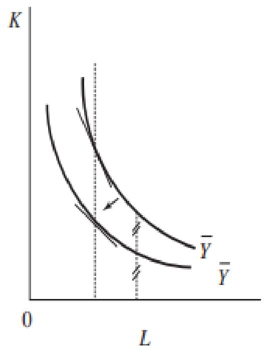



Source: Ozak, 2022

- Solow-neutral - Technological progress augments capital input. The relative input share of the labour-output ratio changes.

  F (K, L, A) = F (A (K) , L)

Figure 24: Solow Neutral




Source: Ozak, 2022

Input shares require the knowledge of the factor's marginal products[9]. As shown in the formula above, it is estimated from the average price of a factor's services from the total income factor earned by the number of units of service (it provided). Because it is assumed that a factor's marginal product equals the average price for the services of existing units (Miller, 1989).

$S_K$, denotes the share of capital i.e. relative weightage of capital component contributing to

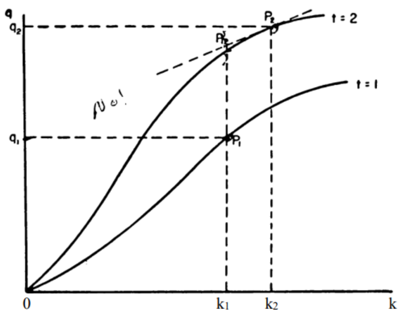
[9] Marginal product of input is increase in output resulting from one additional unit of input.
MPK (Marginal Product of Capital) = dY/dK ; MPL (Marginal Product of Labour) = dY/dL

total income. Similarly, $S_L$ denotes the share of labour i.e. relative weightage of labour component contributing to the total income.
The condition $S_K + S_L = 1$or $Y = P_K K + P_L L$ must hold true if all of the income associated with the gross domestic product, Y, is attributed to one of the input factors which is restricted to capital and labour here. In an international context, some net factor income may accrue to foreign-owned factors, and $P_K K + P_L L$ abides by the net factor income (Barro et al., 1998).

$G_Y = G_a + S_K G_K + S_L G_L$[10] => Growth Accounting Equation

In the following graph, Solow showed the case of neutral shifts and constant returns to scale for production function.

Figure 25: Solow Growth Model




Source: Solow, 1957

Growth accounting decomposes output growth into the growth of various inputs (O'Mmahony & Timmer, 2009), notably:

- Labour
- Capital
- Technology

Prior to 1957, economists focussed on capital investments and labour supply to justify GDP growth. There was a gap which they could not justify based on these two factors. Solow introduced technological progress as a third factor to explain the residual gap. Hence, the concept is also popular as 'Solow residual' (Kenton, 2021a).

Growth accounting can be applied to study productivity growth at the sectoral and industrial level. The study of productivity at the disaggregated level provides a better understanding of the sources behind the total aggregate growth. This enables the researcher to identify the impact of shifts in the structure of the economy on aggregate economic growth (Crafts & Woltjer, 2021).

[10] Every model is based on assumptions. A few of the assumptions of the Solow concept are production function is homogenous i.e.one unit of capital deepening leads to an increase of one unit output, savings are constant and so on. Hence, researchers realise these assumptions and leading weakness of the concept, but the Growth accounting model remains one of the most used models for economic growth estimation.

## 4.4. Ideas other than Solow Growth Model

As discussed in the previous sections, the Solow model assumes the savings rate, the depreciation rate and most importantly the rate of technological progress are exogenous factors. Paul Romer and Robert Lucas presented the endogenous growth theory in 1986 and 1988 respectively, where they emphasised the importance of physical and human capital accumulation and spillovers in the economic growth (Gong, 2020).

Romer (1986) estimates capital stock based on a learning-by-investing model. Similarly, Griliches (YEAR) treats k as knowledge capital measure based on knowledge-creating activities, such as R&D with the spillovers, common across companies and industries, as representation of the spread of knowledge. In contrast, Lucas (1988) displays k as human capital measured by education level to capture spillover effects due to cooperation and learning in groups. Also, Barro (1999) indicated decreasing returns to scale. It can be due to traffic congestion and environmental damage, which implies negative spillover effects and diseconomies of scale (Gong, 2020).

The Hicksian model of induced innovation (also known as induced technical change) explained how changes in relative input prices not only lead to changes in input proportions but would also affect the direction of innovation. The companies substitute capital for labour if the relative price (wage–rental ratio) increases. Hence, if labour becomes more expensive, companies will innovate and invent machines to replace labour. Later economists utilised the model of induced innovation and illustrated that the direction of technical change in agriculture was based on changes in relative resource endowments and factor prices. Similarly, for the manufacturing industry, technology is developed to substitute power and machinery for workforce, whereas in biological and chemical technology, innovation is to substitute fertilizer and other chemicals for land over time (Gong, 2020).

## 4.5. EU KLEMS Approach to Growth Accounting

Because we will use the EU KLEMS database to estimate the contribution of intangible capital formation to productivity growth, it is necessary to understand the EU KLEMS approach to economic growth and the growth accounting model.

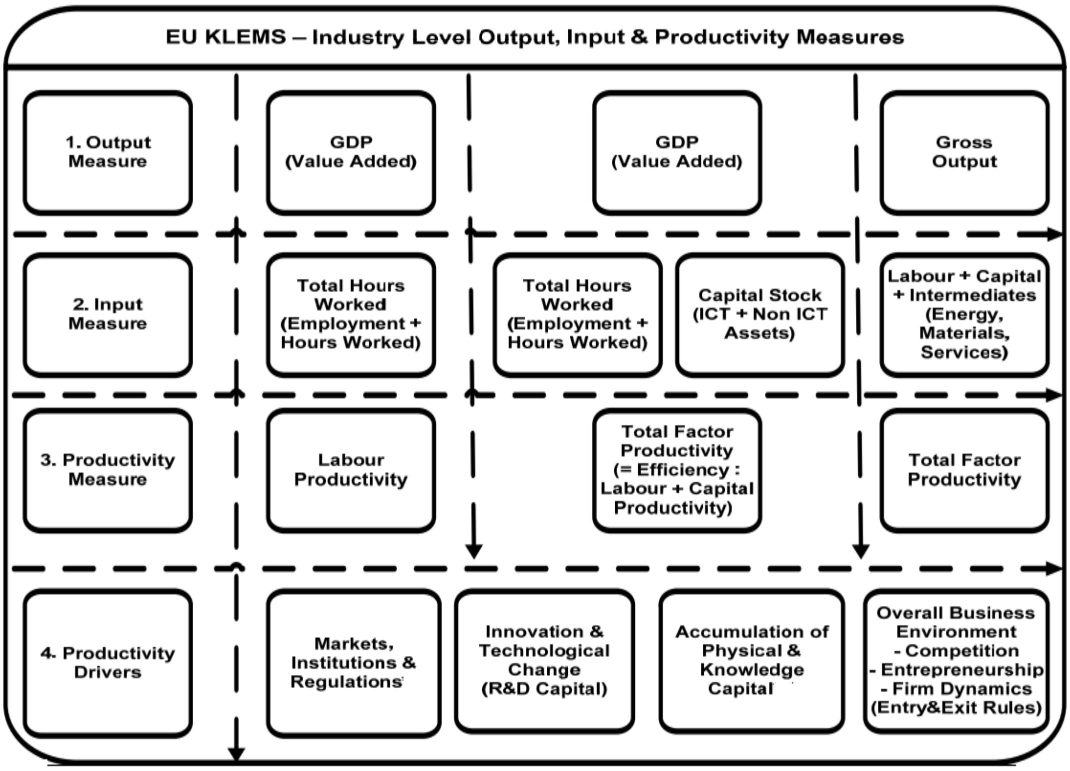
EU KLEMS methodology is based on the national accounting, input-output analysis and growth accounting centred on the contributions of economists such as Leontief, Solow, Griliches and Jorgenson (Timmer et al., 2007). Their methodology is distinguished from earlier growth accounting studies. They provide a breakdown for both gross output which includes intermediates (knowledge capital) as well as for value added growth, although the breakdown for gross output is still in the research phase and they only account for intangibles considered by SNA (Koszerek et al., 2007a). Their analysis is distinctive from the Solow growth accounting model based on the production function inputs which includes:

- productive capital (a volume index of capital services)
- human capital (a skills-based indicator of the average qualifications of the labour force)
- labour i.e. employment levels adjusted for hours worked
- residual term (the level of efficiency associated with the use of the various factors of production)

The capital service flows weigh the growth of the capital stocks by the share of each asset in total capital compensation, linked with the rental price of each asset. The rental prices for the different asset types are determined by their real rates of return (i.e. the nominal rate of return adjusted for asset-specific capital gains, with the latter derived from investment price indices) and the rate of depreciation as discussed in the Solow Growth Model above.

EU KLEMS collect data on hours worked and compensation by labour type to reflect changes in both the quantity (hours worked) and quality (skill levels etc) of labour (Koszerek et al., 2007a). Figure 26 shows the EU KLEMS industry level input, output and productivity measures. Gross Output wherein intermediates like energy, and material services are considered for TFP estimation is still in the research phase. Also, the EU KLEMS team understands the underlining drivers for productivity and economic growth and emphasise studies on these factors which include intangible like knowledge capital, R&D.

Figure 26: EU KLEMS Industry level Measures




Source: (Koszerek et al., 2007a)

The next section discusses the changes made by authors Carol A. Corrado, Charles R. Hulten and Daniel E. Sichel to incorporate intangibles in the growth accounting model utilised by many researchers recently.

## 4.6. CHS Framework

The CHS framework developed by Corrado, Hulten and Sichel is being utilised for measuring intangibles and analysing their impact on labour productivity growth. Several other growth accounting studies have been conducted using the CHS framework for country, industry and firm-level analysis (Roth, 2019).

CHS define production functions for consumer goods, conventional investment goods, and intangibles. The model is based on how the economy's input and output growth change when business investment in intangibles is capitalized. The model is based on two sectors:

- Upstream or Knowledge-producing sector or Innovation sector
- Downstream or Knowledge-using sector or Production or Final Output/ Aggregate Value-Added sector

The upstream sector utilises readily available concepts or ideas, i.e. basic knowledge to produce finished ideas or commercial knowledge (e.g., patents, blueprints). Commercial knowledge denoted as N is an input to the downstream sector where output is a sum of consumption and investment. It should be realised commercial knowledge is non-rival and appropriable but only for a time. It is traded at a monopoly price to the final output sector during the period of appropriability. Hence, the final output sector is a price-taker for knowledge.

Final Output (Y) = Consumption (C)+ Investment (I) in closed economy[11]

$P^Y Y = P^C C + P^I I$

$P^Y$ , $P^I$ , $P^C$ denotes the price of output, price of investment and price of consumption corresponding to the quantity of output Y produced utilized in quantity of investment (I) and quantity of consumption (C)

If Intangibles, N are also considered as intermediate goods which require labour and capital for their production, the production function of intangible, N can be defined follows:

$N = F(L^N,K^N) \quad \Rightarrow P^N N = P^L L^N + P^K K^N$

$P^N$ , $P^L$ , $P^K$ denotes the price of intangible N, price of labour L and price (user cost) of capital K corresponding to quantity of intangible N produced with the quantity of labour L and quantity of capital K assigned for the production process

Investment and Consumption can be decomposed into individual production functions requiring labour (L), capital (K) and intangible (N) for their production, hence the production function of I and C are as follows:

---

[11] In an open economy, where exports and imports are part of an economy, Y +M = C+I+E where E = supply of goods and services produced in our economy for the rest of the world, M = demand of goods and services produced by the rest of the world in our economy (Storm & Naastepad, 2020b)

$I = F(L^I, K^I, N^I) \Rightarrow P^I I = P^L L^I + P^K K^I + P^N N^I$

$C = F(L^C, K^C, N^C) \Rightarrow P^C C = P^L L^C + P^K K^C + P^N N^C$

Similarly, $L^I$, $K^I$, $N^I$ corresponds the quantity of labour, capital and intangible inputs required to produce investment quantity I. Whereas, $L^C$, $K^C$, $N^C$ corresponds the quantity of labour, capital and intangible inputs required to produce consumption quantity C

$P^Y Y = P^C C + P^I I = P^L L + P^K K$

where Total labour Input $L = L^N + L^I + L^C$, Total Capital $K = K^N + K^I + K^C$, and Total Intangible $N = N^I + N^C$ utilized for producing Y quantity of output

However, the net accumulation of capital stock is determined by $K_{t+1} = I_t + (1 - \delta_K) K_t$

There is no stock of intangibles i.e. N=0, therefore production of output Y is only the outcome of labour and capital, and N gets lost as an intermediate component of capital and labour.

N is both an output [12](intermediate good including investments and consumption) but only identified as an immediate input to the total labour and total capital and hence, nets out in the aggregate. Hence, the N component doesn't contribute considerably in the final output or GDP (Corrado et al., 2012).

**Introducing the concept of stock or accumulation of commercial knowledge:**

The stock of commercial knowledge $R^Y$ which is the accumulated output of upstream production N; $R^Y{}_t = N + (1 - \delta^R)R^Y{}_{t-1}$, where $\delta^R$ = the rate of decay of appropriable revenues from the existing stock of commercial knowledge. In this model, intangible N appears as cumulative stock and not just simultaneous input. The accumulation of intangible stock is separately analysed and depreciated just like tangible stock.

The production functions can be modified to

$N = F(L^N, K^N, R^N) \Rightarrow P^N N = P^L L^N + P^K K^N + P^R R^N = \mu(P^L L^N + P^K K^N)$

$I = F(L^I, K^I, R^I) \Rightarrow P^I I = P^L L^I + P^K K^I + P^R R^I$

$C = F(L^C, K^C, R^C) \Rightarrow P^C C = P^L L^C + P^K K^C + P^R R^C$

$P^{Y'} Y' = P^C C + P^I I + P^N N = P^L L + P^K K + P^R R$

where $L = L^N + L^I + L^C$, $K = K^N + K^I + K^C$, $R = R^I + R^C + R^N$

The authors assume that $R^N = 0$, as there are no payments to basic knowledge it is generated for free from universities or academia and is considered outside the model.

$\mu$ = measure of the degree of market power, $\mu \geq 1$.

[12] Please understand output here doesn't mean final output but the goods and services used for consumption and investments by the people of a country.

According to the authors "This parameter varies across industries as it depends on customers' price elasticity of demand for an industry's products (think new Apple products vs. new varieties of bubblegum)" (Corrado et al., 2012, p7).

$P^R$ is price of renting a unit of the finished knowledge stock (e.g., a license fee for a patent, blueprint)

$P^R = P^N (r - \pi + \delta^R)$ [Rental Cost of intangible by Jorgenson (1963)]

Where,

$P^N$ = price of a unit of newly produced finished knowledge, i.e. an investment or asset price

r = net rate of return (taxes are ignored)

$\pi$ = expected capital gain loss on intangible capital hence expected change in $P^N$

$\delta^R$ = rate of decay

New aggregate output $P^{Y'}Y' = P^Y Y + P^N N = P^C C + P^I I + P^N N = P^L L + P^K K + P^R R$

$d\,Y' = s^L_Y\, d\,L + s^K_Y\, d\,K + s^R_Y\, d\,R + TFP'$

TFP' = TFP after capitalization of intangibles

And s = income shares for the alternative measures of aggregate value-added;

$s^L_Y = P^L L/Y$; $s^K_Y = P^K K/Y$; $s^R_Y = P^R R/Y$ (Corrado et al., 2012)

CHS is a promising framework which understands the unique properties of intangible assets. They argue intangible output can be based on the accumulation of own stock done in the previous years. And hence provide an estimation methodology which utilises intangibles as both intermediate goods and outputs in the overall production process. Although authors understand the difficulty of segregating $P^R R$ into price and quantity, especially for intangibles generated internally but argue the rationalisation of exclusion of intangibles from the estimation frameworks based on this difficulty. The economic character of the intangible should be the deciding factor for the inclusion and implementation of intangibles in the framework (Corrado et al., 2009). CHS acknowledges spillovers and externalities associated with intangible assets and believe TFP to pick up the remaining unmeasured component within a production function. In our analysis, we will try to compare the economic growth and contribution of intangible assets to growth output based on our analysis from EU KLEMS data from the CHS analysis for the USA.

EU KLEMS and OECD don't yet recognise economic competencies like brand-equity and firm-specific resources as intangibles and lack data for the same in their databases. CHS applies the data from the INTAN research project which utilises NIPA (National Income and Product Accounts) series for computer software, NSF (National Science Foundation) and SAS (Census Bureau's Services Annual Survey) for R&D, BLS (Bureau of Labour Stat/SAAS for firm-specific data and also include intangible information and data for the firms based on American Society for Training and Development (ASTD) surveys (Corrado et al., 2009). Also, the Growth accounting model and EU KLEMS methodology of input-output analysis utilise intangibles as capital input similar to physical or tangible capital (Koszerek et al., 2007a). The user or rental costs of intangibles are unavailable to understand the share of intangibles in the total income in EU KELMS and OECD databases.

## 4.7. Conclusion

This chapter covers the basics of estimation of labour productivity and economic growth. The Growth accounting model has been remodelled over the years where economists included different qualities of capital or labour, R&D contribution etc. (Barro et al., 1998). The CHS framework is the updated version of the growth accounting model established in 2005. It takes into account intangibles investments. Also, CHS treat intangibles as part of intermediate inputs to capital and labour, which in the end produces output, i.e. labour productivity. The CHS framework is applied by researchers to incorporate intangibles in economic growth and labour productivity growth estimation to date.

# Chapter 5: Sources, Data and Methodology

## 5.1. Introduction

The previous chapter covered the importance and growth of intangibles at the industrial and economic levels. This chapter discusses the empirical model, data and methodology used for the analysis of productivity and economic growth for the EU, the UK, and the US during the period 1996-2019.

## 5.2. Data

We are using the following two databases to collect capital input and labour input data for productivity and economic growth analysis:

- EU KLEMS
  EU KLEMS is an industry level, growth and productivity research project handled by the Vienna Institute for International Economic Studies (WIIW) (EU KLEMS, 2022). KLEMS is based on capital (K), labour (L), energy (E), materials (M) and service (S) inputs. (EU KLEMS, 2022b; Jager, 2017)The purpose of the database is to measure economic growth, productivity, employment creation, capital formation and technological change at the industry level for all European Union member states from 1970 onwards (Jager, 2017). It includes capital and labour inputs in particular with growth accounting techniques. The data are included for EU-27 countries, several EU aggregates, and the United States since the 1970s. The projects are in participation with 15 organisations from across the EU, with a mix of academic institutions and national economic policy research institutes and have support from various statistical offices and the OECD. We have used the older version of EU KLEMS (http://www.euklems.net/ ) for ease and to be able to include data and analysis for earlier years (1988-2005).

- OECD
  The Organisation for Economic Co-operation and Development was founded by OEEC (Organisation for European Economic Cooperation) members in association with Canada and US in 1960 (OECD Convention, 2020). The aim was to provide a platform for not only the collection and analysis of economical data but to establish international standard setting and prepare public policies for economic growth and employment in future (OECD.org, 2022). The OECD is funded by its 34 member countries and is in agreement talks with potential new members: the Russian Federation, Brazil, China, India, Indonesia and South Africa . The family of organisations within OECD also includes the International Energy Agency (IEA), the Nuclear Energy Agency (NEA) and the International Transport Forum (ITF) (OECD Convention, 2020). OECD compile their investment data in terms of

gross fixed capital formation (GFCF[13]) according to 2008 SNA standards since 1970 (OECD Data, 2022a). Data on GDP, forecasted GDP and investments are available on https://data.oecd.org/gdp.

The following table sums up the design and the analysis plan for the thesis.

Table 7: Methodology of the study

| Database | Countries | Variables | Source | Years | Method |
|---|---|---|---|---|---|
| OECD | US, UK, NL, DE, EU-27 | ICT Shares | Investment by Asset | 1995-2020 | Comparative Study |
| | | Intellectual property Shares | Investment by Asset, Gross fixed capital formation (GFCF) | 1995-2020 | Comparative Study |
| EU KLEMS | US, UK, NL, DE, EU-27 | Intangible Investments | Total Investments | 1996-2015 | Comparative Study |
| | | ICT Shares | Total Investments | 1996-2015 | Comparative Study |
| | | Labour Productivity, Growth Outputs, Growth Inputs | Value Added, Capital Input, Labour Input Shares | 1996-2015 | Value Added per capita |
| | | TFP Calculation | Growth Output, Growth Inputs | 1996-2015 | Growth Accounting Model |
| | | Contribution of TFP, Tangible Capital, Intangible Capital and Labour Compensation | Labour Productivity, Growth Outputs, Growth Inputs, TFP Calculation | 1996-2015 | Comparative Study based on the calculations |
| CHS framework, EU KLEMS | USA | Contribution of TFP, Tangible Capital, Intangible Capital and Labour Compensation | Analysis from 'Intangible capital and U.S. economic growth' (Corrado et al., 2009), Contribution Calculations | 1988-2015 | Comparative Study |

Source: Author's Interpretation

[13] Gross fixed capital formation (GFCF), also called "investment", is defined as the acquisition of produced assets (including purchases of second-hand assets), including the production of such assets by producers for their own use, minus disposals.

## 5.3. Variables

We discuss the process and method of EU KLEMS and OECD to understand the collection and calculation of value added, capital input and labour input which will be applied in our analysis.

### 5.3.1. Value- Added Output

EU KLEMS understands that for estimation of the aggregate economy, industry-level productivity analysis is needed. Their database includes a consistent set of inter-industry transaction accounts using a methodology introduced by Jorgenson, Gollop and Fraumeni (1987). The quantity of output in industry j is defined as an aggregate of M distinct outputs (using the Tornqvist index) :

$$\Delta \ln Y_{jt} = \sum_{i=1}^{m} \bar{y}^{Y}_{ijt} \, \Delta \ln Y_{jt}$$

where $\bar{y}$ = average share of product in the nominal value of output for two-period. And the value share of each product is defined as follows:

$$y^{Y}_{ijt} = \left( \sum_{i} p^{Y}_{ijt} \, Y_{ijt} \right)^{-1} p^{Y}_{ijt} \, Y_{ijt}$$

where $p^{Y}_{ij}$ = basic price received by industry j for selling commodity i. Basic prices including subsidies on products received by the producer are used to calculate the value share of products. Hence, the estimation is done from the producer's point of view.

In 1995, the European System of Accounts 1995 (ESA) introduced the supply and use tables (SUTs) as the building blocks for the construction the National Accounts, i.e. to estimate of levels of value-added. The supply tables are input-output tables which give the composition of output by product for each industry. These tables are used to derive industry gross output indices (Timmer et al., 2007).

As mentioned before, EU KLEMS uses the Tornqvist quantity index for all aggregation (over products or industries) which is a discrete-time approximation to a Divisia index[14]. The aggregation approach uses annual weights based on averages of adjacent points in time (Timmer et al., 2007).

[14] The Divisia index is a continuous-time index that is connected to an underlying economic structure via a potential function in its current implementation. Under certain circumstances, the index can extract key aspects of the underlying structure, i.e. potential function without having a complete understanding of the structure itself using just prices and quantities. The Divisia index is frequently used in productivity analysis debates and has other significant uses. In reality, discrete-time superlative indices like the Tornqvist or chain indices are used to approximate it. The Divisia's discrete-time axiomatic characteristics were emphasized in earlier applications (Hulten et al., 2008).

## 5.3.2. Capital Input

Two key inputs are required to calculate a measure of capital services:

1. *Capital stock estimation for certain asset categories*.
   The method used for capital stock measurement is the Perpetual Inventory Method (PIM). In this approach, the capital stock of a particular asset k at time t is defined as follows: $A_{k,t} = (1 - \delta_k) A_{k,t-1} + I_{k,t}$
   Afterwards, the aggregation is done to take into account the widely different marginal products from the heterogeneous stock of assets.
   $\Delta \ln K_t = \sum_k \bar{y}_{k,t} \Delta \ln A_{k,t}$ where $\bar{y}_{k,t} = ½ (y_{k,t} + y_{k,t-1})$ i.e. Average share of capital in total capital compensation; $y_{k,t} = (\sum_k p_{k,t}^K A_{k,t})^{-1} p_{k,t}^K A_{k,t}$ with $p_{k,t}^K$ is the price of capital goods or services from asset type k.
2. *Capital service flow estimation*.
   This is done by weighting the growth of the capital stocks by the share of each asset in total capital compensation, with these shares linked to the rental price of each asset. Rental prices, or user-costs of capital, are estimated using the standard approach introduced by Jorgenson and Griliches (1967). The rental fee is estimated based on the nominal rate of return (r), the rate of economic depreciation and the asset-specific capital gains (Timmer et al., 2007).
   $p^K_{k,t} = r_{k,t} p^I_{k,t-1} + \delta_k p^I_{k,t}$

   The two methods for estimating rate of return are: "ex ante" and "ex post" procedures. Exogenous values such as interest rates of government bonds, are the foundation of the ex-ante capital services method. EU KLEMS also uses the ex-post (endogenous), Jorgenson-inspired method. It calculates the internal rate of return as a residual based on the value of capital compensation from the national accounts, depreciation, and capital gains (Koszerek et al., 2007a).

## 5.3.3. Asset Types

EU KLEMS consolidate investments for different industries as capital input shares. The asset types have been modified as per SNA 2008 requirements. In EU KLEMS, intangibles are categorised under Intellectual property products (N1171G) where computer software and databases (N1173G), research and development (N1171G) and other intellectual property assets (OIPP) such as mineral exploration and artistic originals are included (Jager, 2017). The following table elaborates the asset breakdown (tangibles and Intangibles) in EU KLEMS in detail:

Table 8: Classification of Assets in EU KLEMS

<table>
<tr><td rowspan="11">Total GFCF (N11G)</td><td rowspan="4">Machinery and Equipment (N11MG)</td><td colspan="2">Transport (N1131G)</td></tr>
<tr><td colspan="2">Other Machinery, Equipment and Weapons (N11OG)</td></tr>
<tr><td rowspan="2">ICT Equipment (N1132G)</td><td>Computer Hardware (N11321G)</td></tr>
<tr><td>Telecom. Equipment (N11322G)</td></tr>
<tr><td colspan="3">Cultivated Assets (N115G) *For US, they are treated as intermediate inputs under NIPA, national income and product accounts</td></tr>
<tr><td colspan="3">Dwellings (N111G)</td></tr>
<tr><td colspan="3">Other Buildings and Structures (N112G)</td></tr>
<tr><td rowspan="4">Intellectual Property Products (N117G)</td><td colspan="2">Computer software and databases (N1173G)</td></tr>
<tr><td colspan="2">Research and development (N1171G)</td></tr>
<tr><td rowspan="2">OIPP</td><td>Mineral exploration</td></tr>
<tr><td>Artistic originals</td></tr>
</table>

Source: (Jager, 2017)

EU KLEMS uses the depreciation rates as per the US Bureau of Economic Analysis (BEA) and applies them in a harmonised way across countries. Though there is not much of country variation, depreciation rates differ by asset type and by industry, with rates ranging from .011 for residential structures up to .315 for computing equipment. This shows an important point that computer equipment is going to be technologically obsolete after only a few years whereas residential structures may continue to provide annual capital service flows for many decades (Koszerek et al., 2007a). The following table shows the depreciation rates for other asset types used by EU KLEMS for capital input shares:

Table 9: Depreciation rates defined by EU KLEMS

| Euk asset type | Minimum over industries | Maximun over industries |
|---|---|---|
| Residential structures | 0.011 | 0.011 |
| Non-residential structures | 0.023 | 0.069 |
| Infrastructure | 0.023 | 0.069 |
| Transport equipment | 0.061 | 0.246 |
| Computing equipment | 0.315 | 0.315 |
| Communications equipment | 0.115 | 0.115 |
| Other machinery and equipment | 0.073 | 0.164 |
| Products of agriculture and forestry | 0.073 | 0.164 |
| Other products | 0.073 | 0.164 |
| Software | 0.315 | 0.315 |
| Other intangibles | 0.315 | 0.315 |

Source: (Timmer et al., 2007)

OECD categorises assets into the following six major groups:

1. Transport equipment (ships, trains, aircraft, etc.)
2. Dwellings (excluding land)
3. Other buildings and structures (roads, bridges, airfields, dams, etc.)
4. Cultivated biological resources (managed forests, livestock raised for milk production, etc.)
5. Intellectual property products (such as R&D, mineral exploration, software and databases, and literary and artistic originals, etc.)
6. Information and Communication Technology (ICT) equipment (computer software and databases, telecommunications equipment and computer hardware) (OECD Data, 2022a)

Though the breakdown of assets in EU KLEMS and OECD is somewhat similar, it should be noted that ICT has altered groupings in these databases.

EU KLEMS data are consolidated for 34 industries (Agriculture inclusive) and 8 aggregates according to the ISIC Rev. 4[15] (NACE Rev. 2) industry classification. As mentioned earlier, the previous version of EU KLEMS shares data from 1995-2015. The data after 2015 are collected from the newer version of the database. OECD investments by asset can be accessed for the period 1970-2021. Though, for intellectual property products, the data are readily available only from 1995 for most of the countries, as we understand their importance increased considerably after the late 90s (Jager, 2017).

OECD utilises the Perpetual Inventory Method (PIM) to calculate capital stock estimates as well, where

$$K_{t+1} = (1 - \delta_t)\, K_t + I_t \qquad \text{(Burda et al., 2008)}$$

According to OECD, PIM is the "Approach towards estimating capital stocks by cumulating flows of investment, corrected for retirement and depreciation (in the case of net stocks) or efficiency losses (in the case of productive stocks) (OECD, 2009, p 232)". OECD considers extra parameters such as retirement profile and consumption rate of fixed capital while formulating net capital stocks i.e.

$$W_{tE} = W_{tB} + I_t - \delta(I_t/2 + W_{tB}) + X_t$$

Where $W_{tE}$ and $W_{tB}$ are the end-year and beginning-of-the-year net capital stocks (Net GFCF), $\delta(I_t/2+W_{tB})$ is the consumption of fixed capital, and $X_t$ is other changes in the volume of the group of assets. All variables are valued at average prices of a reference period at year t (OECD, 2009).

[15] The International Standard Industrial Classification of All Economic Activities (ISIC) sets the classification structure of economic activities based on internationally agreed concepts, definitions, principles and classification rules (United Nations, 2008).

## 5.3.4. Labour Input

EUKLEMS labour input measures take the heterogeneity of the labour force into account and follow Jorgenson, Gollop and Fraumeni, (JGF), 1987 methodology. The total labour services are calculated as a quantity index of the different labour types. The weights used in the aggregation process are the average share of each type of worker in total labour compensation. It ensures that the changing composition of the labour force over time is being reflected in the labour services estimates (Timmer et al., 2007).

$\Delta \ln L_t = \sum_l \bar{y}_{l,t} \Delta \ln H_{l,t}$

where $\bar{y}_{l,t} = ½ (y_{l,t} + y_{l,t-1})$ i.e. Average share of each type in total labour compensation;

$y_{l,t} = (\sum_l p_{l,t}^L H_{l,t})^{-1} p_{l,t}^L H_{l,t}$ with $p_{l,t}^L$ is the price of one hour work of labour type l.

EU KLEMS use National Accounts data as the major starting point for constructing the employment data. National accounts also often provide actual hours worked and this concept of hours is used in EU KLEMS as well. When the national accounts do not provide hours worked measures, EU KLEMS makes these estimations from other measures. Compensation data (including wages and salaries) are often available from the same source and for the same labour types. In few cases where the time period for compensation is shorter than for numbers employed, EU KLEMS assumes that the relative compensation levels remain the same over the time (Timmer et al., 2007).

For labour types, industry detail was restricted to 15 industries. EU KLEMS assume the labour characteristics do not vary widely across closely related industries (Timmer et al., 2007).

EU KLEMS database is in accordance with the latest industry classification (ISIC [16]Rev.4/NACE Rev.2) and the new European System of National Accounts (ESA 2010). The output as well as capital inputs are consolidated as per the native industry the North American Industry Classification System (NAICS) classification. The data for USA is an aggregate of BEA (Bureau of Economic Analysis) releases which conform to the SNA standards. BEA also perform estimates for value adds (VA) in response to a questionnaire prepared by the Organisation for Economic Co-operation and Development (OECD). Data for labour inputs are from BLS (Bureau of Labor Statistics) (Jäger, 2017d). For UK, EU, Netherlands (NL), Germany (DE), output, capital and labour inputs are from Eurostat (Jäger, 2017c, 2017b, 2017a).

[16] NACE (Nomenclature statistique des Activités économiques dans la Communauté Européenne) is the standard industry classification used in EU. It is in association with United Nations' International Standard Industrial Classification of all Economic Activities (ISIC) and North American Industry Classification System (NAICS) to build standards for industry classification related to all the economic activities (Connect, 2022; Rollet, 2009).

## 5.4. Methodology

We apply the growth accounting equation in our analysis. Specifically, we have:

$G_Y = G_a + 1\text{-}\alpha\ G_K + \alpha\ G_L$

or

$G_Y = TFP + S_k\ G_K + S_L\ G_L$

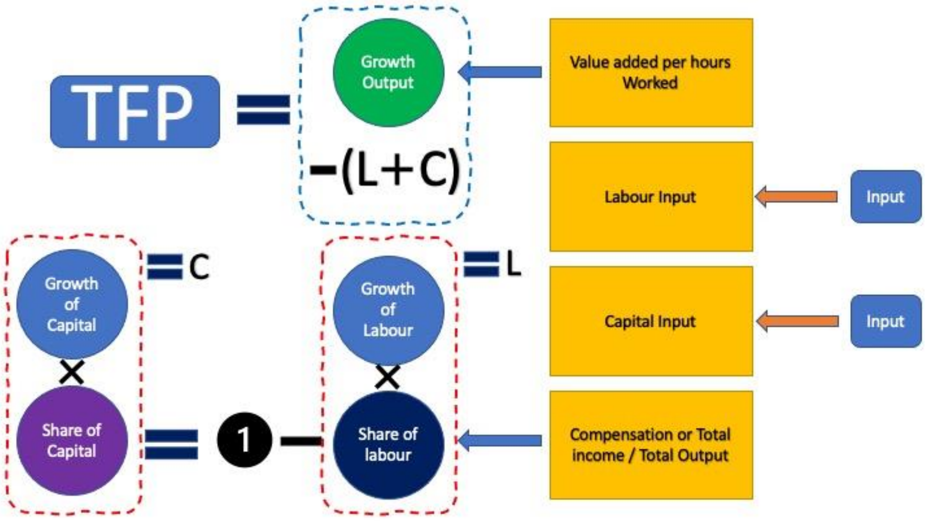
where $\alpha = P_L L/Y$ (Share of labour, $S_L$) and $1\text{-}\ \alpha = P_K K/Y$ (Share of capital, $S_K$), $P_L$ = Price of labour (wage) and $P_K$ = Cost of machine or Price of capital. And, GY, Ga (TFP), $G_k$ and GL are growth rate of output, technology progress (constant), growth rate of capital and growth rate of labour.

We have obtained the base data and capital data files from EU KLEMS website. The base year for the analysis is year 1995 with an exception of USA for . As the previous version of the database has missing data for previous years in the newer releases of data files. We go through the previous version and consolidate the data based on the reverse analysis.

The calculation of growth rate of outputs and input is done step by step:

1. Growth Output Estimation: To calculate productivity for each year, gross value added at current basic prices (in millions of Euros) (VA) is divided by consolidated total hours worked by employees (thousands) (H_EMPE) for each respective year. Then we calculate growth rates using logs to encapsulate the changes in terms of continuous compounding.
2. Growth Capital and Labour Inputs: To calculate the growth rates we find the difference of logs for every periodic year for Labour compensation (in millions of Euros) (LAB) and Capital compensation (in millions of Euros) (CAP).
3. Share of Inputs: To calculate the share of labour, Compensation of employees (in millions of Euros) (COMP) is divided by total output i.e., gross value added at current basic prices (in millions of Euros) (VA). It is less than 1. The rest of the value which adds up to 1 is the share of capital.
4. Using the Growth Accounting equation, we calculate TFP based on the equations presented above.

Figure 27: Methodology




Source: Author's Interpretation

Calculations of the contribution of intangible, tangible capital, labour and TFP to growth output is determined using the above-mentioned calculations where the separate values of shares of tangible and intangible are required. We use the growth output (Y), growth tangible (Tan K) and growth intangible (InTan K), growth labour (L) data to determine the coefficients of Tan K, InTan K and L. The growth accounting model looks like this now:

$G_Y = TFP + S_{Tan\ K}\ G_{Tan\ K} + S_{InTan\ K}\ G_{InTan\ K} + S_L\ G_L$

We use Ordinary least squares (OLS) Regression to determine the values of the shares of tangible and intangible capital i.e. $S_{Tan\ K}$, $S_{InTan}$. Regression modelling of dependent variable Y (output) against these three independent X variables (Tan K, InTan K and L) provides the required coefficients for our estimation. Although these calculations should be done using the price estimations but EU KLEMS database lacks price estimation data for capital. Value of $S_L$ is maintained from the output analysis. The coefficients of $S_{Tan\ K}$, $S_{InTan}$ are realised from the regression analysis. However, the sum of all these shares should be 1.

Contribution calculations is done as follows:

Contribution of intangible capital formation (InTan K) to growth output (Y)= $\frac{S_{InTan\ K} * G_{InTan\ K}}{G_Y}$

Similarly, Contribution of Tan K to Y = $\frac{S_{Tan\ K} * G_{Tan\ K}}{G_Y}$

Contribution of L to Y = $\frac{S_{Tan\ K} * G_{Tan\ K}}{G_Y}$

Contribution of TFP to Y = $\frac{TFP}{G_Y}$

For asset analysis, we highlight the growth of intangibles and the difference in investments across ICT and non-ICT during time period.

## 5.5. Conclusion

EU KLEMS and OECD are the most reliable and versatile sources for estimation of outputs and inputs for economic analysis of productivity and TFP. Recently, these databases have incorporated intermediate inputs, i.e., not only intangibles assets, but also energy, material and services and have inculcated the data and estimations based on that. EU KLEMS and OECD allow us to estimate the contribution of intangibles to growth. Intangibles such as Intellectual Property Products, computer databases, R&D and artistic originals are included in the EU KLEMS database. However, economic competencies like brand equity and firm-specific resources that provide an edge to businesses and have become a major reason for higher Tobin's ratio, are missing in their estimations.

The CHS framework and methodology is the major groundwork for the future establishment of the impact of intangibles in economic growth methodologies. INNODRIVE project is the first coherent dataset on CHS intangible investments for EU-27 + Norway over the period 1995-2005. The INDICSER project also produced data on CHS intangible assets and included productivity statistics accordingly over 1997-2007. Based on INNODRIVE, the INTAN-Invest dataset was released for the extended time-frame i.e. 2010 and included data for the US (Roth, 2019a). The second INTAN[17]-Invest dataset released in 2017 provided data on the CHS Intangibles at the industry-level for the timeframe 1995-2015. Additionally, the SPINTAN project filled the gap of measuring the intangible investments employed by the public sector for EU countries between 2000-2012 (Corrado et al., 2017b).

[17] Databases contributing in estimation of intangible investments are discussed in Appendix 2.

# Chapter 6: Results

## 6.1. Introduction

This chapter presents and analyses the empirical contribution to output growth of increases in tangible and intangible capital. Using the growth accounting model and OECD data, we will do so using data for the USA, the UK (GBR), Switzerland (CHE), the Netherlands (NLD) and Germany (DEU) for the period 1995-2020-21. In addition, using EU KLEMS data, we calculate TFP growth, growth output and growth of factor inputs for the USA, the UK, the EU-27[18], Germany and the Netherlands. The calculations are made as discussed in the previous Chapter. We also discuss the contributions to output growth of inputs such as labour, tangible, and intangible investments as well as TFP on output.

## 6.2. Growth of Tangible and Intangible Assets

Before we proceed to the growth accounting analysis, it is useful to look more closely into the different asset classes that are distinguished in the databases. The following figures depict the growth of different asset classes during the period 1991-2020 based on the OECD database. The assets classes include transport equipment (TRANSPEQT), dwellings (DWELLING), other buildings (OTHBUIDLING), ICT equipment, intellectual property products (IPP) and cultural biological resources (CULTASSET). IPP here is an accumulation of R&D, mineral exploration, patented software and databases and literary & artistic originals. ICT shares in total fixed capital formation in the OECD database are the grouping of computer software and databases, telecommunications equipment and computer hardware. Interestingly, IPP solely represents the group of intangible assets combined together whereas ICT contains part of intangible asset and another part of group of tangible assets. The unpatented computer software and databases are included in ICT shares.

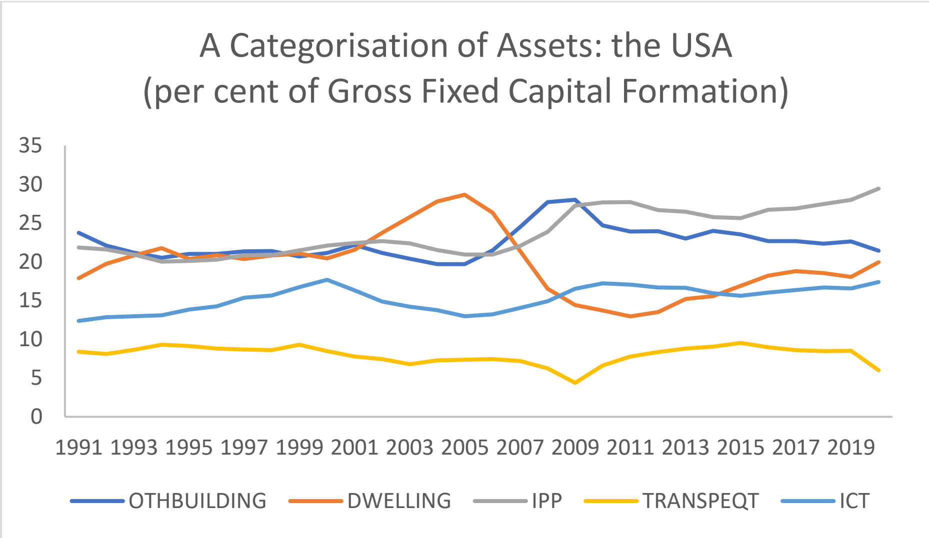
Please note for the USA and EU, the cultural asset and ICT equipment estimations are simultaneously missing. Also, please understand that the numbers in the following figures based on the OECD database are the percentage of total investments i.e. gross fixed capital formation (GFCF).

As is shown in Figure 27, the share of IPP in total fixed capital formation in the USA increased from around 20% during 1995-2007 to almost 30% in 2020. Since 2009, it can be observed that the IPP grew more than important tangible assets like dwellings and other buildings like roads, bridges, airfields, dams. The ICT shares have hardly changed over the time period 1991-

[18] EU-27 comprises countries such as AT, BE, BG, HR, CY, CZ, DK, EE, FI, FR, DE, EL, HU, IE, IT, LV, LT, LU, MT, NL, PL, PT, RO, SK, SI, ES and SE. Growth output and growth input, i.e. labour and capital are available as output files. Hence, the report contains TFP calculations for EU-27. However, due to a lack of data on capital stocks, it was not able to draw tangible versus intangible capital comparisons for EU-27.

2020. The highest growth of almost 18% can be observed for the ICT shares in 1999. The US economy maintains 17% ICT shares out of the total investments in 2020.

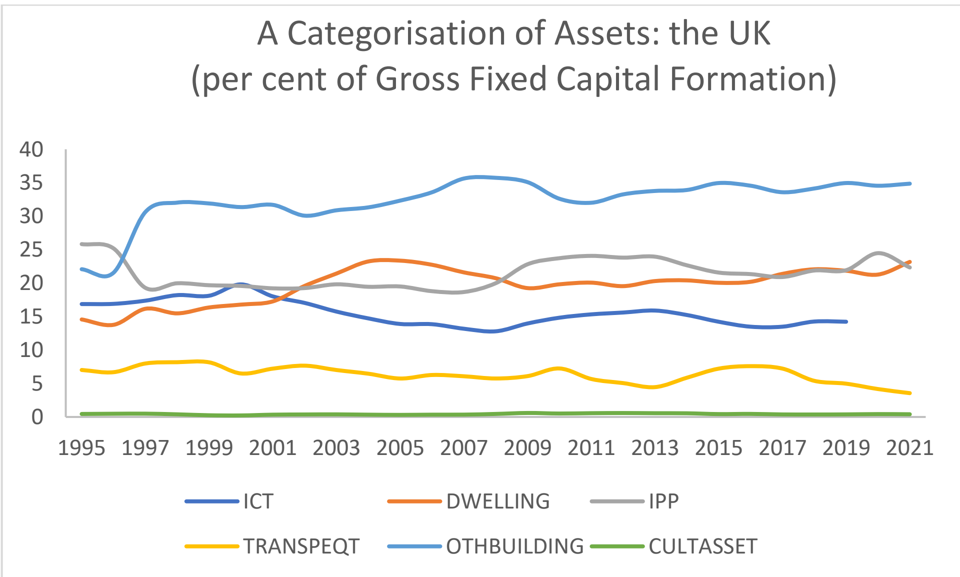
Figure 28: Categorisation of Assets for USA




Source: OECD database

Figure 28, presents changes in the asset composition of investment for the UK. As can be seen, the share of IPP in gross fixed capital formation in the UK was almost 26% in 1995, but this share declined to circa 19% in 1997, slowly rising to 23% in 2020. The share of 'Other buildings' increased over time – from 21% in 1995 to more than 34% in 2020. The shares of 'Dwellings' and 'IPP' fluctuated around a long-run average of around 20% of total fixed capital formation. ICT equipment made up around 15% of British fixed capital formation.

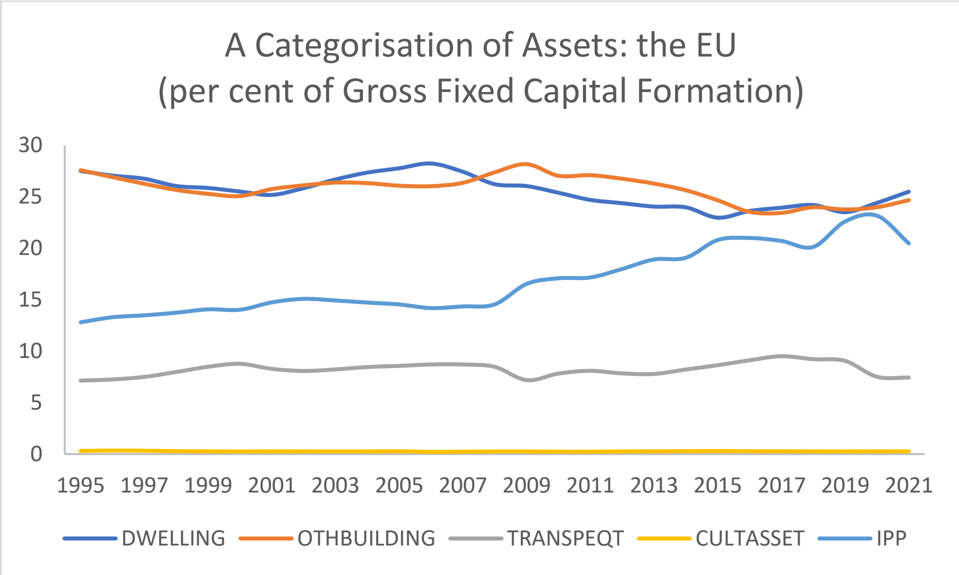
Figure 29: Categorisation of Assets for the UK




Source: OECD database

For the EU, the shares of different assets in gross fixed capital formation appear in Figure 29. The share of IPP in gross fixed capital formation increased from 12.8% in 1995 to 23% in 2020. The percentage of investments in tangible assets i.e. dwellings and transport equipment have slightly decreased from 28% in 2003-2009 to about 25% in recent years. Cultural assets are almost the same with the average of approximately 3 % throughout the time period 1995-2021.

Figure 30: Categorisation of Assets for the EU

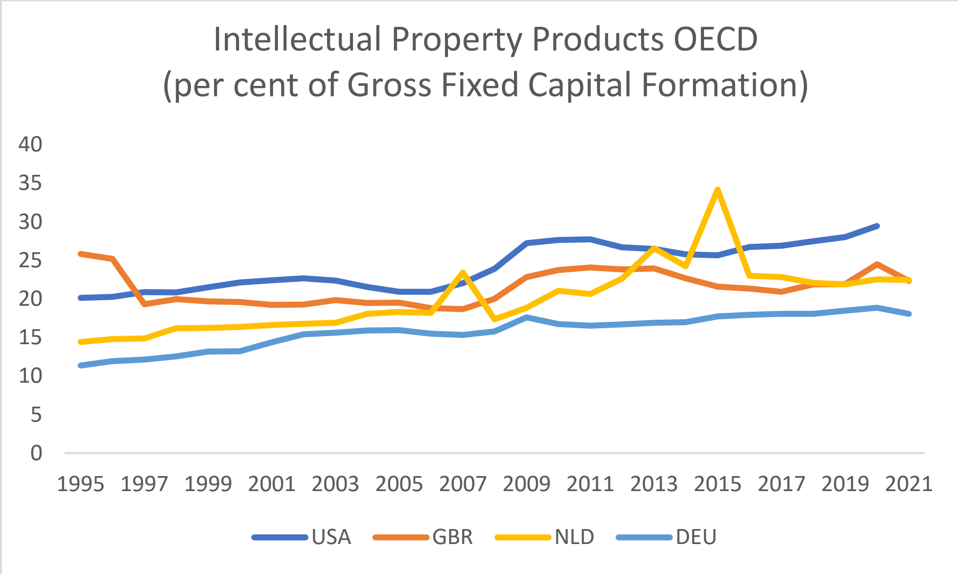



Source: OECD database

In our next analysis in Figure 31, we attempt to understand the importance and growth of intangibles (defined as IPP) in the following countries i.e., USA, UK (GBR), the Netherlands (NLD) and Germany (DEU) for the time period 1995- 2020. To do so, we again use the percentage of investments in a particular asset out of the total investments (GFCF). Based on Figure 31, we can make the following conclusions. First, the share of intangible assets (defined in terms of IPP) in gross fixed capital formation has increased in all countries (included in the graph). In Germany, the share of intangibles in total investment increased from 11.4% in 1995 to 18.1% in 2021, in the Netherlands from 14.4% in 1995 to 24.4% in 2021, in the USA from 20.1% in 1995 to 29.4% in 2020 and in the UK from 17.9% in 1997 to 22.5% in 2021 (which is tad low from the highest investment seen in IPP shares for the UK in year 1995 at 25.8%).

Second, it can be seen that there are major differences in the share of intangibles in total investment across countries. The share of intangible investment in total investment in 2020/2021 is relatively high (around 30%) in the USA, but lower in the Netherlands (22.5%), Germany (18.1%) and the UK (22.5%).

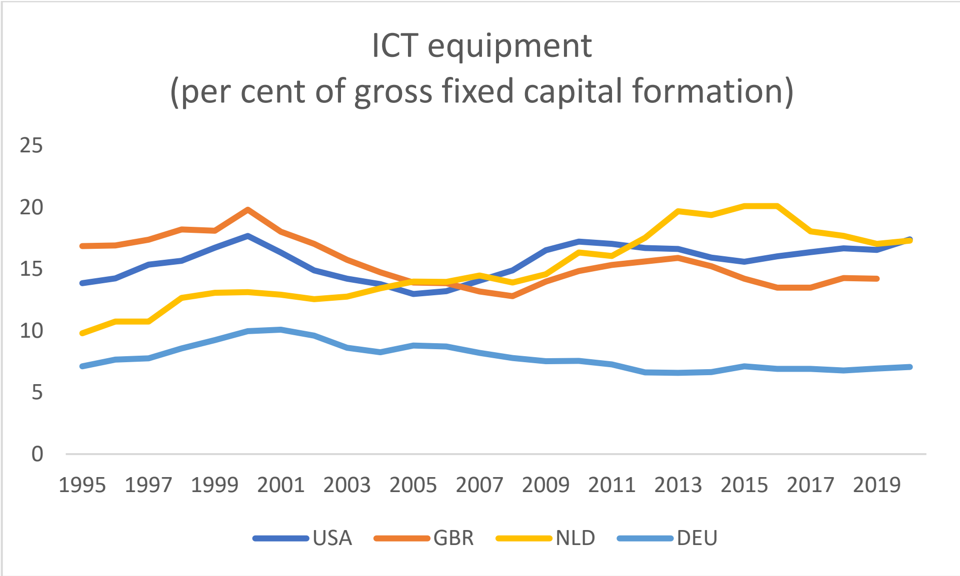
Figure 31: Country-wise IPP Shares




Source: OECD database

Figure 32, represents the analysis for ICT Shares which represents only a part of intangible assets as it contains both tangible and intangible assets. Computer software and databases are identified as intangible assets along with telecommunication equipment and computer hardware which form the part of the tangible asset class. We can draw the following conclusions from our analysis for ICT shares out of the % gross fixed capital formation shown in Figure 32: First, a similar pattern of growth of ICT shares for all the countries (except Germany) where a drop was seen in the years 2000-2005 (which can be identified as a dot-com bubble phase) with a gradual increase from there till 2020/2021. In the USA, share of ICT shares (representing both intangible and tangible assets) increased from 13% in 2005 to 17.4% in 2020, in the Netherlands from 14% in 2005 to 17.3% in 2020, in the UK from 13.8% in 2005 to 14.2% in 2019. Germany showed consistency with the average of 7% in second of innings from 2007 to 2020 which is less than long around average of 8.7% since for 1995-2006. Second, there are major differences in the share of intangibles in total investment across countries. The share of intangible investment in total investment in 2019/2020 is relatively high (around 17%) in the Netherlands and the USA, but lower in Germany (6.9%) and the UK (14%). Third, the intangible investments in terms of IPP are approximately 1.5 times more than ICT shares out of the total investments (GFCF) for all the countries.

Figure 32: Country-wise ICT Shares




Source: OECD database

Next, we turn to an analysis of intangible investment based on EU KLEMS data. We analyse the growth of nominal tangible and intangible capital stock as well as ICT and non-ICT shares from the total GFCF for the USA, the UK, Germany and the Netherlands in figures 33 and 34. The tangible stock includes Computing Equipment, Communications equipment, Transport Equipment, Other Machinery and Equipment, Residential structures, Non-residential investment and Cultivated assets. In comparison, the intangible capital stock consists of computer software and databases, Research and development and other IPP assets.

The analysis is done for the growth of % of intangible assets from GFCF in comparison to the growth of total investments (GFCF) in subsequent years. The formula can be denoted as:

$$100^{*}\ [(\text{InTan } K_{t+1} / GFCF_{t+1}) - (\text{InTan } K_{t+1} / GFCF_{t})] / (GFCF_{t+1} - GFCF_{t}).$$

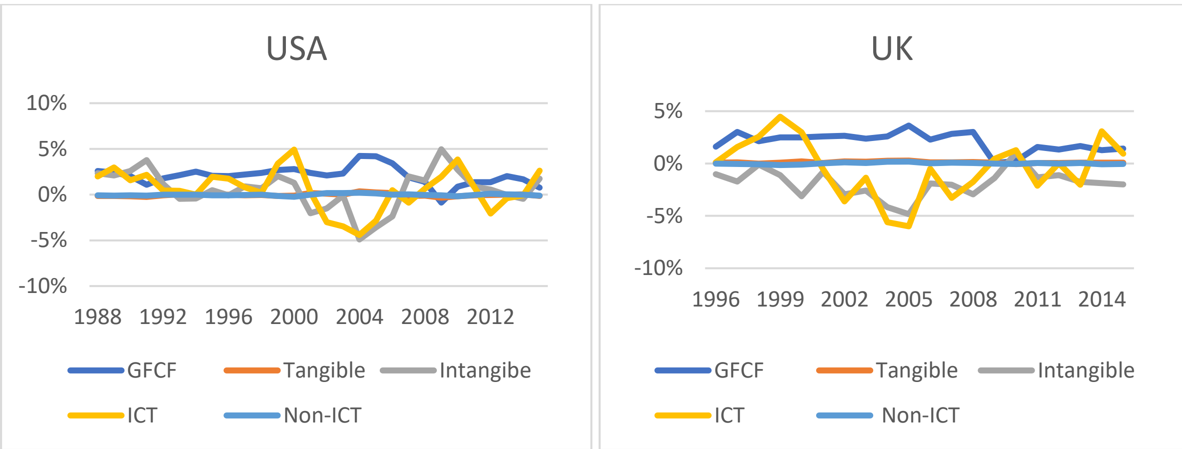
Similarly, calculations are done to understand the growth of tangible, ICT and non-ICT shares. Please note the tangible investments and non-ICT investments are more in amount as compared to intangible and ICT investments from the total investments but we are trying to analyse the growth of these investments.

The intangible and ICT share investments for USA have been high with spikes and downfalls over the time period 1988-2015. The following conclusions are made based on the observations: First, the significant growth of intangibles and ICT shares of 5% and 3% respectively can be seen during the time period 1998-2000 which can be identified as the dot-com[19] bubble phase. There is a significant drop after this time period due to the stock market

[19] The late 1990s market's investments in Internet-based businesses led to the dot-com bubble. There was a sharp increase in the value of U.S. technology stocks. Several internet start-ups and companies also got busted

crash due to the dot-com bubble crisis. Similarly during the financial crisis [20]of 2008- 2009 the intangible investments are 5% and 4% for the USA. Although, the growth in total investments is negative for these years. In subsequent years, the growth of intangible and ICT shares also turns negative like we observe in the dot-com phase. Second, the total investments for the USA have decreased from 4.2% in 2004 to almost 0.8% in 2015. Whereas the amount of intangibles and ICT growth out of these investments to be on rise to 3% for both ICT and intangibles shares. Third, tangible investments and Non-ICT shares growth is consistent to an average of 0.1%.

Figure 33: Annual growth rates of gross fixed capital formation (GFCF)




Source: Based on author’s calculations, EU KLEMS Database

Conclusions for the UK based on our analysis are discussed as follows: First, the intangible shares have shown a consistent decline with a negative average of almost 2% for the time period 1996-2015. Although, ICT shares showed the average growth of 2% from 1996-2000, they declined after 2000 with again showcasing negative average growth of 0.5%. The dot-com bubble can be one of the reason for decline of ICT investments after 2000. Second, the total investments growth has declined from 3.6% in 2005 to 1.4% in 2015. Major, drop in GFCF can be seen in years 2009 and 2010 with 0.05% and 0.25% growth respectively. Third, tangible and Non-ICT investments are observed consistent for the UK as well with growth of 0.1 %and 0.02% out of the total investment growth

In case of Germany our observations are concluded as follows: The growth of intangible investments and ICT shares are seen to at its best during 1999-2001 with an average 3% and 5.7% respectively. The intangible investments drop in subsequent years with gradual growth

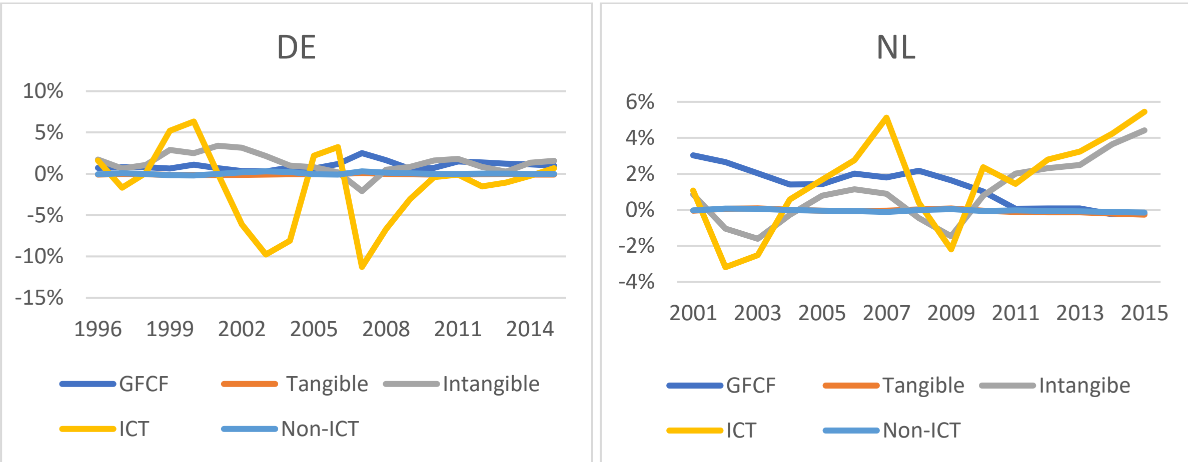
as the actual value of their technology was much less than their stock value (Tobin’s Q). NASDAQ index rose from below 1,000 points to more than 5,000 points between the years 1995 and 2000. It all came crashing down after March 2000 (Hayes, 2019).

[20] The Great Financial Crisis of 2008-09 started in the US had a global impact. The housing market bubble led to the collapse of the financial sector in the USA. The big banks and insurance companies defaulted, firms went bankrupt, unemployment rose and hence the economy of the USA fell into a deep recession. It spread like wildfire and banks of Europe, Japan and other countries suffered similarly soon after (Storm & Naastepad, 2015).

of 1.2 % observed in time period 2010-2015. The ICT shares show negative results with -1.5% growth seen in 2015. Second, the total investments are consistent with an average growth of 1% for 1996-2015 time period. Interestingly, Germany doesn't show abrupt drop in total investments in dot-com phase as well as in the Great Financial Crisis. Third, tangible and Non-ICT shares growth are seen to be consistent with an average of around 1.2% and 0.04%.

Interesting results are witnessed for the Netherlands which can be summed up as follows: First, intangible investments are shown to be increasing especially after 2009 from 0.8% to 4.4% in 2015. Also, with ICT shares gradual growth is observed from 1.5% in 2011 to 5.4 % in 2015. The Great Financial Crisis effect can be seen in the year 2009 when both intangible and ICT shares declined and the growth is seen to be negative i.e. 1.4%and -2.2%. Second, the total investments are on a decline, wherein 2001 shows 3% growth and 2015 shows negative 0.2 % growth.

Figure 34: Annual growth rates of gross fixed capital formation (GFCF) and its component in Germany and the Netherlands.




Source: Based on author's calculations, EU KLEMS Database

## 6.3. TFP, Growth Output, Input Analysis

Based on the growth accounting model, the growth output (GY), the growth of capital deepening (capital per capita) (Gk) and growth labour productivity (G LP) estimations (value added per hours worked) have been calculated for the USA, the UK, the EU-27, Germany and the Netherlands. TFP growth rates have been calculated following the methodology that was explained in the previous chapter. Table 10 shows the growth-accounting results for these countries for various time periods.

For the USA, the analysis is done for the time period 1988-2015. As we can see from the table 10 the growth output and growth capital deepening have been declining. Additionally, TFP hasn't shown any significant improvement over the decades. However, the table represents the TFP in the long run i.e., the mean over a decade for USA. Nevertheless, there is a slight improvement for 2006-2015 time period as it can be seen the value to change from -0.01% to 0%. These changes can be seen in the contribution of TFP per output analysis as well as contribution of TFP to output improves from -0.7% in 1997-2005 to 0.1% in 2006-2015 (Refer Table 11). But, it is to be noted that labour productivity shows an increase of 0.1% in the time period 1997-2005, in spite of less growth in output, capital deepening and TFP. The increased efficiency of labour in producing more output for the same inputs may have led to this increase. Capital deepening aids higher productivity with an increase in capital per hour worked, i.e., net investments which ultimately increase total output, consuming the same amount of labour in the industry or economy. However, capital deepening can be affected by a high depreciation rate in the economy which results in the decline of net investments. Capital deepening in our case means that capital intensity (capital stock per hour worked) increases, where capital stock is measured in terms of plant, equipment, tools, machinery, accumulation of intangible assets (also known as capital intensity) or implementation of new technology. The analysis excludes 2009 year in the average calculations for the USA as it shows abrupt changes in the growth of all parameters due to the global financial crisis.

The estimates for the UK show negative capital deepening during 1996-2002 to 2 03-2008 from growth values seen as -0.75% and -0.12% respectively. But there is consistent growth output of 2.12 % from time periods 1996-2002 and 2003-2008 . However, labour productivity has improved by approximately 0.4% although the TFP decreases but is still positive with a value of 0.01% for the latter time period. In the next [phase, we observe the growth rates of output and labour productivity decrease by an average of 0.75% and 1% respectively in the next six years. The TFP turns negative in this time period (2009-2015) with a value of -0.04%. But, we notice the capital deepening has improved by approximately 0.5% in this period. The tangible capital contribution to output in the table 11 also asserts that the contributions of tangible and intangible assets to growth output have increased over this period[21].

Following observations are made for the EU based on the table: The estimates for the EU 27 show consistency in the growth rates of output with slightly better growth output of around 1.6% in the time period 2003-2008, whereas labour productivity grows over the period 1996-2015 from 0.9% to 1.2%. Capital deepening was negative initially with -0.03% growth in 1996-2002 but improvement is observed over the years with increased growth of 0.33% in 2009-2015. TFP growth which was positive with 0.5% value turns negative in next phases, with an average value of -0.55% over the decade.

Germany has shown slow growth in output as there is around 0.5% increase from 1996-2015. Also, the labour productivity growth can be considered consistent with an average of 1% over the years 1996-2015. Capital deepening can be seen as 1.8% in 2003-2008 which is the highest amongst all the time periods. However, please note exceptions are made in calculations for 2008 and 2009 in our estimations as the values were extreme. Also, 2004 and 2005 in the contributions analysis showed intense figures where the tangible capital contributions to growth output can be observed as 100% along-with with TFP contribution to growth value to be -22%. The contribution of growth of the labour force is relatively low for Germany as

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[21] Exception in the average calculations has been made for years 2001, 2009 for the UK as it showed sharp changes.

compared to other countries. TFP value is negative for Germany with -0.4% value in 2009-2015.

Estimates for the Netherlands show positive results for TFP with maximum growth of 0.53% in 2003-2008. The growth of output has declined from 1.98% to 0.7% approximately over the time periods 2003-2008 and 2009-2015. However, the labour productivity growth stayed constant with growth observed as 1.6% in 1996-2002 and 2003-2008 time periods with slight decline of 0.8% in next time period (2009-2015). Capital deepening growth is negative throughout with an average of approximately 0.7% from 1996-2015.

Table 10: Growth Accounting Analysis: Average Annual Growth Rates

| USA | G Y | Gk | TFP | G LP |
|---|---|---|---|---|
| 1988-1996 | 2.47% | 0.15% | -0.01% | 1.87% |
| 1997-2005 | 2.31% | 0.09% | -0.01% | 1.96% |
| 2006-2015 | 1.65% | 0.01% | 0.00% | 1.08% |
| UK | | | | |
| 1996-2002 | 2.12% | -0.75% | 0.04% | 1.52% |
| 2003-2008 | 2.12% | -0.12% | 0.01% | 1.90% |
| 2009-2015 | 1.37% | 0.35% | -0.04% | 0.87% |
| EU | | | | |
| 1996-2002 | 1.25% | -0.03% | 0.05% | 0.90% |
| 2003-2008 | 1.57% | 0.44% | -0.07% | 0.97% |
| 2009-2015 | 1.13% | 0.30% | -0.04% | 1.17% |
| DE | | | | |
| 1996-2002 | 0.93% | 0.39% | -0.04% | 1.11% |
| 2003-2008 | 1.07% | 1.80% | -0.18% | 1.01% |
| 2009-2015 | 1.54% | 0.42% | -0.04% | 1.02% |
| NL | | | | |
| 1996-2002 | 2.51% | -0.06% | 0.30% | 1.56% |
| 2003-2008 | 1.86% | -0.10% | 0.53% | 1.59% |
| 2009-2015 | 0.68% | -0.04% | 0.17% | 0.84% |

Source: Based on Author’s Calculations

Table 11: Growth Accounting: The Contributions of Labour, Tangible Capital, Intangible Capital and TFP growth to Output Growth (percentage shares)

| USA | Labour | Tan K | Intan K | TFP |
|---|---|---|---|---|
| 1988-1996 | 53.6% | 42.6% | 4.4% | -0.5% |
| 1997-2005 | 53.5% | 44.2% | 2.9% | -0.7% |
| 2006-2015 | 54.7% | 41.0% | 4.3% | 0.1% |
| UK | | | | |
| 1996-2002 | 64.6% | 30.3% | 1.4% | 3.4% |
| 2003-2008 | 55.1% | 43.4% | 1.3% | -0.7% |
| 2009-2015 | 54.1% | 44.4% | 2.7% | -1.8% |
| DE | | | | |
| 1996-2002 | 50.5% | 50.4% | 7.7% | -4.0% |
| 2003-2008 | 39.0% | 58.0% | 11.3% | -7.8% |
| 2009-2015 | 55.2% | 42.0% | 4.5% | -0.7% |
| NL | | | | |
| 2001-2007 | 45.9% | 56.5% | 3.5% | -6.0% |
| 2008-2015 | 47.8% | 50.5% | 7.7% | -5.6% |

Source: Based on Author's Calculations

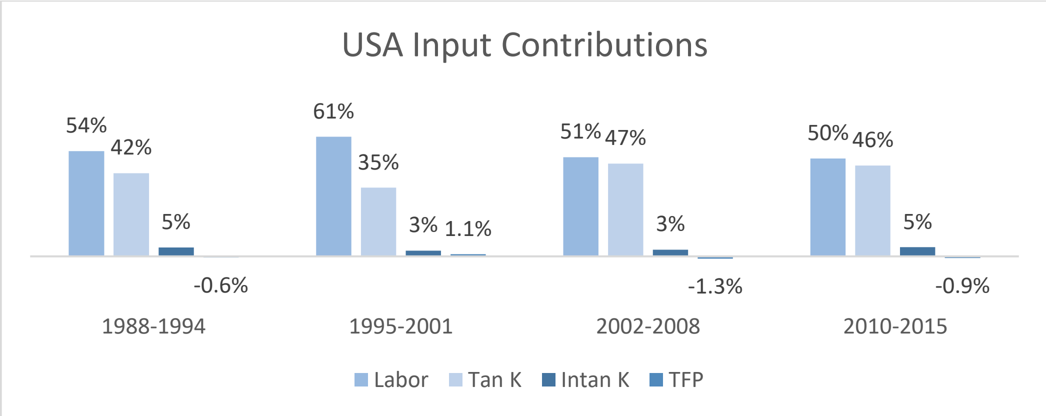
The contributions of labour, tangible capital, intangible capital and TFP growth to output growth appear in Table 11. It can be seen from Table 11 that the contribution of labour force growth to output growth is higher than that of tangible capital stock growth in the USA and the UK. The contribution of intangible capital growth to growth output is relatively small, but increases over time in the UK and increased between 1997-2005 and 2006-2015 in the USA. It follows from this that the contribution of capital deepening, which is equal to the difference between the contribution of tangible and intangible capital stock growth and labour force growth, will be small.

TFP contribution to output negative has been negative with an exception of the USA in recent years. The productivity paradox by Brynjolfsson (2018) discussed in the Introduction helps to explain this outcome. Because the adoption of technology embodied in intangible assets (such as AI) and its involvement in increasing the efficiency of the production process is displayed only over a decade or so, one can argue that the productivity-enhancing impacts of intangible assets are not yet observable in the productivity numbers.

The intangible capital contributions to output are positive and improving in recent years as shown in the table. The Netherlands receives the largest benefit from intangible investments over the time period 2008-2015. Intangible contributions are increasing for all the countries except Germany. Also, when we analyse their contribution using the figures appearing below, it can be seen that the contributions of intangible capital to GDP are not growing steadily and predictably. The UK shows similar patterns but much less variance.

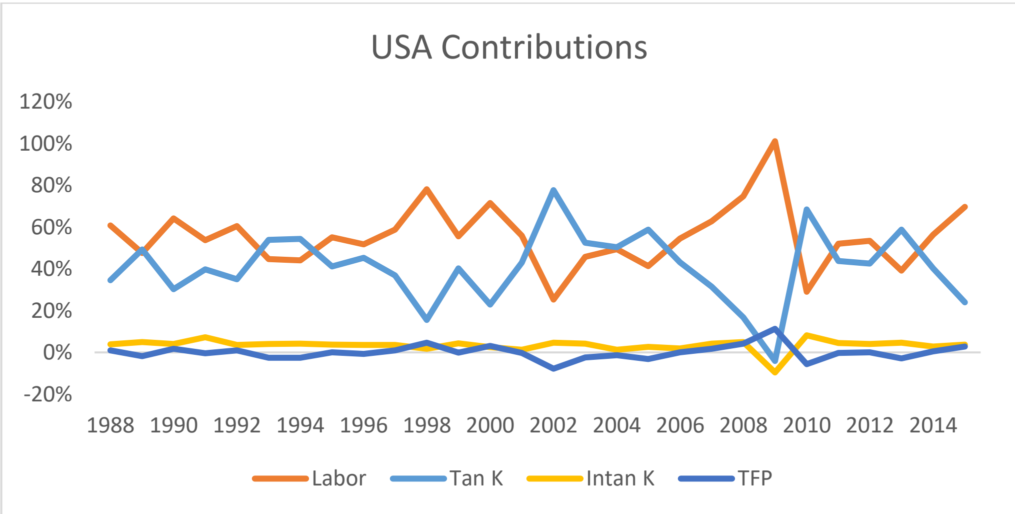
The graphs (35-42) showcase the average contributions of labour to growth output, contribution of tangible assets to growth output, contribution of intangible assets to growth output and contribution of TFP to GDP for the countries. Similarly, the contributions of all these factors to GDP over the years are also included below to understand the changes in scenario for the USA, the UK, Germany and the Netherlands better. Figures 35-42 highlights although we can observe the growth in intangible investments in the previous sections, the contribution of intangible assets to GDP is not significant. Figures 35, 36 For USA, the labour growth to GDP is significant for almost 25 years now. The intangible contributions to GDP and TFP contribution to GDP is seen to be suitable for period 1988-1994. Although a tad improvement seen for both intangible (3.7%) and TFP contribution (2.8%) to GDP in 2015.

Figure 35: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for USA




Source: Based on Author's Calculations

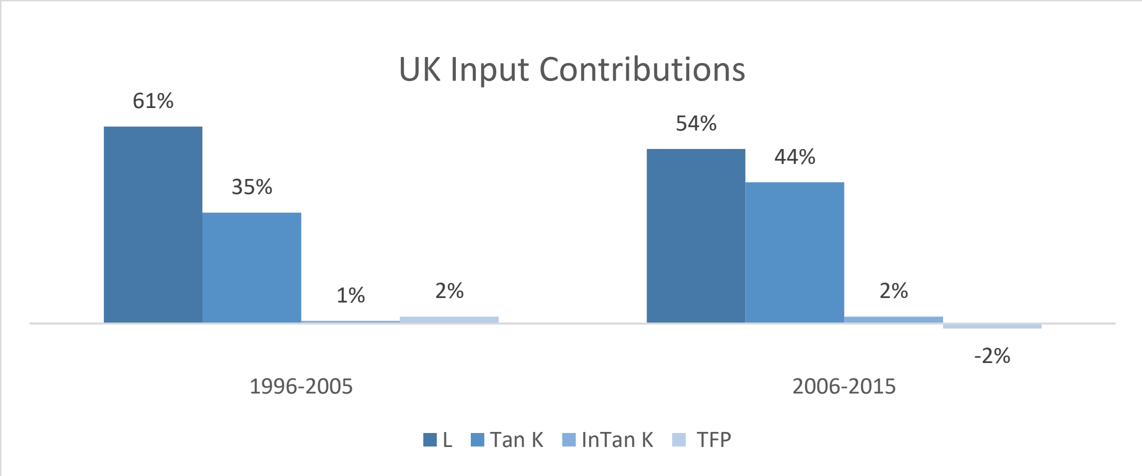
Figure 36: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for USA annually from 1988 to 2015




Source: Based on Author's Calculations

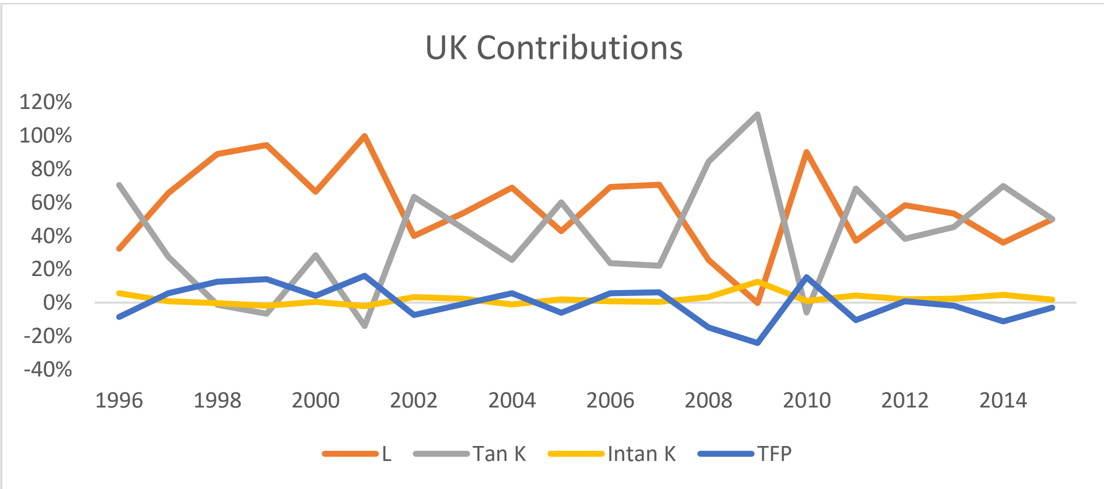
From, figures 37, 38 we observe that labour contribution to GDP is slowly shifting to tangible capital. Intangible. 2008 showed a peak in intangible capital contribution to GDP with a value of 12.5% but as discussed earlier, data for 2008 can't be blindly relied upon due to the financial crisis. In the recent years the average contribution of intangible asset is 2% which is significantly low. Please observe the TFP contribution to GDP is negative in recent years for the UK.

Figure 37: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for UK




Source: Based on Author's Calculations

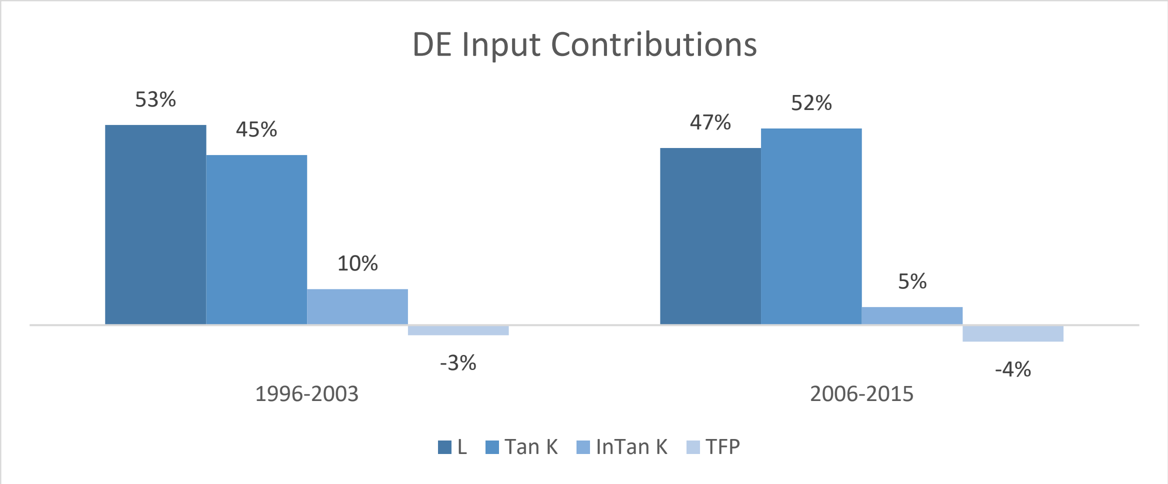
Figure 38: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for UK annually from 1996-2015




Source: Based on Author's Calculations

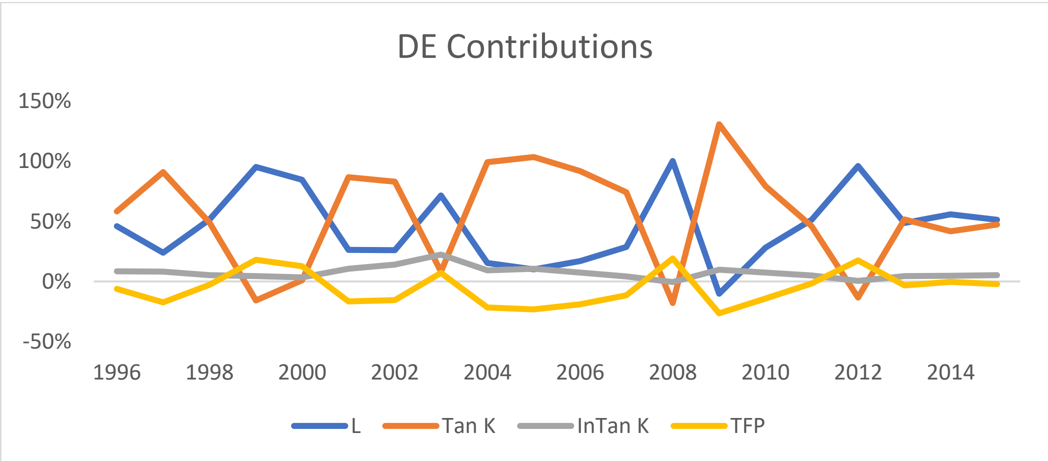
In figures 39, 40, Germany shows better results in terms of intangible contribution to GDP as we can observe 10% value for 1996-2005 which drops down to 5% in 2006-2015 but still finer as compared to the UK where we already observed the average of 1.5% intangible contribution growth to growth output from 1996 to 2015. Interestingly, the contribution of tangible growth to GDP is more as compared to USA and UK and is improving from 45% to 52%. Also, we observe the TFP to GDP contribution is yet again depressing for Germany.

Figure 39: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for Germany




Source: Based on Author's Calculations

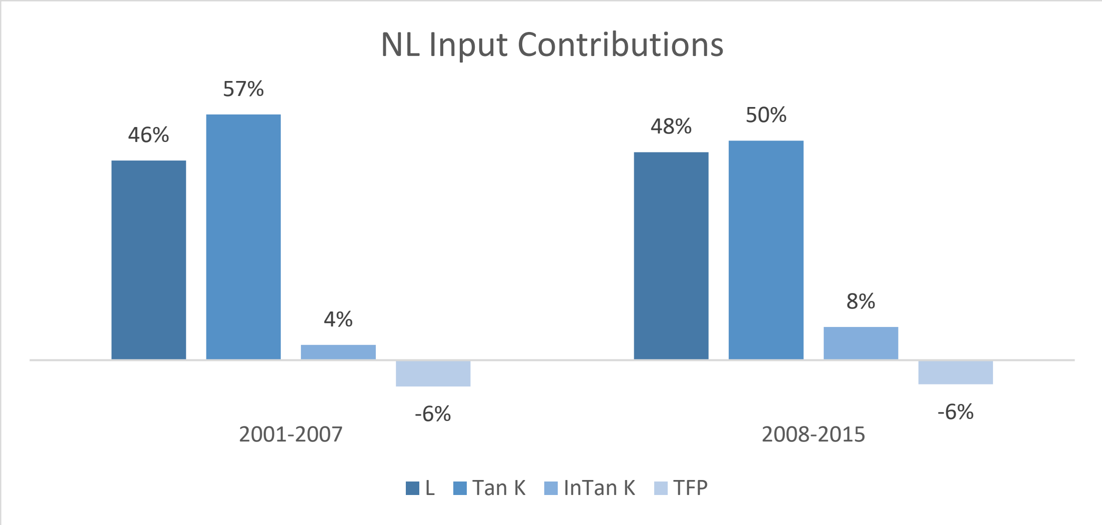
Figure 40: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for Germany annually from 1996-2015




Source: Based on Author's Calculations

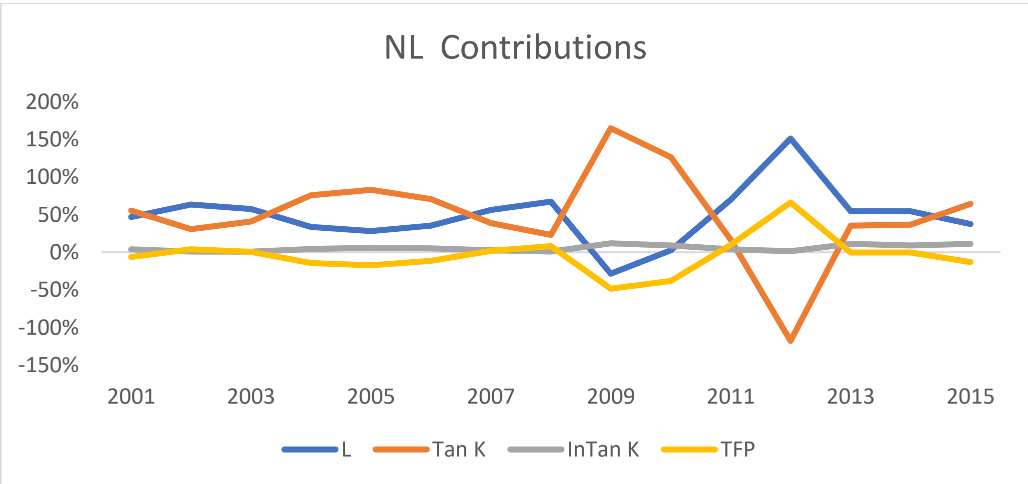
From figures 41, 42, we can observe the tangible contributions to GDP (54% approximately) are higher than labour contributions (47% average) from 2001-2015. Also, the values of intangible growth contribution to GDP are highest from all the other countries with 8% seen in 2008-2015. In recent years the intangible contribution growth to GDP seems to be even improving with 11.4% observed in 2015 particularly. On the other hand, TFP contribution to GDP is yet negative for the Netherlands like all the other countries with an average of -6% in 2001-2015.

Figure 41: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for Netherlands




Source: Based on Author's Calculations

Figure 42: Contribution of Labour, Tangible Capital, Intangible Capital, TFP to GDP for Netherlands annually from 1996-2015




Source: Based on Author's Calculations

Figures 35-42 clearly depict, although we did notice the growth in intangible investments in the previous sections, that the contribution of intangible assets to GDP is not that significant for the observed countries. But, we see definite growth in contribution of intangible to GDP in recent years. The contributions of TFP growth to GDP growth are bit alarming as we notice negative results throughout these years.

## 6.4. Comparison with CHS Analysis

As discussed in Chapter 4, the CHS framework is the groundwork for the inclusion of intangibles as not only intermediate inputs but also primary inputs for the estimation of labour productivity and GDP in the existing exogenous growth model. In this section, we have included the results for 'Intangible capital and U.S. economic growth' (Corrado et al., 2009) and illustrated comparisons with our analysis for USA. The CHS analysis is done for the period 1975-2003. However, the estimations in this report are made to cover the holistic view of growth inputs and output as well as TFP for the USA, especially in more recent years 1988-2015. The data sources for CHS are more detailed as compared to the data included in EU KLEMS, especially for intangibles. Also, as discussed in previous chapters. they include intangibles which additionally concern firm-specific resources like organisational structure, human capital, industry research and brand equity including advertising and marketing strategies. The tables highlight the analysis for CHS, with and without the inclusion of intangibles as well as the contribution analysis for labour, capital (tangible and intangible) and MFP[22] (or TFP).

It is intriguing that the labour contribution to productivity growth from the CHS perspective is relatively low and the contribution of MFP is relatively high with and without intangibles. The intangibles contribution to productivity growth is significant as per their analysis. The capital deepening increases in their case with the inclusion of intangibles by 16% and 23% out of which 7% and 30% are economic competencies (i.e., firm-specific and brand equity intangibles) for 1973-1995 and 1995-2003, respectively. Also, the data and information on intangibles used by CHS are extrapolated as per the surveys from industries. However, EU KLEMS information on intangibles is specific to data obtained from BLS and Eurostat for USA and UK respectively. The inclusion of R&D and software intangibles in the EU KLEMS capital databases is relatively recent (following the establishment of SNA 2008).

Also, as iterated in the discussions of this chapter, the 1995-2000 time period is known to be the dot-com phase for the US. CHS acknowledge this period as a period of 'technology boom and a technology bust' (Corrado et al., 2009, p 20) which can be the prime reason for the observed increase in MFP. However, in view of the fact that the years 1995-2000 ended with a crisis, the second half of the 1990s cannot be entirely understood as a productive period for technology building.

Additionally, the price estimations for intangibles by CHS are based on restrictive assumptions concerning the shares of intangible assets growth. The intangible assets are yet to build a homogenous market where the proprietorship/renting prices for intangible assets can be established. For this thesis, the calculations for intangible shares are based on OLS regression analysis. Also, the depreciation rates considered for intangibles by CHS are on the lower side. For example, the depreciation rate for R&D in CHS is 0.20, whereas EU KLEMS uses 0.32 for

[22] Multi-factor productivity (MFP) is used as a synonym for TFP. Multi-factor productivity is similarly a residual which measures the efficiency of the production process based on combined inputs i.e. labour, capital and additionally other resources such as materials, energy and services (Kenton, 2022).

R&D-specific capital estimations. This increases the value of intangible capital stock in the estimations which may depict a higher value of intangible assets to GDP for CHS.

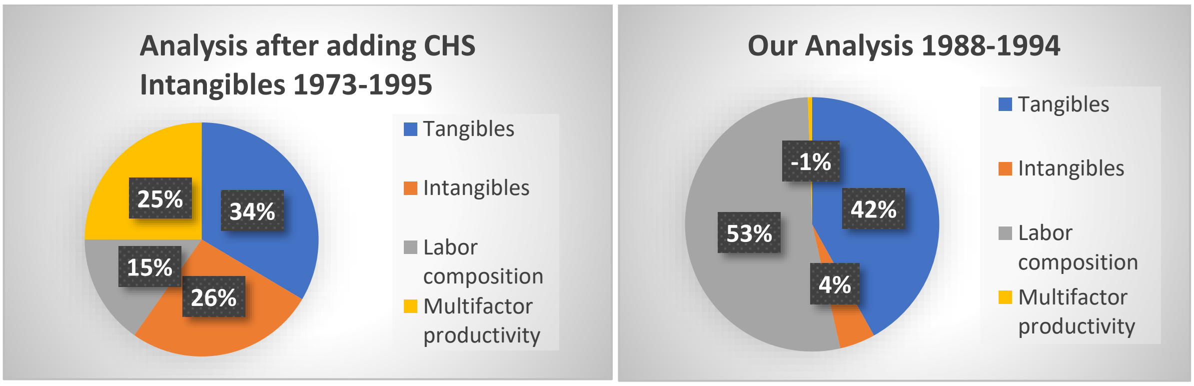
Table 12: CHS and our analysis - Contribution of capital to GDP, labour to GDP and TFP to GDP for the USA

| **CHS Analysis** | **1973–95** | | **1995–2003** | |
|---|---|---|---|---|
| **Capital deepening** | 0.44 | | 0.35 | |
| **Labour composition** | 0.21 | | 0.14 | |
| **Multifactor productivity** | 0.35 | | 0.51 | |
| | | | | |
| **CHS Analysis based on CHS Intangibles** | **1973–95** | | **1995–2003** | |
| Tangibles | 0.34 | | 0.28 | |
| Intangibles | 0.26 | | 0.30 | |
| **Labour composition** | 0.15 | | 0.12 | |
| **Multifactor productivity** | 0.25 | | 0.39 | |
| | | | | |
| **Our Analysis** | **1988-1994** | **1995-2001** | **2002-2008** | **2010-2015** |
| Tangibles | 0.42 | 0.35 | 0.47 | 0.46 |
| Intangibles | 0.05 | 0.03 | 0.03 | 0.05 |
| **Labour composition** | 0.54 | 0.61 | 0.51 | 0.50 |
| **Multifactor productivity** | -0.01 | 0.01 | -0.01 | -0.01 |

Source: Based on CHS and Author's Calculation

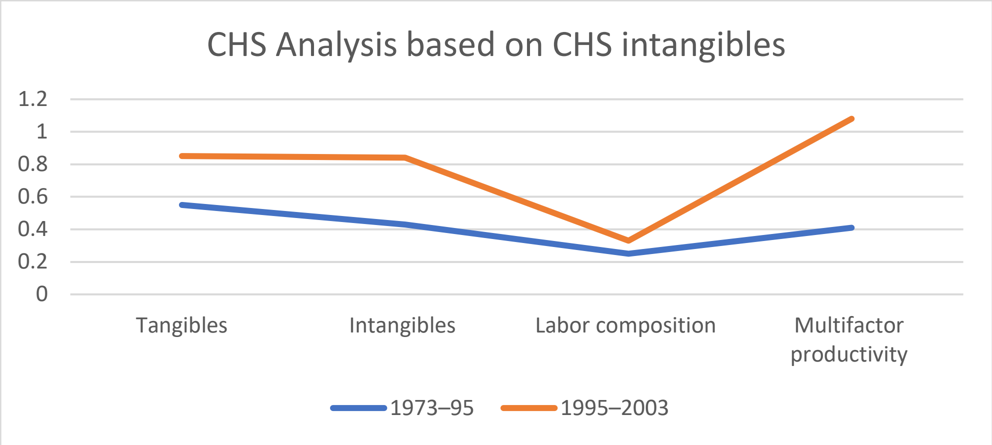
The graphical assessments for CHS and our analysis are as below:

Figure 43: Graphical Representation of CHS and our analysis for USA



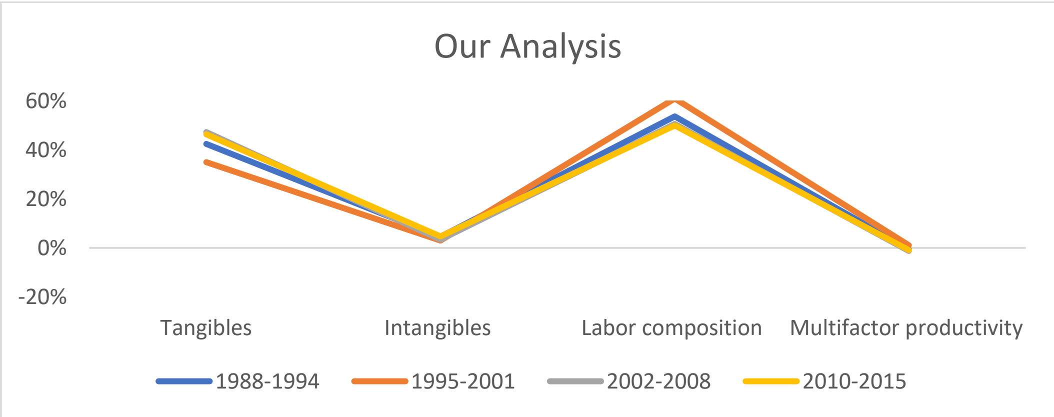

Source: Based on Author's Calculations

Figure 44: CHS Analysis for Contribution Tangible, Intangible, Labour and TFP to GDP from 1973-1995 to 1995-2003




Source: Based on Author’s Calculations

Figure 45: Our Analysis for Contribution Tangible, Intangible, Labour and TFP to GDP from 1988-2015




Source: Based on Author’s Calculations

## 6.5. Conclusion

The empirical evidence presented in this chapter has shown that intangible investments have increased in the USA, the UK, the EU (as a whole), Germany and the Netherlands. However, the growth of intangible assets has not been so strong as anticipated. Results based on OECD data highlight slow yet linear growth for intangible assets, i.e., IPP and ICT (see Figures 28-32). The USA is slowly catching up in raising its IPP assets. The share of ICT capital in gross fixed capital formation is relatively high in the Netherlands as per the results from the OECD. The commonalities can be seen in the intangible growth analysis for the Netherlands in both OECD and EU KLEMS-based estimations. The Netherlands shows a constant spike in ICT and intangible investments after 2010. However, for USA, UK and Germany, total investments

(GFCF) as well as intangible and ICT shares have grown in a haphazard manner during (2008-2015)

The TFP calculations and analysis gave an in-depth insight in the contributions of labour and capital input growth to the growth of output and labour productivity. Based on the calculations in this chapter, TFP growth has been found to be negative, but improving in recent years for the USA, the UK and the Netherlands, but not for Germany. In general, we find that the contribution to output growth of the growth in hours worked is larger than that of the growth of (tangible) capital stock. In the UK input contributions of intangible assets to GDP is low as per the analysis. In contrast, for the USA, Germany and the Netherlands, intangible contribution to GDP is better and are even improving in recent years. TFP contribution to GDP is disappointing for the USA, Germany and the Netherlands. The year 2009 is a consistent exception in this analysis that supports the effect of the financial crisis across the globe.

The comparison of the present analysis based on EU KLEMS data with the analysis by CHS for the USA shows major differences in labour contribution to be much less as compared to ours. They make their calculations based on CHS intangibles which comprises of economic competencies in addition to four intangible assets defined by SNA 2008. MFP is also observed to be high for CHS whereas our values show technological aspect to be lagging behind for the US economy.

# Chapter 7: Conclusion

This chapter concludes the study and discusses the answers to the research questions posed at the start of the thesis, described in the Introduction. We also discuss our recommendations and limitations in later sections of this chapter.

## 7.1. Conclusions

The secular stagnation and productivity paradox, despite the evolving breakthroughs in the fields of AI and robotics, are alarming for the world in recent years. The economic situation is rightly summarised by economist Robert Solow, who stated that "*you can see the computer age everywhere but in the productivity statistics*" (Solow, 1987). Researchers have anticipated the stagnation as an oversight in calculating economic growth as the defined models are unable to fully estimate the gross domestic product (GDP) or productivity due to unanticipated growth of intangible capital within the corporations and various industries in past few years (Fragkandreas, 2021; Brynjolfsson et al., 2018; Crafts, 2018).

Hence, the interest of this study was to understand the growth of intangible investments for developed economies and understand the contribution of these intangible investments to economic growth and productivity growth.

We have argued that *intangible assets do not only improve business performance, but also reinforce the competitive advantage for the firms. The positive impact of intangible capital formation is expected, therefore, to show up at* the business, the industrial and the national level. However, the clarity on definition of intangibles is still unresolved, as they are still identified as intellectual capital, intellectual property products, goodwill and so on in the literature. SNA 2008 has streamlined the definition and helped in classifying other forms of intangibles like R&D, software, computer databases and artistry and literary articles. The classification by Corrado, Hulten and Sichel (CHS) covers the competitive advantageous side of intangible assets as it includes brand equity and important firm-specific resources like organisational structure, and market strategies. Interestingly, the increased Tobin's Q highlighting the higher stock value of the firms is based on these important aspects like brand reputation and firm-specific competencies which makes investors excited and invest in a firm.

The unique properties of intangibles like scalability, non-rivalry, exclusivity and so on for different types of intangible assets were interesting to note. The complementarities and synergies between the tangibles and intangibles are strongly observed and the difficulty in examining and evaluating them as separate entities has been highlighted. We also observe the *industry-specific relevance and demand of different types of intangibles*. ICT industry growth based on the accumulation of ICT shares and hence leading to better productivity has been found to be interconnected with higher Tobin's Q of the industry concerned (Gambardella & McGahan, 2010).

Although the importance and growth of intangible assets are well understood, the reporting and valuation of intangibles remain nevertheless a challenge to resolve; the issue of mismeasurement of intangibles in the analysis at each level continues to be a problem, therefore. The International Accounting Standards Board (IASB) involved in *setting the industry standards for financial reporting and auditing has created standards for the recognition and capitalisation of intangible assets* based on the nature of their creation. Three Intangible Asset Valuation techniques issued by the International Valuation Standards Council (IVSC): Cost Approach, Market Approach and Expected Income Approach is definitely positive in covering the financial aspect of intangible assets based on the costs incurred and future cash flow analysis. The supplementary methods such as balanced score card are good to have to qualitatively analyse intangible assets and evaluate the company's performance based on it. But, these methods are not explicitly utilised in reporting methods by the industry, which leads to a mismatch in the investment analysis. Also, the techniques and methods for the valuation of IASB and IVSC are a start for estimating the intangible assets, but they may not cover the different types of assets based on their unique features. This brings us to the hypotheses discussed in Introduction. Even though the literature acknowledges the growth of intangible investments backing their business importance based on competitive advantage and industry specific significance but standardisation of intangibles in terms of definition, types and measurements isn't completely there yet. EU KLEMS and OECD have introduced the intangibles in their databases as per guidelines of SNA 2008 but, the categorisation varies a bit. CHS has different understanding of intangibles and also include the assets carrying economic competencies in intangibles list.

After covering the intangible assets at the firm and business levels and discussing their estimation methods, we review the *growth models and accounting techniques which are used to estimate the impact and growth of capital/ investments at the national level*. Solow's Growth Model is a standard model based on neoclassical macroeconomics where the factors of production i.e. capital K, and labour L, are used to evaluate the growth of output or labour productivity growth for a nation. The changes in economic growth could be anticipated based on changes in the savings rate, changes in depreciation rate (short-run growth) as well as technological growth (long-run growth) in the country. However, these factors remain exogenous indicative of the neoclassical production function. The Growth Accounting model based on the Solow Growth model decomposes the growth of these factors to analyse the output growth. Solow highlights the technological progress (TFP) as the third factor (besides the growth of the labour force and the tangible capital stock) to describe the residual gap. We also discuss endogenous growth models where the importance of human capital, and knowledge capital accumulation is emphasised for economic growth. The policies and regulations are established as promoters of innovational and technological progress, highlighting them as internal factors in economic growth.

We also discuss the EU KLEMS methodology of analysing economic growth and labour productivity. The *CHS framework developed by Corrado, Hulten and Sichel has been used widely economists for measuring intangibles as both intermediate goods and inputs in the production function* and for analysing their impact on labour productivity and economic growth.

*In our empirical analysis, the data from EU KLEMS and OECD were consolidated to enable an analysis of the growth of intangible investments for the USA, the UK, the EU-27, Germany and the Netherlands for the time period 1995-2015 (mostly).* The capital stock and labour input estimations are already available from the EU KLEMS databases in the form of capital and output files for application of the growth accounting model in the estimation of TFP, growth output (value added), labour productivity growth (value added per hours) and growth inputs (capital – tangible and intangible growth, labour growth). The weights of these factors (labour, tangible capital, intangible capital) in contributing to the total income or growth output, denoted as the income shares of labour and capital, could not be analysed directly from the files as price estimations or income generated by the physical or intangible capital is not covered in the EU KLEMS databases. We decided to identify these weights (or income shares) from OLS regression. Based on these estimations, we also compare the contribution of TFP, tangible and intangible capital inputs as well as labour compensation to the growth output for all these countries. It also helps us in understanding the comparison in estimations and analysis of CHS and our results for the USA.

Based on the OECD database, we could draw comparisons for the growth of different types of assets i.e. Buildings (roads, bridges, dams etc.), Dwellings, Transport equipments embracing tangible assets, whereas Intellectual Property Rights (IPP) and ICT covering intangible assets for countries like the USA (1991-2019), the UK, (1990-2021), and the EU[23] (1990-2021). The growth in Intellectual Property Products was observed for the USA since 2007. The highest growth in ICT shares was seen in the year 1999 for the USA, the growth of ICT shares slowed after this year and has not achieved the same growth of ICT shares since then, although it is seen to be improving. In contrast, the UK's investments in IPP and ICT shares is found to be slowly growing although the growth can be considered as consistent throughout this time period. For the EU, the growth of IPP is examined to be steeper after the financial crisis of 2008. While understanding the country-wise IPP investments and ICT shares out of their own total GFCF (Gross fixed capital formation) investments. The USA has been aligned in IPP investments and maintains the first position throughout the time period 1995-2021 in comparison to the UK, the Netherlands and Germany. In comparison, the Netherlands can be seen to be more focussed on improving its ICT shares since 2013, gaining the top rank in country-wise comparisons based on the OECD database.

We also compared and analysed the growth of total investments (GFCF), total tangible and total intangible investments in comparison to investment in ICT shares and non-ICT shares in the USA (1980-2015), the UK (1996-2015), the Netherlands (2000-2015) and Germany (1996-2015) based on the EUKLEMS database. We observe that the total investments have decreased for all these countries since the year 2008. However, the intangible capital and ICT shares are seen to be improving significantly for the Netherlands since 2010. The USA shows messy growth for intangible and ICT shares throughout the time period with a sharp downfall within the time period 2002-2005 which can be analysed as the after-effect of the dot-com bubble. The UK intangible and ICT investment growth can be observed as negative since 2000. The intangible investments show growth in 2014 for the UK. The intangible and ICT

[23] The ICT share data for EU is missing in OECD database

investments are relatively low throughout the period of analysis for Germany. Hence, the growth of intangible investments varies for countries but we can say there is overall positive increase in intangible investments across the world, especially in terms of IPP. We could have analysed the growth of intangibles hypothesis better if CHS-intangibles data was accessible. We discuss it more in the further sections of this chapter.

After applying the growth accounting model, we calculated the growth rates of output (GY), growth in capital deepening i.e. capital per hour worked (Gk), TFP and growth of labour productivity (GLP) for the USA (1988-2015), the UK (1996-2015), the EU-27 (1996-2015), the Netherlands (1996-2015) and Germany (1995-2015) based on the EUKLEMS . We also estimated the contributions of labour, tangible capital, intangible capital and TFP to growth output for the USA (1988-2015), the UK (1996-2015), the Netherlands (2001-2015) and Germany (1996-2015) to understand the role of these factors on production function better. The growth output for all the countries is observed to be decreased in the time period 2009-2015 except Germany. USA shows decreasing capital deepening from the time period 1988-1996 to 2006-2015 with a slight improvement in TFP in the latter period which was negative for 1988-1996 and 1997-2005. Whereas, for the UK, capital deepening has improved in time-period 2009-2015, but TFP is still struggling and shows negative value. Germany has positive capital deepening growth but shows a downfall in time period 2009-2015. However, TFP growth has been negative and low for a decade for Germany since 2003. The EU shows a similar pattern to Germany in technological growth and capital deepening growth. The Netherlands is the only country to maintain TFP growth but has shown negative capital deepening throughout the time period 1996-2002. The growth in intangible contributions to growth outputs can be seen for the USA, the UK and Netherlands but Germany shows better results in 2003-2008 with a decrease in the amount of contributions of intangibles to output in the next seven years. The labour component has been contributing the most in terms of growth of output for the USA, the UK and Germany. Tangible capital's contribution to output growth can be observed more in the case of the Netherlands. The contributions of TFP growth to output growth have been negative for all the countries except the USA.

*Therefore, this builds case for our last hypothesis, we definitely see a continuous decline in output growth, but it is still early to relate all of it to intangible investments. There is definitely an increase in the growth of intangible investments, but the contributions of intangible investments to economic growth are relatively small at this stage. Particularly, the low value of technological factor i.e. TFP growth, also confirms the low impact of intangible investments on economic growth. We understand that the transformation of new technologies brings an increase in capital investments, but observe low TFP or productivity growth initially.*

*This does not mean, however, that intangible capital formation has a negative impact on output growth. As is argued by Brynjolffson et al. (2018) the (positive) impact of intangible capital formation on output growth could well materialise with a (long) time-lag, as has been the case with earlier General Purposes Technologies. This phenomenon is known as the J-curve, or Productivity Paradox, and it may explain the negative TFP and growth outputs in our findings for the period 1995-2015.*

*Labour is the major instrument in economic growth which should be further analysed. Labour quality i.e. human capital contributions to economic growth can be studied in the future.*

*The comparison with CHS for the USA in terms of the contribution of individual inputs shows the contribution of capital including both tangible and intangible assets to be more significant for CHS (as compared to our analysis based on OECD and EU KLEMS data). Also, CHS shows a positive and higher value of TFP growth as compared to our findings.*

## 7.2. Recommendations

The following section briefly discusses the what is needed to enable a more precise estimation of the contribution of intangible investment to output growth, TFP growth and labour productivity growth. The first recommendation is meant for policymakers whereas the latter three are more for researchers and academia to work upon.

**Infrastructure, funding and assistance for equal opportunities**

Besides, the 'shift' also calls for the development of infrastructure and knowledge creation activities. Government should facilitate education, infrastructure planning, and public spending for the change to become beneficial for all. In fact, this can help in fostering the technological innovation of GPTs and achieving impending economic growth across the nation. Moreover, powerful companies like Apple, Microsoft seem to be benefitting the most, being the early players who estimated the potential of intangible assets and hence made those investments from the very beginning (Hazan et al., 2021). Whereas, low growers and small businesses are lagging behind and still need explicit support in understanding the strength and capacity of intangible assets as well as the implementation of these assets within their businesses. Policymakers' and governments 'efforts can be helpful in accelerating the change for them to be able to catch up and bridge the widening gap between top-growers and low-growers within the industries.

**Clear Definitions and Categorisation of Intangible Assets**

As discussed at length in Chapter 2, although intangible assets are now recognised by academia, financial and auditing as well as economic institutes, there is still no clear definition and categorisation of intangible assets (Parshakov & Zavertiaeva, 2017a). The introduction of intangible assets in the SNA guidelines (SNA 2008) has improved their status, but there is a need to further explore and specify within the defined categories (for e.g.: computer databases; see figure 6) and add other important categories like brand-equity and firm-specific resources in the classification of Intangible assets as discussed by Corrado et al., (2012).

Collaborations amongst academia involved in research, industries providing data, and government agencies involved in labour and economic analysis, are required. A proper framework involving intangible assets needs to build to define and cover the realised intangible assets in businesses and industries. The user costs or rental costs of intangible assets are still to be measured appropriately amongst different industries. Price estimations and depreciation rates are still unknown and assumed differently throughout the literature due to the absence of a homogenous market. However, the complex properties of intangible assets cannot be denied, but to be able to evaluate and utilise them better for building up the economy the clarity of these assets is a must. In fact, governments can draw tax policies based on these investments and refine them based on the economic situation for accelerating such investments and update and benefit in the future when there is economical boom overall (OECD, 2022a).

The differentiation based on properties like complementarities and spillovers, appropriability and excludability can be used to define the categories of intangible assets as discussed earlier. The industry-specific prominence is another area where economists and policymakers should focus. Data collection and reporting can be done accurately if the industry-specific usage of intangible assets is kept in mind. For example, the display of ICT investments made by IT or service-based industries can be made mandatory in the annual financial reporting under IFRS and IAS guidelines for improvement in data collection and analysis for the future.

But again, as discussed elaborately in Chapter 3, suitable measurement techniques after clear definitions are amongst the prerequisites for precise estimation (of the intangible assets and their impact) which needs to be extended by financial reporting and auditing institutes (IAS) with the help of economic analysis & research bodies like OECD. Businesses and industries follow the norms and create financial statements and annual reports based on the guidelines of reporting and auditing committees. The improvement in measurement techniques at the industrial level will help in upgrading productivity and growth output analysis at national and global levels.

**Standardisation of Human Capital in estimation procedures**

However, this study lacks an estimation of human capital for economic growth. Human capital is considered as one of the fundamental inputs to boost growth within a country and is known to be capable of generating wealth and growth differences across the countries (Botev et al., 2019; Temple, 2000). The EU KLEMS database recognises the importance of education and skills in economic growth and includes labour input analysis based on age, gender and level of education to account for labour quality i.e. human capital measures for economic growth analysis (EU KLEMS, 2022a). OECD has also conducted projects and studies for the inclusion of human capital in the estimation of labour productivity (Hamilton & Liu, 2014; OECD, 2022) Furthermore, researchers perform growth accounting based on the upgraded growth models with the inclusion of human capital as one of the factors in growth outputs.

However, human capital can be regarded as an intangible asset as well. The competitive advantage for companies having highly educated employees definitely exists which results in improved labour productivity and profitability throughout the business. This translates into national-level labour productivity growth and output growth (Ducharme, 1998). Also, education at the academic level and trainings and skill development at the corporate level (both come under the concept of human capital), are known to be the key contributors to technology and innovation for a nation. But, as seen in Chapter 2 they are also examined under intangible investments for the firms. Therefore, it is necessary for policymakers to understand and regulate human capital uniformity in the estimation methods as a separate entity or as part of the classification of intangible assets; to avoid miscalculation or double counting of human capital in the economic growth estimations.

**Reconstruction of Growth Accounting Model**

The growth accounting model constitutes a valuable economic growth analysis technique (Crafts & Woltjer, 2021). However, there are theoretical assumptions like the constant returns to scale , the production function based on Hick-neutral technological advancement, perfect competition and closed economy which can make estimations less realistic (Whelan, 2021). Crafts & Woltjer (2021) have listed the limitations of the growth accounting model in their paper 'Growth Accounting in economic history: Findings, Lessons and New directions' discussing the need of modern techniques to fill the gap as "A one-size-fits-all approach will not always do justice to the variety of historical experiences since the conventional assumptions may sometimes be inappropriate." (Crafts & Woltjer, 2021, p. 670)

Also, the growth accounting model traditionally excludes the intangibles component . As observed, the CHS framework (Chapter 4) does provide a technique to include intangibles both as intermediate input and output for analysing the economic growth based on these investments. Although CHS is used by economists for analysis of economic growth , further research and studies are required to establish robust findings on the impact of intangible investment on economic growth.

## 7.3. Scope for Improvement

This section highlight major limitations and discusses the scope and improvement in research that can be conducted to understand the growth of intangible investments at the firm, industrial and national levels and analyse the further impact of economic growth and intangible assets based on the availability of the latest data.

TFP growth calculations can be done to understand the consistency in the long run. The comparisons in technological advancements in the third [24]and fourth industrial revolutions can beneficial in understanding the progression of TFP during the transformation of the production process in both these times and help us predict the growth and development in recent times. It will be interesting to understand if the J-curve hypothesis actually holds significance in explaining the slowdown of TFP and growth output as discussed in Introduction.

Also, further economic growth analysis can be done based on the CHS framework. The databases dedicated to intangible investments (Appendix table 2) can be utilized for elaborative analysis of intangible investment growth and its impact on economic growth. Due to the unavailability of access, it was not feasible to perform analysis for CHS intangibles (brand equity and firm-specific resources) as well as draw comparisons between databases to validate the estimations of intangible contributions to output growth and labour productivity

[24] Third industrial revolution contributed to the advancement of the electrical and electronics industry and introduced computer and computer technologies to the world. The fourth industrial revolution is nonetheless evolving and is bringing breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things (IoT), autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing (Schwab, 2022)

growth. As observed in the previous chapters, intangible capital data are capable of altering the contribution of capital deepening to growth output and changing the value of TFP.

Data for capital inputs are observed to be different for the countries such as the USA, the UK in the databases. Cultural assets or biological resources are not included in EU KLEMS. Also, industry classifications as per ISIC Rev 4 is not extended in the previous versions. Moreover, it can be analysed that the data of intangibles is engineered and extrapolated to include the analysis for previous years as SNA guidelines for intangibles were only introduced in 2008. Furthermore, the time period and variable analysis isn't consistent for all the countries as there is lack of capital input files for EU-27, the intangible capital inputs are missing for the Netherlands before the year 2000 and so on.

It is interesting to understand the differentiation of investments by top-growing and low-growing companies. Due to the unavailability of firm-level data, it was not possible to understand the differences in intangible asset accumulation and ICT share investments between the two. Further studies can be done to understand the comparisons of types of investments and its impact on the profitability achieved in recent years by these firms.

## Reflection

I understand the dilemma of economists and researchers resolving the mystery of the continuous economic slowdown and support the analysis of the contribution of intangible investment on the growth outputs to understand and implement the changing trend in growth analysis. But, I feel the traditional growth accounting model as reflected in the literature may not be an appropriate method for growth analysis anymore. The intangible investment, a missing element of the production function should directly, or indirectly have its impact on economic growth and can be seen in the residual component of the growth accounting model i.e. TFP growth. As understood in the definition of TFP/MFP by OECD, MFP is measured as a residual, i.e. that part of economic growth that cannot be explained by changes in labour and capital inputs. Hence, changes in MFP reflect the effects of knowledge, network effects, spillovers, changes in management practices, brand reputation, organisational change which can't be easily estimated (OECD, 2012). Researchers and economists need to be careful while estimating the effect of intangibles as there are chances of double counting as well as overestimation of the factors to the production process, giving us misleading economic growth estimations.

Authors like CHS discuss the need for knowledge capital to be included in economic growth models (Corrado et al., 2009). However, as per my understanding, the importance and strength of knowledge capital is surely undeniable for innovation and technological advancement but the inclusion of knowledge as another capital component can be highly risky. We cannot deny the subjectivity involved with knowledge and hence produce varied results within a firm or industry. Also, it is not only impossible to value knowledge but also one should not forget that knowledge has been an important factor in carrying all the industrial revolutions throughout the years .

But, having said that, big data is definitely one area where I think researchers can dive deep, as the data economy has created high value for businesses like Amazon, Facebook (Meta) and definitely should be considered for the study of their overall impact on the three levels. The data economy is getting bigger day by day and not only new tools are being generated for their analytics but platforms are being made for the exchange of data between sellers and buyers. And hence, data can be treated as another type of intangible asset.

Besides, I also want to highlight the lack of motivation across the businesses in changing their ways of financial reporting to fulfil the gaps (productivity decline or Tobin's Q) after having extended discussions with a C-level stakeholder of a manufacturing company.

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# Appendices

## Appendix 1

The other methods i.e. quantitative as well as qualitative methods for valuation of intangible assets or intellectual capital are discussed in the following table:

Table 13: Other Methods for Valuation of Intangible assets

| Classification | Description | Quantification | Historical vs future performance | Usability for benchmarking |
|---|---|---|---|---|
| ***Invisible balance-sheet*** Individual cap, Structural cap | The invisible balance-sheet is an extension of human resource accounting, dividing intellectual capital into individual capital and structural capital. The individual capital focuses on the professional competence based on expertise of employees. The attributes pondered upon are education, experience, number of persons in the company with relevant background and the distribution of responsibilities in context to customers and projects. The structural capital highlights the competitive advantage of the firm based on employee's reputation, experience and specific products, services or production methods. | Relative | Historical costs | No |
| ***Intangible asset monitor*** External view, Internal view, People's competence, Tangible assets | The intangible assets monitor is to measure intangible assets in simple fashion and displays a number of relevant indicators for measuring Intangibles or IC. The indicators are adjusted based for each company on their own circumstances. The important areas to monitor company's performance includes growth, efficiency and stability. It is useful to design a management information system or to perform an audit. It is similar to BSC | Qualitative | Both | No |
| ***Balanced score-card*** Financial view, Customer view, Process view, Innovation and learning view | It has been already discussed. However, it should be noted that BSC is also company specific and provides no possibility for external comparison | Qualitative | Both | No |
| ***Economic value added*** Financial planning, Budgeting, Goal setting, Compensation | EVA is comprehensive measure that utilizes the variables of capital budgeting, financial planning, goal setting, performance measurement, shareholder communication and incentive compensation to account for all ways in which corporate value can be added or lost. it is accepted throughout the financial system hence EVA may increase the genuineness and reputation of a company in the eyes of financial market. However, EVA uses book assets for historical costs, which give little indication of the current market or replacement value hence no appropriate valuation of intangible assets. | Yes | Historical costs | Internal only |
| ***IC Index*** Strategy, financial and non-financial measures | The IC-index is a method which allows management to evaluate and compare two alternative Intellectual Capitals based on its effects on the company as well in the market. It is restrictive model where only intangibles-creating processes that are directly/indirectly are under the control of the company itself should be included. | Single index | Value-creating potential | Limited |

| | | | | |
|---|---|---|---|---|
| | The IC-index also allows for systematic benchmarking of making comparisons at both business unit and corporate levels. | | | |
| ***Technology Broker*** Market assets, Human assets, Intellectual property, Infrastructure assets | Technology broker' approach is combination of Brooking defines IC as the combined amalgam of four components: market assets, human-centered assets, intellectual property assets, and infrastructure assets. Market assets showcases the potential from market-related intangibles such as brands, customers, repeat business, backlog, distribution channels, contracts and agreements . Human-centered assets are based on employee's collective expertise, creative and problem-solving capability, leadership, entrepreneurial and managerial skills. Intellectual property assets contain the legally protected assets such as know-how, trade secrets, copyrights, patents and various design rights, trade and service marks. And, infrastructure assets entails technologies, methodologies and processes of the organization. However, TB offers company's complete package to evaluate company's performance and assign a value based on audit questions but these questions are still subjective in nature whereas quantitative method utilised suffers the uncertainties. | From qualitative to quantitative values | Both (cost/market/ income approach) | Limited |
| ***Return on assests*** Overall earnings performance over assets | ROA is the ratio of a company's average earnings (EBIT, average pre-tax earnings of a company over three to five years) divided by average tangible assets over the same period of time. The ratio is then compared to the industry average to calculate the difference. If the difference is negative or zero or negative, it means company have no excess intangible capital compared with its industry average and the value of its intangible capital is assumed to be zero. However, if it is positive, then the company is assumed to have excess intangibles as compared to its industry. This excess ROA is multiplied to the company's average tangible assets to calculate the average annual excess earnings. Dividing excess earnings by the company's average cost of capital, gives the value of its intellectual capital. | Single figure | Historical costs | Yes |
| ***Market capitalization method*** Difference between market and book value | MCM calculates the Tobin's Q and evaluate the gap as intangible capital but it has been already discussed that it may or may not imply the accumulation of intangible assets | Single figure | Historical costs | Yes |
| ***Direct IC method*** Market, Intell. property, Technology Human structural assets | The direct intellectual capital (DIC) method focuses on major categories of a company's intangible assets: market assets, intellectual property, technology assets, human assets, and structural assets. After all the components are measured, the total value of a company's intangibles is established. DIC is complex but is most close to value intangible assets of a firm | Quantified | Components of market assets | Yes |
| ***Skandia business navigator*** Financial, Customer, Process, Human, Development KPI | Skandia monitors company' performance based on 30 key performance indicators (KPI) in various areas. Customer focus, process focus, human focus, and development/ renewal focus are included in addition to traditional financial focus area. | Relative | Both | No |

| | | | | |
|---|---|---|---|---|
| ***FiMIAM***<br>Human,Customer, structural capital and their cross-sections | FiMIAM model establishes firm's intangible capital based on human, customer and structural assets. The overlaps represents the synergy or combinations of two or three of the intangibles. For example, combination of human and customer capital include customer relationship and the skillset of employees to fulfil customer needs. FiMIAM method provides monetary values to each relevant intangible component to evaluate company's performance. | Quantified | Market price | Yes |

Source: Rodov & Leliaert (2002)

# Appendix 2

The following table shows the list of databases discussed throughout the literature which can be utilised for intangible investment estimations at the industrial and national levels. Unfortunately, access to these databases is limited but they can definitely be used for further research on the topic.

Table 14: Databases contributing in intangible investments estimations

| Project | Main source | Period | Countries | Variables | Level | Economic sector |
|---|---|---|---|---|---|---|
| EUKLEMS | O'Mahony and Timmer (2009) | 1970-2015 | EU-28, US | Tangibles and NA intangibles | Industry | Business |
| INNODRIVE | Jona-Lasinio *et al.* (2011) | 1995-2005 | EU-27, NO | CHS intangibles and adjusted productivity measures | Country | Non-agricultural and Business |
| INDICSER | O'Mahony *et al.* (2012) | 1995-2007 | AT, BE, CZ, DE, DK, ES, FI, FR, HU, IE, IT, NL, SE, UK | CHS intangibles, and adjusted productivity measures | Industry | Business |
| SPINTAN | Corrado *et al.* (2017b) | 2000-2012 | AT, BE, CZ, DE, DK, EE, EL, ES, FI, FR, HU, IE, IT, LU, NL, NO, PL, PT, SK, SE, UK, US | Public sector intangibles | Country | Public |
| INTAN-Invest | Corrado *et al.* (2018) | 1995-2015 | AT, BE, CZ, DE, DK, FI, FR, EL, ES, HU, IE, IT, LU, NL, PT, SK, SI, SE, UK, US | CHS intangibles, and adjusted productivity measures | Industry | Business |
| EUKLEMS (Statistical + Analytical Database) | Stehrer *et al.* (2019) | 1995-2017 | EU-28, JP, US | Tangibles, NA and CHS intangibles, adjusted productivity statistics | Industry | Whole economy |

Source: Roth, 2019

# Appendix 3

This section highlights the calculations of growth output, growth input and TFP. We have included all the calculations for the USA. Similar estimations are made for UK, EU, NL and DE.

The following tables Table 15-17 are the calculations done for the USA from the EU KLEMS database

Table 15: TFP calculations using growth accounting models

| Year | Growth Y | GL | SL | GL*SL | GK | SK | GK*SK | GY | TFP | Gk | GLP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 0.032 | 0.035 | 0.562 | 0.020 | 0.028 | 0.438 | 0.012 | 0.032 | 0.000 | -0.007 | 0.021 |
| 1989 | 0.032 | 0.028 | 0.556 | 0.015 | 0.039 | 0.444 | 0.017 | 0.032 | -0.001 | 0.012 | 0.023 |
| 1990 | 0.024 | 0.027 | 0.560 | 0.015 | 0.018 | 0.440 | 0.008 | 0.024 | 0.000 | -0.009 | 0.020 |
| 1991 | 0.014 | 0.013 | 0.560 | 0.007 | 0.015 | 0.440 | 0.006 | 0.014 | 0.000 | 0.001 | 0.020 |
| 1992 | 0.025 | 0.027 | 0.562 | 0.015 | 0.022 | 0.438 | 0.010 | 0.025 | 0.000 | -0.005 | 0.024 |
| 1993 | 0.022 | 0.018 | 0.556 | 0.010 | 0.029 | 0.444 | 0.013 | 0.022 | -0.001 | 0.011 | 0.013 |
| 1994 | 0.027 | 0.021 | 0.549 | 0.012 | 0.035 | 0.451 | 0.016 | 0.027 | -0.001 | 0.013 | 0.017 |
| 1995 | 0.021 | 0.021 | 0.549 | 0.011 | 0.021 | 0.451 | 0.009 | 0.021 | 0.000 | 0.000 | 0.014 |
| 1996 | 0.024 | 0.023 | 0.547 | 0.012 | 0.026 | 0.453 | 0.012 | 0.024 | 0.000 | 0.003 | 0.017 |
| 1997 | 0.027 | 0.029 | 0.548 | 0.016 | 0.024 | 0.452 | 0.011 | 0.027 | 0.000 | -0.005 | 0.016 |
| 1998 | 0.023 | 0.033 | 0.559 | 0.018 | 0.009 | 0.441 | 0.004 | 0.023 | 0.001 | -0.024 | 0.019 |
| 1999 | 0.026 | 0.026 | 0.561 | 0.015 | 0.027 | 0.439 | 0.012 | 0.026 | 0.000 | 0.001 | 0.018 |
| 2000 | 0.027 | 0.034 | 0.570 | 0.019 | 0.016 | 0.430 | 0.007 | 0.027 | 0.001 | -0.018 | 0.020 |
| 2001 | 0.014 | 0.013 | 0.570 | 0.008 | 0.014 | 0.430 | 0.006 | 0.014 | 0.000 | 0.001 | 0.018 |
| 2002 | 0.014 | 0.006 | 0.560 | 0.004 | 0.027 | 0.440 | 0.012 | 0.014 | -0.001 | 0.020 | 0.018 |
| 2003 | 0.020 | 0.017 | 0.554 | 0.009 | 0.026 | 0.446 | 0.012 | 0.020 | 0.000 | 0.009 | 0.022 |
| 2004 | 0.028 | 0.025 | 0.550 | 0.014 | 0.032 | 0.450 | 0.014 | 0.028 | 0.000 | 0.007 | 0.023 |
| 2005 | 0.028 | 0.021 | 0.543 | 0.012 | 0.038 | 0.457 | 0.017 | 0.028 | -0.001 | 0.016 | 0.022 |
| 2006 | 0.025 | 0.025 | 0.543 | 0.013 | 0.024 | 0.457 | 0.011 | 0.025 | 0.000 | 0.000 | 0.016 |
| 2007 | 0.019 | 0.022 | 0.547 | 0.012 | 0.015 | 0.453 | 0.007 | 0.019 | 0.000 | -0.007 | 0.014 |
| 2008 | 0.007 | 0.009 | 0.551 | 0.005 | 0.003 | 0.449 | 0.001 | 0.007 | 0.000 | -0.006 | 0.009 |
| 2009 | -0.008 | -0.016 | 0.541 | -0.008 | 0.002 | 0.459 | 0.001 | -0.008 | -0.001 | 0.018 | 0.016 |
| 2010 | 0.017 | 0.009 | 0.533 | 0.005 | 0.027 | 0.467 | 0.013 | 0.017 | -0.001 | 0.018 | 0.017 |
| 2011 | 0.016 | 0.015 | 0.534 | 0.008 | 0.016 | 0.466 | 0.008 | 0.016 | 0.000 | 0.001 | 0.009 |
| 2012 | 0.018 | 0.018 | 0.534 | 0.009 | 0.018 | 0.466 | 0.008 | 0.018 | 0.000 | 0.000 | 0.009 |
| 2013 | 0.014 | 0.011 | 0.530 | 0.006 | 0.019 | 0.470 | 0.009 | 0.014 | 0.000 | 0.009 | 0.007 |
| 2014 | 0.018 | 0.019 | 0.533 | 0.010 | 0.017 | 0.467 | 0.008 | 0.018 | 0.000 | -0.002 | 0.009 |
| 2015 | 0.016 | 0.020 | 0.538 | 0.011 | 0.009 | 0.462 | 0.004 | 0.016 | 0.000 | -0.011 | 0.007 |

The share values of USA calculated based on GY (dependent variable), G Tan K, G InTan K, GL (independent variables) is shown below:

Table 16: Regression for the USA

| | | Independent VariableS X | | | | | |
|---|---|---|---|---|---|---|---|
| Year | Dependent Variable Y | L | Tan K | InTan K | Sl | S Tan K | S In Tan K |
| 1988 | 0.032345659 | 0.034978398 | 0.027599 | 0.038275 | 0.562046 | 0.405108 | 0.032847 |
| 1989 | 0.032213313 | 0.02763089 | 0.0387 | 0.048328 | 0.555888 | 0.410803 | 0.033308 |
| 1990 | 0.023822019 | 0.027311813 | 0.017684 | 0.029559 | 0.559629 | 0.407343 | 0.033028 |
| 1991 | 0.013912538 | 0.013373087 | 0.013614 | 0.030889 | 0.559779 | 0.407204 | 0.033017 |
| 1992 | 0.024827868 | 0.026733513 | 0.021489 | 0.026882 | 0.562244 | 0.404924 | 0.032832 |
| 1993 | 0.022146865 | 0.017788135 | 0.029045 | 0.026955 | 0.556183 | 0.410531 | 0.033286 |
| 1994 | 0.026612889 | 0.021360353 | 0.034665 | 0.032676 | 0.549414 | 0.416792 | 0.033794 |
| 1995 | 0.020789891 | 0.020891622 | 0.020487 | 0.022738 | 0.549008 | 0.417168 | 0.033824 |
| 1996 | 0.024016732 | 0.02272435 | 0.025956 | 0.02556 | 0.546603 | 0.419392 | 0.034005 |
| 1997 | 0.026621183 | 0.028561485 | 0.023456 | 0.027698 | 0.547983 | 0.418115 | 0.033901 |
| 1998 | 0.02336903 | 0.032680827 | 0.008881 | 0.012119 | 0.559202 | 0.407738 | 0.03306 |
| 1999 | 0.026482786 | 0.026234086 | 0.026229 | 0.035529 | 0.560924 | 0.406145 | 0.032931 |
| 2000 | 0.027173685 | 0.034090381 | 0.015649 | 0.021668 | 0.570183 | 0.397581 | 0.032236 |
| 2001 | 0.013682026 | 0.01340931 | 0.014806 | 0.005151 | 0.570128 | 0.397632 | 0.03224 |
| 2002 | 0.01418413 | 0.0064051 | 0.027102 | 0.020055 | 0.560293 | 0.406729 | 0.032978 |
| 2003 | 0.020394038 | 0.016832344 | 0.025932 | 0.025427 | 0.553834 | 0.412704 | 0.033462 |
| 2004 | 0.027796708 | 0.02498052 | 0.033629 | 0.010221 | 0.550254 | 0.416015 | 0.033731 |
| 2005 | 0.028011897 | 0.021369144 | 0.038892 | 0.022063 | 0.542589 | 0.423105 | 0.034306 |
| 2006 | 0.024642793 | 0.024770213 | 0.025147 | 0.014018 | 0.542715 | 0.422988 | 0.034296 |
| 2007 | 0.018962747 | 0.021789142 | 0.014268 | 0.023409 | 0.546812 | 0.419199 | 0.033989 |
| 2008 | 0.00659309 | 0.00895011 | 0.002655 | 0.009694 | 0.550862 | 0.415453 | 0.033685 |
| 2009 | -0.008347289 | -0.015606008 | 0.000808 | 0.0233 | 0.541073 | 0.424508 | 0.03442 |
| 2010 | 0.016595638 | 0.009067029 | 0.026318 | 0.038809 | 0.532643 | 0.432305 | 0.035052 |
| 2011 | 0.015663231 | 0.015285966 | 0.0159 | 0.020001 | 0.533628 | 0.431394 | 0.034978 |
| 2012 | 0.017665183 | 0.017707566 | 0.017425 | 0.02006 | 0.533596 | 0.431424 | 0.03498 |
| 2013 | 0.014332984 | 0.010600112 | 0.019419 | 0.019168 | 0.530343 | 0.434433 | 0.035224 |
| 2014 | 0.017941348 | 0.018955089 | 0.016726 | 0.014536 | 0.532781 | 0.432177 | 0.035041 |
| 2015 | 0.015658102 | 0.020273492 | 0.008777 | 0.016879 | 0.538408 | 0.426973 | 0.034619 |

Based on these shares we analyse the contribution of each input to GDP, as shown in the following table:

Table 17: Contribution Calculations

| Year | GL | SL | GL*SL | GK | SK | GK*SK | G Y | TFP | Gk | G LP | Contribution of TFP/Y | Contribution of L/Y | Contribution of K/Y | S In Ta | G Tan K | S Tan K | G Intan K | Contribution of IntanK/Y | Contribution of Tan K/Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988 | 0.035 | 0.562 | 0.020 | 0.028 | 0.438 | 0.012 | 0.032 | 0.000 | -0.007 | 0.021 | 0.010 | 0.608 | 0.383 | 0.033 | 0.028 | 0.405 | 0.038 | 0.039 | 0.346 |
| 1989 | 0.028 | 0.556 | 0.015 | 0.039 | 0.444 | 0.017 | 0.032 | -0.001 | 0.012 | 0.023 | -0.019 | 0.477 | 0.542 | 0.033 | 0.039 | 0.411 | 0.048 | 0.050 | 0.494 |
| 1990 | 0.027 | 0.560 | 0.015 | 0.018 | 0.440 | 0.008 | 0.024 | 0.000 | -0.009 | 0.020 | 0.017 | 0.642 | 0.341 | 0.033 | 0.018 | 0.407 | 0.030 | 0.041 | 0.302 |
| 1991 | 0.013 | 0.560 | 0.007 | 0.015 | 0.440 | 0.006 | 0.014 | 0.000 | 0.001 | 0.020 | -0.005 | 0.538 | 0.467 | 0.033 | 0.014 | 0.407 | 0.031 | 0.073 | 0.398 |
| 1992 | 0.027 | 0.562 | 0.015 | 0.022 | 0.438 | 0.010 | 0.025 | 0.000 | -0.005 | 0.024 | 0.009 | 0.605 | 0.385 | 0.033 | 0.021 | 0.405 | 0.027 | 0.036 | 0.350 |
| 1993 | 0.018 | 0.556 | 0.010 | 0.029 | 0.444 | 0.013 | 0.022 | -0.001 | 0.011 | 0.013 | -0.026 | 0.447 | 0.579 | 0.033 | 0.029 | 0.411 | 0.027 | 0.041 | 0.538 |
| 1994 | 0.021 | 0.549 | 0.012 | 0.035 | 0.451 | 0.016 | 0.027 | -0.001 | 0.013 | 0.017 | -0.026 | 0.441 | 0.585 | 0.034 | 0.035 | 0.417 | 0.033 | 0.041 | 0.543 |
| 1995 | 0.021 | 0.549 | 0.011 | 0.021 | 0.451 | 0.009 | 0.021 | 0.000 | 0.000 | 0.014 | 0.001 | 0.552 | 0.448 | 0.034 | 0.020 | 0.417 | 0.023 | 0.037 | 0.411 |
| 1996 | 0.023 | 0.547 | 0.012 | 0.026 | 0.453 | 0.012 | 0.024 | 0.000 | 0.003 | 0.017 | -0.007 | 0.517 | 0.490 | 0.034 | 0.026 | 0.419 | 0.026 | 0.036 | 0.453 |
| 1997 | 0.029 | 0.548 | 0.016 | 0.024 | 0.452 | 0.011 | 0.027 | 0.000 | -0.005 | 0.016 | 0.009 | 0.588 | 0.403 | 0.034 | 0.023 | 0.418 | 0.028 | 0.035 | 0.368 |
| 1998 | 0.033 | 0.559 | 0.018 | 0.009 | 0.441 | 0.004 | 0.023 | 0.001 | -0.024 | 0.019 | 0.046 | 0.782 | 0.172 | 0.033 | 0.009 | 0.408 | 0.012 | 0.017 | 0.155 |
| 1999 | 0.026 | 0.561 | 0.015 | 0.027 | 0.439 | 0.012 | 0.026 | 0.000 | 0.001 | 0.018 | -0.001 | 0.556 | 0.446 | 0.033 | 0.026 | 0.406 | 0.036 | 0.044 | 0.402 |
| 2000 | 0.034 | 0.570 | 0.019 | 0.016 | 0.430 | 0.007 | 0.027 | 0.001 | -0.018 | 0.020 | 0.030 | 0.715 | 0.254 | 0.032 | 0.016 | 0.398 | 0.022 | 0.026 | 0.229 |
| 2001 | 0.013 | 0.570 | 0.008 | 0.014 | 0.430 | 0.006 | 0.014 | 0.000 | 0.001 | 0.018 | -0.003 | 0.559 | 0.444 | 0.032 | 0.015 | 0.398 | 0.005 | 0.012 | 0.430 |
| 2002 | 0.006 | 0.560 | 0.004 | 0.027 | 0.440 | 0.012 | 0.014 | -0.001 | 0.020 | 0.018 | -0.078 | 0.253 | 0.825 | 0.033 | 0.027 | 0.407 | 0.020 | 0.047 | 0.777 |
| 2003 | 0.017 | 0.554 | 0.009 | 0.026 | 0.446 | 0.012 | 0.020 | 0.000 | 0.009 | 0.022 | -0.024 | 0.457 | 0.567 | 0.033 | 0.026 | 0.413 | 0.025 | 0.042 | 0.525 |
| 2004 | 0.025 | 0.550 | 0.014 | 0.032 | 0.450 | 0.014 | 0.028 | 0.000 | 0.007 | 0.023 | -0.013 | 0.495 | 0.519 | 0.034 | 0.034 | 0.416 | 0.010 | 0.012 | 0.503 |
| 2005 | 0.021 | 0.543 | 0.012 | 0.038 | 0.457 | 0.017 | 0.028 | -0.001 | 0.016 | 0.022 | -0.031 | 0.414 | 0.618 | 0.034 | 0.039 | 0.423 | 0.022 | 0.027 | 0.587 |
| 2006 | 0.025 | 0.543 | 0.013 | 0.024 | 0.457 | 0.011 | 0.025 | 0.000 | 0.000 | 0.016 | 0.001 | 0.546 | 0.454 | 0.034 | 0.025 | 0.423 | 0.014 | 0.020 | 0.432 |
| 2007 | 0.022 | 0.547 | 0.012 | 0.015 | 0.453 | 0.007 | 0.019 | 0.000 | -0.007 | 0.014 | 0.017 | 0.628 | 0.354 | 0.034 | 0.014 | 0.419 | 0.023 | 0.042 | 0.315 |
| 2008 | 0.009 | 0.551 | 0.005 | 0.003 | 0.449 | 0.001 | 0.007 | 0.000 | -0.006 | 0.009 | 0.041 | 0.748 | 0.211 | 0.034 | 0.003 | 0.415 | 0.010 | 0.050 | 0.167 |
| 2009 | -0.016 | 0.541 | -0.008 | 0.002 | 0.459 | 0.001 | -0.008 | -0.001 | 0.018 | 0.016 | 0.113 | 1.012 | -0.125 | 0.034 | 0.001 | 0.425 | 0.023 | -0.096 | -0.041 |
| 2010 | 0.009 | 0.533 | 0.005 | 0.027 | 0.467 | 0.013 | 0.017 | -0.001 | 0.018 | 0.017 | -0.056 | 0.291 | 0.765 | 0.035 | 0.026 | 0.432 | 0.039 | 0.082 | 0.686 |
| 2011 | 0.015 | 0.534 | 0.008 | 0.016 | 0.466 | 0.008 | 0.016 | 0.000 | 0.001 | 0.009 | -0.003 | 0.521 | 0.482 | 0.035 | 0.016 | 0.431 | 0.020 | 0.045 | 0.438 |
| 2012 | 0.018 | 0.534 | 0.009 | 0.018 | 0.466 | 0.008 | 0.018 | 0.000 | 0.000 | 0.009 | 0.000 | 0.535 | 0.465 | 0.035 | 0.017 | 0.431 | 0.020 | 0.040 | 0.426 |
| 2013 | 0.011 | 0.530 | 0.006 | 0.019 | 0.470 | 0.009 | 0.014 | 0.000 | 0.009 | 0.007 | -0.028 | 0.392 | 0.636 | 0.035 | 0.019 | 0.434 | 0.019 | 0.047 | 0.589 |
| 2014 | 0.019 | 0.533 | 0.010 | 0.017 | 0.467 | 0.008 | 0.018 | 0.000 | -0.002 | 0.009 | 0.005 | 0.563 | 0.432 | 0.035 | 0.017 | 0.432 | 0.015 | 0.028 | 0.403 |
| 2015 | 0.020 | 0.538 | 0.011 | 0.009 | 0.462 | 0.004 | 0.016 | 0.000 | -0.011 | 0.007 | 0.028 | 0.697 | 0.275 | 0.035 | 0.009 | 0.427 | 0.017 | 0.037 | 0.239 |

The results for the OLS regression for the USA, the UK, the Netherlands are as below. Germany was an exception as an insignificant correlation is seen between output and intangibles. Hence, an average for USA, UK and NL is taken for DE.

Table 182: Coefficients for USA, UK, NL and DE

| Average | SL | S Tan K | S InTan K |
|---|---|---|---|
| USA | 0.549966 | 0.416282 | 0.033753 |
| UK | 0.555725 | 0.407252 | 0.037023 |
| NL | 0.550377 | 0.422373 | 0.02725 |
| DE | 0.552023 | 0.415302 | 0.032675 |

The following table shows the linear regression for the USA with a positive correlation of 0.999 between the dependent and independent variables.

Table 39: Regression Output- USA

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.99989 |
| R Square | 0.99978 |
| Adjusted R Square | 0.99975 |
| Standard Error | 0.00013 |
| Observations | 28 |

| | *Coefficients* |
|---|---|
| Intercept | -0.00002 |
| Growth Labour | 0.60170 |
| Growth Tangibles | 0.37026 |
| Growth Intangibles | 0.02909 |

Following figures showcase a positive linear association between Y and X variables.

Figure 46: Scatter Plot against growth output and growth labour

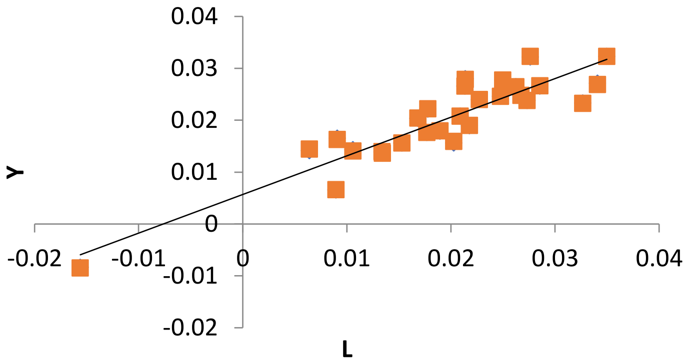


Figure 47: Scatter Plot against growth output and growth tangible capital

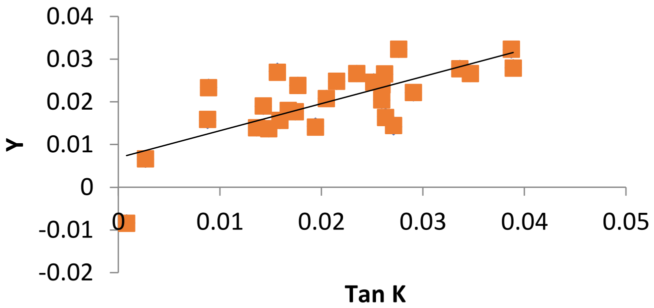


Figure 48: Scatter Plot against growth output and growth intangible capital