DELFT UNIVERSITY OF TECHNOLOGY

Modelling the Dynamic Nature of Networks, Enabling Smart Living

by

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"All truth passes through three stages. First, it is ridiculed. Second, it is violently opposed. Third, it is accepted as being self-evident."

Arthur Schopenhauer (1788-1860)

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Abstract

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Holons are universal and omni-present. They are organized in holarchies (hierarchical networks). Networks change continuously over time. At the aggregation level of the Sector Network and of the Telecom Network, diverse drivers cause changes. To provide for a better quality of life, trans-sector orchestration of change is required. Therefore, it is imperative to understand the sector network architecture, the major dilemmas, the drivers causing change and the interdependency with outer aggregation levels. In the Sector Network, households historically had a predominantly consumptive role. But they are increasingly becoming producers, or prosumers. Therefore, the introduction of the Smart Living concept into households will fuel the Sector Network evolution profoundly. Consequently, the influence of the Smart Home on the Sector Network and its lower aggregates, like the Telecom Network, also will be significant. This thesis mainly investigates the drivers that influence telecom transport network changes over time as well as the sector network dynamics over time, thereby providing insight into trans-sector orchestration over network evolution. . .

Keywords: Trans-sector Innovation, Smart Living, Holon, Sector Network, Complex Network

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Abbreviations

Acronyms	**Full Form**
ATM	Asynchronous Transfer Mode
CP	Connection Point
DVB	Digital Video Broadcasting
EoL	End of Life
eTOM	enhanced Telecom Operations Map
FCAPS	Fault, Configuration, Accounting, Performance and Security Management
FTTH	Fibre To The Home
GDP	Gross Domestic Product
GSM	Global System for Mobile Communications
HSPA	High Speed Packet Access
IMS	Internet Protocol Multimedia Subsystem
IP	Internet Protocol
IPTV	Internet Protocol TeleVision
ITU	International Telecommunication Union
LBNS	Landelijk Beheer Netwerk Service (KPN's National OSS)
LSP	Label Switched Path
MA	Metro Access
MPLS	Multi-Protocol Label Switching
MVNO	Mobile Virtual Network Operator
NGN	Next Generation Networks
NNI	Network to Network Interface
OAM	Operations, Administration and Management
ODU	Optical Data Unit
OLT	Optical Line Terminal

OPEX	OPerating EXpense
OSI	Open System Interconnection
OSS	Operations Support System
OTN	Optical Transport Network
OTU	Optical Transport Unit
PDH	Plesiochronous Digital Hierarchy
POTS	Plain Old Telephony Service
PSTN	Public Switched Telephony Network
QoL	Quality of Life
QoS	Quality of Service
ROI	Return on Investment
SDH	Synchronous Digital Hierarchy
SPON	Supervised Peer-to-Peer Overlay Networks
STM	Synchronous Transport Module
UMTS	Universal Mobile Telecommunications System
VAS	Value Added Service
VLAN	Virtual Local Area Network
VOD	Video On Demand
VOIP	Voice Over Internet Protocol
WDM	Wavelength Division Multiplexing
X25	An ITU-T protocol for packet switched wide area networks
xDSL	Generic term for all forms of Digital Subscriber Line

Symbols

d	node degree
w_{ij}	Link weight of link connecting nodes i and node j
w_i	Node Weight of node i
$E[D_{nn}]$	Average degree of the neighbours of node n
$Pr[D = k]$	Probability of a node to have degree k
$f_{w_l}(x)$	Probability density function of link weights
$f_{w_n}(x)$	Probability density function of node weights
s_i	Sum of all link weights connected to a node i
s_i/d_i	Node strength
$\sum w_{ij}$	Sum of all inter-activity cluster euro flow
$\sum w_i$	Sum of internal euro flow for all activity clusters
$\sum_w$	Total euro flow in the network, ie, $\sum w_{ij} + \sum w_i$
r	Pearson's coefficient
τ	variable for exponent of power law distribution of link weights and node weights
c	constant multiplier in power law distribution of link weights and node weights

Dedicated to Amma, Appa, Thatha and Paati...

Chapter 1

Introduction

Humans have always tried to improve their condition - John Harris, Muireann Quigley[1]

A nation requires several social and economic activities for survival. Take for instance, social wellbeing. Several national sectors need to co-operate to achieve well being of society. The existence of an easily accessible healthcare system, active environmental care groups and reliable security infrastructure are essential to ensure that our society is robust. Sustainable energy production, well connected telecommunication infrastructure and dependable transport services allow for comfortable living. Stable financial organizations, industries and trade establishments ensure the economic health of a nation.

In all the above respects, historically, man has been continuously in pursuit of improvement, a better Quality of Life. This, despite the fact that the resources at his disposal are limited. That is, standard of life has to be improved bearing in mind limited resources. One of the possible solutions to this dilemma is a sector based approach to innovation[2],[3]. Sectors interact with each other via the exchange of value, in the form of goods, services and money. A sectoral approach to innovation examines each sector as a whole, and studies its innovation processes, considering the strengths of the sector itself as well as the strengths of its dependent and supporting sectors.

Consider the trans-sector innovation process. In the trans-sector innovation approach, we essentially study the different national activities, aggregated into groups called Sectors[4]. Trans-sector Innovation is the inter-sectoral approach to innovation, with an enhanced emphasis on transactions between the sectors with their dependent and supporting sectors. This approach to innovation is complementary to the process of innovation within a sector itself. Trans-sector innovation is required since *"the (sectoral) approach calls for a deep understanding of the interplay between national systems and sectoral systems"*[3].

Trans-sector innovation essentially involves co-operation between different sectors of the socio-economic components of a nation towards a common end. This could be the co-operation between government bodies, universities, financial organizations and an industry to produce value-added output. The objective of the co-operation is to deliver a product (which may be in the form of goods or services) that ultimately simplifies and enriches the day-to-day functioning of humans or society as a whole. The simplification or enrichment may be achieved by a clever combination of services and/or products, enabling mobility, enabling access, or by a removal of impedances faced in the day-to-day functioning of human beings.

To be able to innovate in a trans-sector manner, we need a thorough understanding of different sectors, especially their unique functionality and interrelatedness. The study of the inter-relatedness of the sectors is immense in itself and not entirely accurately defined. This thesis explores the inter-relatedness of sectors, initially, using graph theory and complex network theory. Towards this end, the dataset obtained from Statistics Netherlands, depicting the financial transactions within the country's sectors, is examined.

It is intuitive that Telecom, being a prime connecting sector, offers value which aids, catalyzes and supports innovation amongst and within other sectors. Telecom plays a pivotal role in the the Sector Network. It is responsible for linking up sectors and ensuring fluent flow of information. This enables flow of ideas and removing inconveniences in co-operative innovation.

The Oxford Handbook of Innovation states that - *"New IT is now widely used in physical services, such as transport, logistics, retailing and warehousing ... In the field of entertainment, traditional consumer services like theatre and cinema have been subject to competitions from new ones such as TV and other other AV equipment and, more recently, videogames, PCs and online entertainment ... Professional and business services are also largely concerned with information processes...New IT is thus enormously important - and often very visible - in information services. Such innovations as automated teller machines and smart cards, new telephone and telematics services, and shifts from analog broadcasting to interactive digital media and narrowcasting are all the focus of considerable investment and activity."* [5] The latter functions of broadcasting and narrowcasting are exclusive to the Telecom Sector [4].

Document Outline

Chapter two lays down the background theory of this thesis. The chapter begins with the motivation of the study, which describes the case for trans-sector innovation via supporting literature. Next, the fundamental nature of the evolution of social systems and the nature of the networks under study are illustrated. The chapter then describes the holarchy and the theory behind the Holon model used in this thesis and the reason for choosing this model. Finally, the chapter introduces the sector network as an instantiation of the Holon Model and as a complex network.

Chapter three comprises of the research questions addressed in the thesis.

Chapter four discusses the study of the Dutch sector network. Though the telecom sector is significant for enabling communication between and within sectors, and is pervasive, it cannot be isolated. The telecom sector is a part of a greater whole [4], the sector network. Before studying the evolution of a part of the telecom sector then, it is insightful to understand the nature of the sector network. Fortunately, data regarding the financial transactions in the Dutch sector network was made available by Statistics Netherlands. This thesis examines the Dutch sector network from a mathematical complex network perspective. A three dimensional model of studying networks is enhanced with the fourth dimension, time. This evolutionary novelty is proposed for this complex network study. Chapter four elucidates this proposed model of study of the sector network as well as results of the study and the conclusions therein.

Chapter five concentrates on the telecom transport network. Studying the drivers of telecom transport network evolution is essential in order to understand the forces that cause change in networks. Towards this end, chapter five presents a proposed model of drivers causing changes in the transport network infrastructure. The drivers of change are inter-related. This proposed model is valorized by implications for the Smart Home service bundle.

Chapter six highlights the conclusions of the study and provides recommendations for future research.

Since there is limited example of this kind of study, this thesis is to a large extent, explorative in character.

Methodology

Figure 1.1 depicts the methodology adopted in the process of this thesis study. The sequence of events are in vertical order and each step has its own colour. The initial step in the study was to establish a definition of the research questions to be addressed. Following this, a survey of literature was undertaken. The literature survey involved a study of different disciplines. Literature on network characterization measures and methods was examined to get an overall picture of the existing possibilities in this domain. To be able

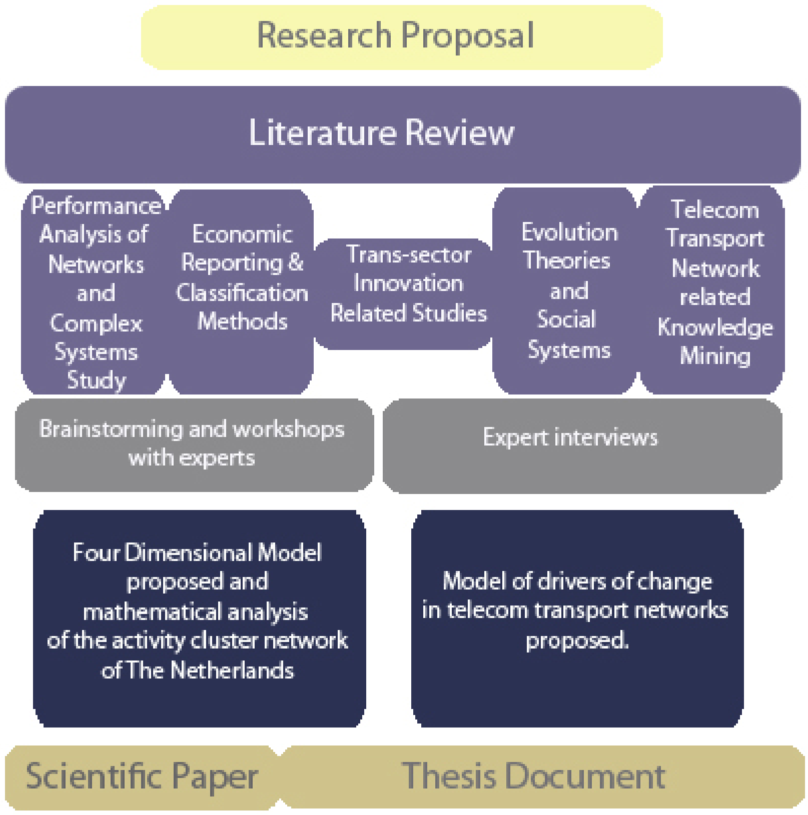

Figure 1.1: Schematic diagram depicting the methodology followed in the study.

to understand the nature of the sector network and to interpret the results, it was necessary to research and understand the definition and structure of classification systems such as the International Standard Industrial Classification of all Economic Activities (ISIC) and the Classification of Economic Activities in the European Union (NACE). A trans-sector innovation related literature survey, covering topics such as the future of transactions, the functional nature of networks and the relevance of the trans-sector innovation method in today's economic situation was undertaken. Literature on the evolution theories was examined to understand the fundamental principles of evolution. Evolution studies specific to economic and social systems were given attention. Finally, existing documentation on the telecom transport network from several organizations was examined.

The literature survey was followed by several interactive sessions with experts. Workshops were conducted with mathematicians from the TU Delft as well as economists and classification experts from Statistics Netherlands. These workshops resulted in the establishment of the proposed model to study the sector network of The Netherlands as a complex network. Interviews and brainstorm sessions were conducted with telecom transport network experts from KPN and Huawei Technologies. The objective of these sessions was knowledge mining from the experience of the experts. The result was the development of the model of drivers of change in the telecom transport networks.

All the results of knowledge mining, data analysis, observations and conclusions are recorded in the thesis document. The proposed model of study of the sector network as a complex network, and the resulting observations and conclusions therein are also recorded in the form of a contribution to a scientific paper.

Chapter 2

Background Theory

In this chapter, the motives of the study, the subject under study and the model used are discussed.

2.1 Motive of Study

To improve and maintain today's Quality of Life, under the condition of limited resources, it is necessary to orchestrate innovative solutions. Trans-sector innovation holds out promising prospects in implementing this vision [3][6]. The trans-sector innovation approach is supported in current literature. A prime example of this is in the work of Baken, et al. The authors state that the network concept of innovation *"opens a far richer set of truly qualitative and often disruptive innovations than the former (nodal concept of innovation) that evokes mostly incremental, quantitative innovations within one sector"* [2]. Examples of this are to be found in the work of Baken, et al, 2008 [7] and [2]. In the work of Malerba and Mani, the authors discuss the importance and relevance of certain factors that affect innovation and production in and around a sector. These factors include "the variety of actors, network demands and institutions." An emphasis is placed on "the role of actors (such as competitors, suppliers, users, universities, financial organizations, public agencies and the government"), the characteristics of demand and the type of institutions (such as for standards, regulations and norms). The authors highlight that innovation and production is vastly influenced by a sector's environment. They state that the reason for increasing interest in the trans-sector approach to innovation is because "it pays a lot of attention to exchange, competition and co-operation in a co-evolutionary setting." [3] Thus, a trans-sector approach to innovation is important.

The telecom sector, is envisioned as an enabler of trans-sector innovation [2]. The household sector is expected to be the main inflection point of the network. The progression to trans-sector innovation involves co-operation between sectors, where the telecom sector could play a pivotal role as a connector. The telecom transport network plays the important role of the enabling tool of the telecom sector [4]. It enables the primary function of the telecom sector, that is, Transfer.

The trans-sector innovation process impacts the sector network as well as the telecom sector and its transport network. This thesis examines the evolution of the sector network as well as the telecom transport network over the past 21 years. Firstly, a novel methodology for the study of the sector network is proposed from a complex network perspective. The novelty of the methodology lies in the inclusion of the time factor and the study of economic data. Secondly, the drivers of change in the telecom transport network are proposed in a seperate new driver model. The first motivation behind this study is to provide insight into the nature of evolution of networks. This provides a novel contribution to the area of trans-sector innovation. The second motivation is to apply the evolution principles observed in literature to networks, both theoretically, on complex networks and practically, on the telecom transport network.

2.2 Evolution of Social Systems

Evolution of social systems is said to follow darwinistic principles at a fundamental level [8], [9]. These priniciples are permutation, selection and reproduction. It becomes clear from literature that these principles would not be sufficient in fully explaining the detailed process of change in all social systems, but represent an abstraction of the change mechanisms, requiring the filling in of empirical information [10].

Examples of social systems include social regulations, communities, societal rules, etc. The definition of such systems is available in literature [11]. It is found that networks under study fit in with the definition of these systems. These systems are said to exist within an environment. The environment makes certain demands of the systems. Only those systems inside the environment which can satisfy these demands, survive in that environment, under the assumption that there is a scarcity of resources. The systems in the environment (also called actors) make demands on the environment too. In this study, we confine ourselves to the demands of the environment on the systems due to limited time.

In the environment, darwinian forces operate to bring about change. Innovation is defined as a means to generate variety, and selection is a mechanism deciding which varieties survive. This definition is directly relevant to this study, since we need to examine the drivers that cause changes in the networks. Studies of the evolution of the above mentioned systems need to address the actual changes of the subject. They also need to examine the mechanisms that cause these changes [8]. This two components then, are inculcated in this work.

2.3 Subject of Study

In this section, we elucidate the nature of the networks under study as well as choose the model to apply on them to facilitate the study. The Dutch sector network is the first network under study in this thesis. The first part of this section discusses the sector network. The second part of this section, discusses the nature of the telecom transport network.

The economy and society of a country are sustained by multiple activities. These activities include trade, manufacturing, transport, construction, healthcare, education, etc. These activities together form the socio-economic fiber of the nation. Each of these activities is being carried out by individuals and organizations. The activities of these organizations are classified into homogeneous clusters called Sectors [12]. There exist several standards for the classification of socio-economic activities into sectors, such as the United Nations International Standard Industrial Classification of All Economic Activities [12], Statistical Classification of Economic Activities in the European Community [13], etc. Each classification divides all the national activities into small sub-groups which have certain common properties. These small sub-groups are aggregated to form a larger group, these larger groups are aggregated to form higher aggregate activity clusters, these clusters are further aggregated to form Sectors.

The use of these hierarchical models to structure the activities executed is a common trait among all classifying standards [12],[13], though the number of aggregation levels varies from standard to standard. On average, economic classification systems consist of five hierarchical levels.

Figure 2.1 illustrates two hierarchical levels of the sector network - the sector level and the activity cluster level [14]. The model can be mapped onto the information from Statistics Netherlands. The higher level shows the Dutch sector network, whereas the lower level shows the level of the activity clusters. The lower level, is simply a view of the higher level sector network with a greater resolution and detail.

We know now that each sector interacts with several other sectors. These interactions are manifested in multiple forms like money and products. All sectors offer value to some other sectors. Some sectors transport goods, some sectors exchange money in terms of investment or in exchange for goods or services. On the one hand, each sector

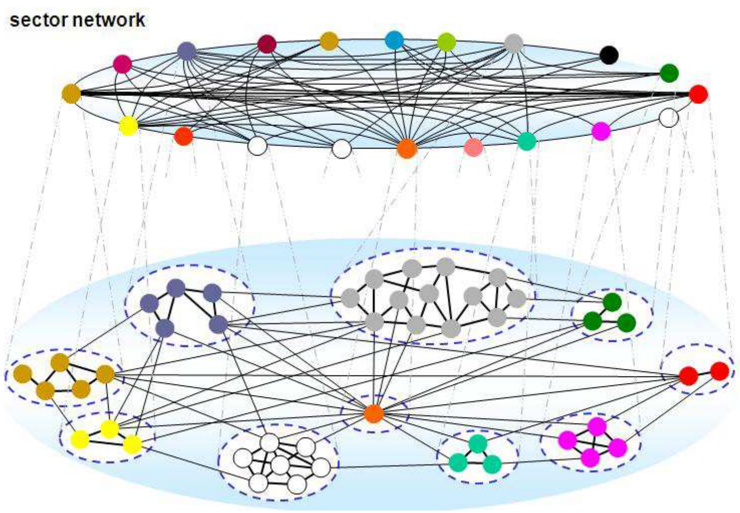

Figure 2.1: Two levels of the hierarchy of the sector network: the higher level is the sector network itself and the lower level is a network of activity clusters.

performs some kind of value addition and provides services to other sectors. On the other hand, each sector is being served by some of the other sectors. Thus, sectors perform some unique value addition, while simultaneously executing transactions. They satisfy a certain demand (supply) while making certain demands from other sectors. Trust and value perception underly these transactions [4],[15].

It is logical to depict the transaction web of sectors as a network. If, in this network, sectors are modeled as nodes, transactions between them can be represented by links [4]. Each sector is essentially an aggregate of activity clusters. The sector network is viewed as a network of activity clusters.

To enhance the functioning of trans-sector co-operations, it is imperative that we understand the underlying network which is formed by existing co-operations. Trans-sector co-operations are complex tasks, involving heterogeneous entities and compound functions. Since structure affects function [16], it's imperative to understand the structure of the network, before an examination of its evolution. In this study, we propose a four dimensional model for the examination of this network (please refer chapter 4). The method involves examining the state of the network over twenty one years. Thus, some of the results automatically reflect the evolution of the network.

The second network under study in this thesis is the telecom transport network. This network has multiple layers of dissimilar entities arranged in layers and having interactions with peers, superior and subordinate layers. There is an abundance of detail in the intricacies of the telecom transport network. But the essential function of each layer in the telecom transport network is Transfer. Also, there are only a very limited number of unique functions implemented. [17],[4] The telecom transport network has some properties similar to the sector network. Firstly, we see a hierarchy in the model. Secondly, there are entities on different levels which may interact with each other. Thirdly, there is an abundance of intrinsic detail which contribute to a larger whole. There is a need in this thesis then, for a model that reflects the common properties of the two networks, while allowing for both detailed insight and a high level view. This holistic framework is provided by the Holon Theory [18].

2.4 The Holon Theory

In 1967, Arthur Koestler re-coined the concept of the Holon. He defines a Holon as follows. *"A holon is an identifiable part of a system that has a unique identity, yet is made up of sub-ordinate parts and, in turn, is part of a larger whole"* [18]. More recently, the Holon Theory was the subject of the speech of Baken [19] at the TEDx Amsterdam conference in 2009.

A holon is a logical entity, a part of a system, and simultaneously, an autonomous system in its own right. These entities can function as an aggregate of their parts autonomously. That is, holons are capable of self-reliant operation and can also function properly as sub-systems.

The salient features of a holon are co-operation and autonomy [4]. As a result of these features, holons are stable forms that allow us to partition reality and control the complexity of a real system. Holons form hierarchical structures called Holarchies which allow this partitioning of real, complex systems. Consider a network of holons, where each node is a holon that self-regulates as well as co-operates with other peer holons. Consider a second, similar holon network lying above this network, where each of the higher level holon nodes is either a representative of, or a controller of, a sub-network in the lower network. Thus, the lower network of holons is aggregated at a higher level using the higher network of holons. They are indispensable for the creation of a large (whole) system while retaining the resolution available on lower scale. This scale of granularity can go to any length of detail.

A holon in a Holarchy has three perspectives. One, its subordinate perspective, where it can see its constituent parts in a layer (or layers) below it. Two, its peer perspective, where it sees other holons on the same plane in the holarchy [4]. And three, its superior perspective, i.e, that holon of which it is a part. Each holon can communicate with peer holons on the same plane in the hierarchy, with its superior holons, as well as its subordinate holons. Thus, the image emerges of overall connectedness and increasing complexity with level of aggregation.

In the sector network, each sector, for instance, can be modelled as a holon. Therefore, the sector network is a holon network.

2.5 Applying Holon Theory to the Sector Network

The study of the sector network in this thesis involves an examination of the physical properties of the network. The Holon Theory based model of the network is to be analyzed and characterized. This is a detailed view as compared to the study of the telecom transport network, where the physical nature is taken as is and the evolution drivers alone are examined. Therefore, a detailed study of the sector network modelled by the Holon Theory is necessary. This is the subject of the the current section.

When we open up a Sector Holon, we can see the next sub-ordinate level in the Holarchy, that is, the level of the activity clusters. If we were to open up an activity cluster, we would see groups, and further down, sub-groups, etc.

By the property of the holon, when we open up a sector holon, we can see the next level in five different perspectives [4]. These perspectives are the syntax components of language, namely, subject, direct object, verb, adverbial adjunct and indirect object. That is, the sector holon opens up to reveal five different kinds of networks. These are a network of tools it uses for its trade (adverbial adjunct), a network of functions (verb), a network of service providers (subject), a network of produce or service (direct object) and a network of customers (indirect object). For example, by opening up the Telecom holon, we would see a transport network (adverbial adjunct perspective), a network of functions (verb perspective), a network of service providers (subject perspective), a network of customers (indirect object perspective) and a network of data (object perspective). The five perspectives of the telecom sector holon are summed up in one sentence: *The Telecom Service Provider Transfers Data over the Transport Network for the Customer.* [4]

Applying holon theory to sector networks, we partition a complex reality into simpler and easily measurable entities, suitable for studying.

2.6 The Sector Network as a Complex Network

As mentioned previously, the sector network is a network of different entities exchanging value in terms of different goods such as money, people, services and products. This network has been simplified using the holon theory to allow for studying. When we open up a sector holon and look at the underlying holarchy from the Subject perspective, we see groups of organizations that execute the particular functions that are unique for that Holon. These groups are called activity clusters. At the level of activity clusters, the network is more detailed than the Sector Network.

Complex Networks is the term used to refer to a wide range of natural and societal (or man-made) networks. These include scientific collaboration networks, peer-to-peer networks, social networks, the World Wide Web, power-grid networks, brain networks, etc. These real networks have evolved over a period of time through some orchestrating or organizing principles. Each network is controlled by a different set of rules. It is important to characterize the networks mathematically. In the immortal words of Steven H Strogatz - *Structure Always Affects Function.*

We know that the socio-economic entities of a country form a network. This network consists of inhomogeneous nodes (sectors), composed of smaller nodes (activity clusters, groups, and so forth), which have multi-functional operations. They Transfer, Transform and Transact. These operations, also known as Meta Functions, are complex in nature, being composed of smaller, simpler functions [4].

Since the Sector Network essentially portrays a group of composed entities executing composite functions, it is a complex network. Also, since the subordinate parts of the sector network are commonly considered complex networks, for example, the internet (provided by the telecom activity cluster), the sector network can be considered a complex network too. In this study, we investigate the property of the sector network from the perspective of a complex network.

Chapter 3

Research Questions

1. We observe changes in euro flows between given nodes in the sector network over time (Source - Data Set from Statistics Netherlands). Between which sectors do we observe the most significant changes? *Chapter 4*
2. What does the link weight distribution of each year's euro flow look like? *Chapter 4*
3. Does the data set reflect any known complex network characteristics? *Chapters 2 and 4*
4. Let the data speak. What can we observe from the data set analysis? *Chapters 4 and 6*
5. *Stretched Target: What are the relevant time scales over which we observe change? Chapter 4*
6. What is a Telecom Network? - Definition *Chapter 5*
7. What is the *scope* and *model* of the Telecom Network for this thesis? *Chapter 5*
8. What changes do we observe regarding this Telecom Network over time? *Chapter 5*
9. What are relevant time aggregates or time scales for the change in the Telecom Network? *Chapter 5*
10. What drives the changes in the Telecom Network? *Chapter 5*
11. *Stretched Target:* Can we rank these drivers? If so, in what order? *Chapter 5*

Chapter 4

Sector Network Dynamics

In chapters one and two, the importance of the sector network in the life of a national community was highlighted. In this chapter, the properties of this network are examined.

The available dataset, provided by Statistics Netherlands, is a record of the monetary transactions between 105 activity clusters that make up the sector network of the Netherlands. The activity clusters are simply a lower aggregation level of the sectors as per the definition of the Department of National Accounts. The data set records the monetary transactions between these activity clusters for each year, for a period of 21 years. Appendix A lists the 105 activity clusters. Euros flow from one activity cluster to another. There are also euro flows that remain within an activity cluster. So each transaction is either a flow of euros from one activity cluster to another, or flows between organizations inside one activity cluster itself. In our study, all numbers are corrected for inflation using data made available by Statistics Netherlands. The data set is taken as given input for the study of the activity cluster network.

Note: If x be the given euro transaction (in the data set) from node i to j, in a year whose inflation value is given as p, then, the inflation corrected value of the transaction, q, is given by: $q = x(1 + p)$

As the dataset represents a weighted an directed network, to retrieve meaningful insights from this data, it is required to remodel the data structure into a simpler, less complex format. The approach we adopted to do this is described below.

The activity cluster network is viewed as a network, with each activity cluster depicted as a node and each transaction being a link, for each separate year. Each link has a value and a direction attached to it. This directivity of links and presence of links from one activity cluster to itself (self loops), complicate the data model and make it difficult to determine an feasible research method.

The process of investigating how to approach research of such a complicated dataset resulted in the birth of an novel research model [14]. This model is essentially a three-dimensional research framework, comprising three network measures: topology, link weight and node weight studies. Each measure is called a dimension and is applied on the data over time. The model is therefore, four dimensional in nature.

The objective of using the three network measures is to characterize the network by, first, studying their properties individually, second, studying the assortativite nature of the nodes and links with respect to each other and finally to depict the trend of their evolution (over time) from different perspectives. These multiple perspectives on the network are essential since the network itself is complex in nature.

The evolution of these properties is investigated over the period of 21 years for which the data is available. This gives us the trends of evolution of each of the network properties.

4.1 Literature Review

The objective of the characterization of the networks is to understand the effect of network structure on its function[20] [21] and to allow for a classification system to emerge. Studies aiming to characterize networks have been extensively carried out in the past. This is especially true in the domains of unweighted and undirected networks. In the context of complex networks, the majority of the studies conducted, tend to be on unweighted ones. We refer to the work of Costa, et all, (2007) [21] for an extensive review of all the metrics used to characterize complex networks.

So far, a number of different methods have been proposed to study the topological characteristics of a network. In most complex network studies, the topological examination focuses on the density of connections around a node. Also, several studies have examined the properties of the node degree and the clustering coefficient of the nodes in the network. Many of the examined unweighted complex networks display the small world property. In the work of Watts [22] we see this property reflected in the short average distance of the network and the density of local connections. In the work of Albert and Barabasi [23] we see the power law distribution in degree which indicates small world property. Topological study of the networks provide insight into the robustness, or the vulnerability, of the network.

A *weighted network* includes information both of topology and of link weights. Link weights are used in complex networks to quantify properties of the links. These could be the bandwidth of the link, the geographical distance between the end nodes, etc. The link weight distribution of a network is interesting because, first, it allows comparison of the network with other networks that have been already examined. Second, a study of the topological distribution of link weights, their appearance or assortativity within triangles or sub-graphs in the network, provides further information of the composition of the network and the behaviour of its components. Finally, following the work of Ramasco and Goncalves[24], the examination of the distribution of link weights around a node proves insightful into the characterization of the nodes in the network. In the work of Barrat, et all [25] and Onella, et all [26] assortatvity measures to examine the topology and link weight structure of weighted networks are introduced.

Several large scale patterns are present in real world networks. These include a propensity of nodes to connect to similar nodes or a propensity to connect to dissimilar nodes. The former network property is called assortativity of nodes and the latter property is called disassortativity. Algorithms exist for detecting these patterns and extracting communities from networks based on these patterns. Such extracted communities from a basic network form a hierarchical structure. This is known as community structure [27], [28]. Many real world networks are hierarchical in nature. For instance, social networks on which community extracting algorithms have been applied, that is community structures, have a hierarchical nature. Such social networks show power law behaviour in certain characteristics, such as Amazon's buyer's network as examined in the work of Clauset, Newman, et al [29]. The network under study, the network of activity clusters, is a lower aggregate level of the sector network. At the same time, each node in the activity cluster is an aggregate of several organizations. In this hierarchical structure lies the similarity between the network under study and the community structure of social networks. The results of degree assortativity tests and the probability distribution of link weight and node weight support the similarity between the network of activity clusters and the community structure of social networks.

4.2 Data Set Modelling for Study

For ease of study and for uniformity, the data set had to be simplified. The data set as modelled for this study is elucidated below.

An activity cluster is represented by a node. A transaction of euro, hereon in referred to as euro flow, is represented by a link. The transactions for each year between the various activity clusters are represented together as a network. Since we have data of transactions for 21 years, we have 21 instances of the activity cluster network. The number of nodes is constant throughout the time period. The variation in the 21 network instances is in the number of links between the nodes, the link weights, and the correlation between these network metrics over time.

The given data set consists of directional transactions. To simplify this, a method is deviced to render the links undirected. In the network, one link between two nodes exists if there is a one-directional or a two-directional transaction between them. Two-directional transaction between a pair of nodes counts as a single link. This makes the network under study undirected.

We have now, a network topology, represented by a graph *G(N,L)*. G consists of a set ν of N nodes, connected by a set Λ of L links. This topology can be represented by an adjacency matrix A. An adjacency matrix is a mathematical representation of network topology, having as many rows and columns as the number of nodes. Each row number and column number correspond to a node in the network. The presence of a zero or a one at any position in the matrix indicates the presence or absence of a link (respectively) between the nodes represented by the row and column numbers[1]. Thus, here, A is an NxN matrix consisting of elements a_{ij} that are either one or zero depending on the presence or absence of a link between nodes i and j.

Since the links in our network are euro flow amounts, the links have a link weight. The link weight of each link, a_{ij}, in a particular year refers to the sum of the amount transacted between the two nodes, normalized by the total euro flow in that year. $\sum_{w}$ gives the total euro flow in a particular year. The adjacency matrix may be extended to replace the ones and zeroes by the actual value of the normalized link weight. Thus, $a_{ij} = w_{ij}$, where w_{ij} denotes the link weight between nodes i and j. For all $i = j$, that is, the diagonal elements, the link weight of the self loops can be expressed as $a_{ii} = w_i$. This is defined as the node weight of a node in the network.

That is, for each year,

$$\sum_{w} = \text{Euro flow between nodes} + \text{Euro flow inside nodes}$$

$$\sum_{i=1}^{N} w_i + \sum_{i \neq j} w_{ij} = 1$$

In this work, we propose including the additional parameter, node weight, for characterizing the network along with traditional parameters such as link weight and other topological parameters. The node weight metric, as proposed in the context of this dataset, shall reflect the amount of euro flowing inside an activity cluster in each year. This allows us to characterize the non-homogenous nodes, and their role in the network as well as their evolution over time.

[1] A zero means that in the given dataset, the euro value of a transaction between or inside an activity cluster is smaller than one million euro.

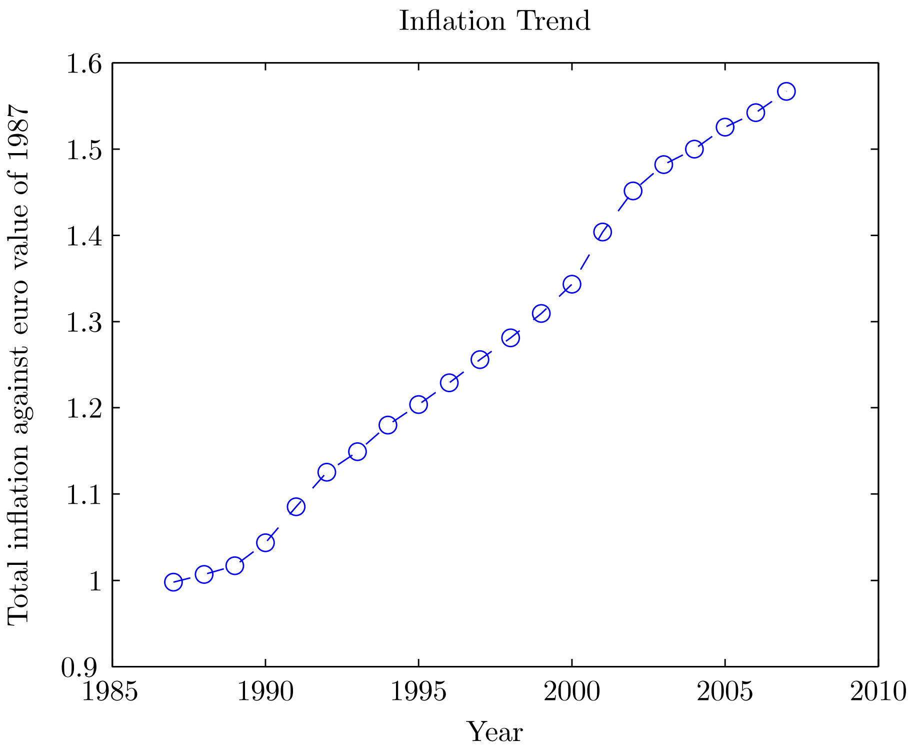

FIGURE 4.1: Trend of Inflation

4.3 Sector Network General Characteristics

All the euro flow numbers in the data and the results of this chapter are in million euros.

The euro flows in the network are corrected for inflation. The inflation trend is depicted in figure 4.1. In figure 4.2, we compare the total amounts being transacted yearly, between inflation corrected euro flows and inflation uncorrected euro flows. As we can see, there is an effect of the inflation on the total transaction amounts, and this slightly distorts the pattern of increase. But there is a marked increase nonetheless and the general trend is maintained upward.

Figure 4.3 depicts the total euro flow in the network each year. The general trend is upward. This is predominantly a contribution of the transactions *between* the activity clusters. This observation is supported by figure 4.4. This figure shows the amounts being exchanged *between* activity clusters over the 21 years. What we observe is essentially the ratio of the euro transactions between activity clusters to the total euros in the network in each year, that is, $\sum_{i \neq j} w_{ij}$. By observation, $\sum_{i \neq j} w_{ij} \approx 0.9$. Then, $\sum w_i \approx 0.1$ Figure 4.5 shows the ratio of the amounts transacted between activity clusters to the total amounts being transacted each year. This figure clearly reflects that over the 21 years, the transactions between activity clusters have contributed to approximately

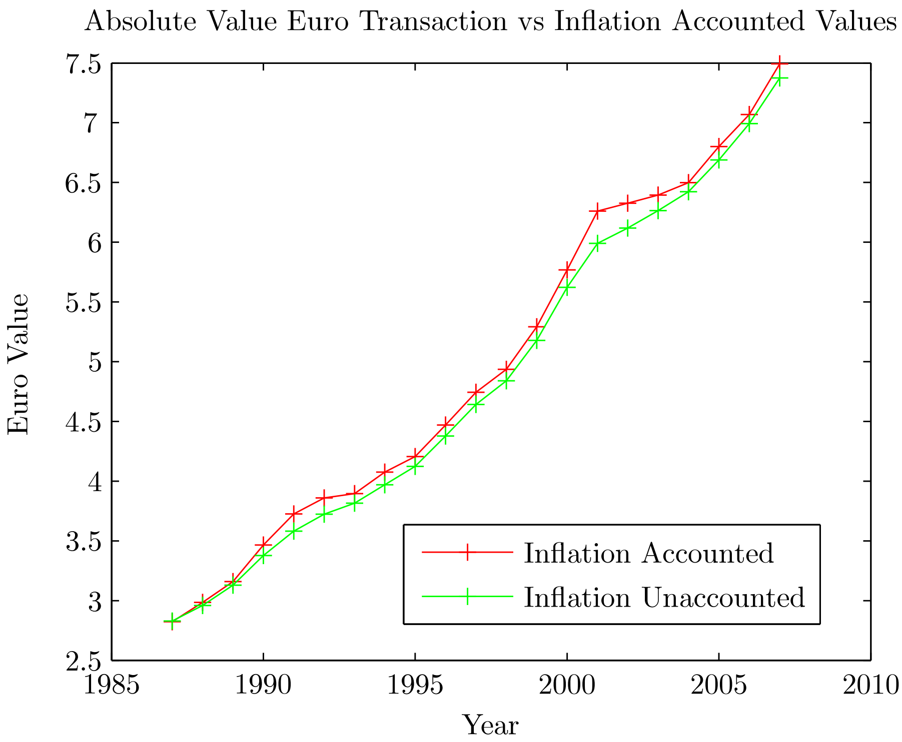

FIGURE 4.2: Comparison of euro flows with and without correcting for inflation, in hundred billion.

ninety percent of the total amounts transacted in the network. This number has remained more or less constant, fluctuating by a very small percent over time. Despite this constant value, there is a slight decrease in the inter-activity cluster transaction amounts. Along with the slight decrease of inter-activity cluster transaction amounts, there is a slight increase of internal euro flows in activity clusters.

Though the overall trend is upward in figure 4.3, there is a significant change in this pattern after the year 2001. After that peak point, up until 2005, there is a drop in the number of transactions as well as amounts transacted within and among activity clusters. This is in direct coincidence with the crash of the Internet bubble.

Table 4.1 highlights the information in figure 4.5. It is evident that the fluctuations around the ninety percent value are small.

Figure 4.6 depicts the growth of internal euro flows within the activity clusters over the twenty years in ten billion. As can be seen, these flows contributes to around ten per cent of the total euro flows for each year.

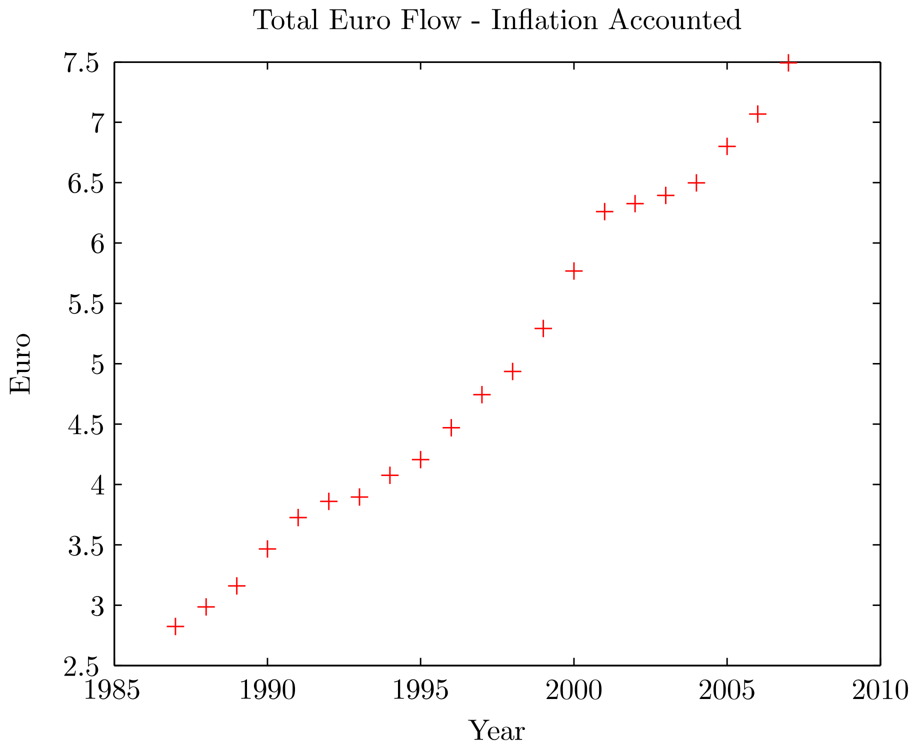

FIGURE 4.3: The total euro flow among and within the activity clusters for each year, in hundred billion euro.

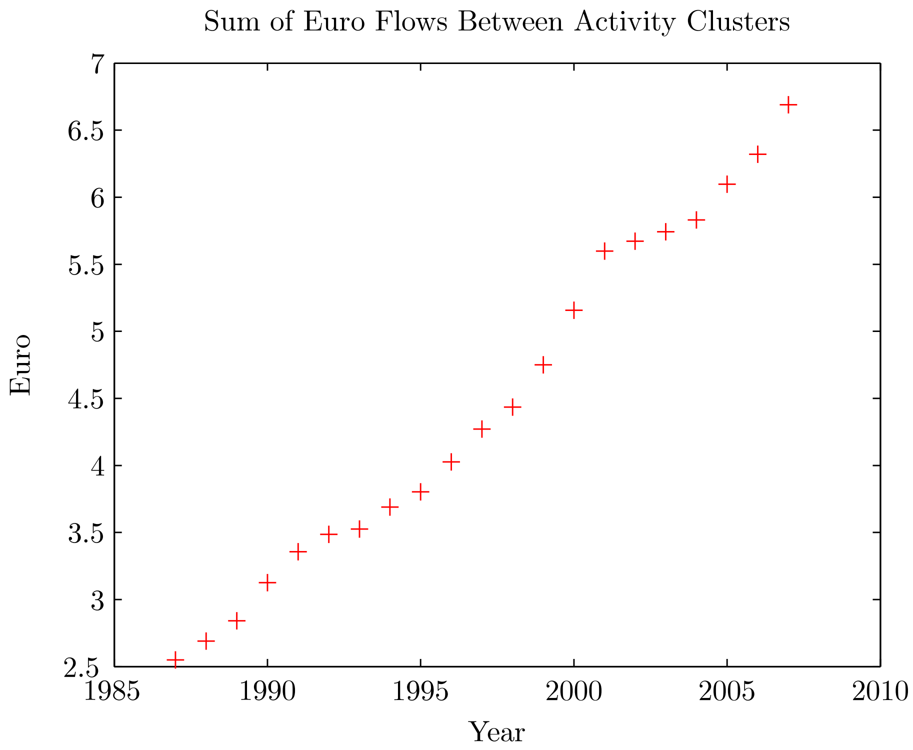

FIGURE 4.4: The total euro flow among activity clusters for each year, in hundred billion euro.

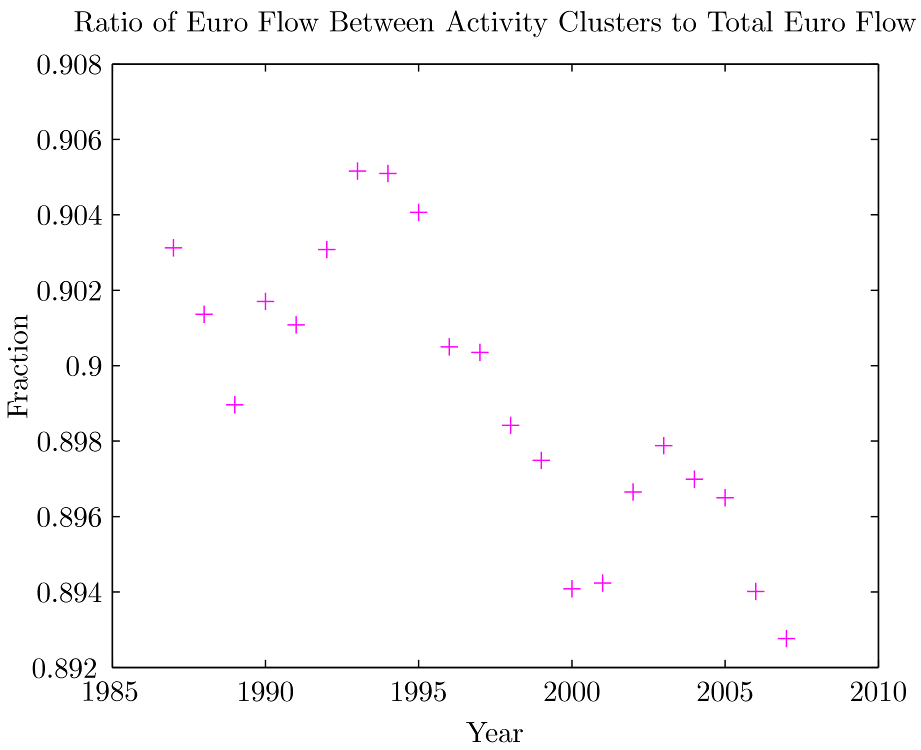

FIGURE 4.5: Ratio of euro flow between activity clusters to total euro flow, $\sum_{i \neq j} w_{ij}$

Year	$\sum_{i \neq j} w_{ij}$
1987	0.903
1988	0.901
1989	0.898
1990	0.901
1991	0.901
1992	0.903
1993	0.905
1994	0.905
1995	0.904
1996	0.900
1997	0.900
1998	0.898
1999	0.897
2000	0.894
2001	0.894
2002	0.896
2003	0.897
2004	0.896
2005	0.896
2006	0.894
2007	0.892

TABLE 4.1: Y axis values of figure 4.5

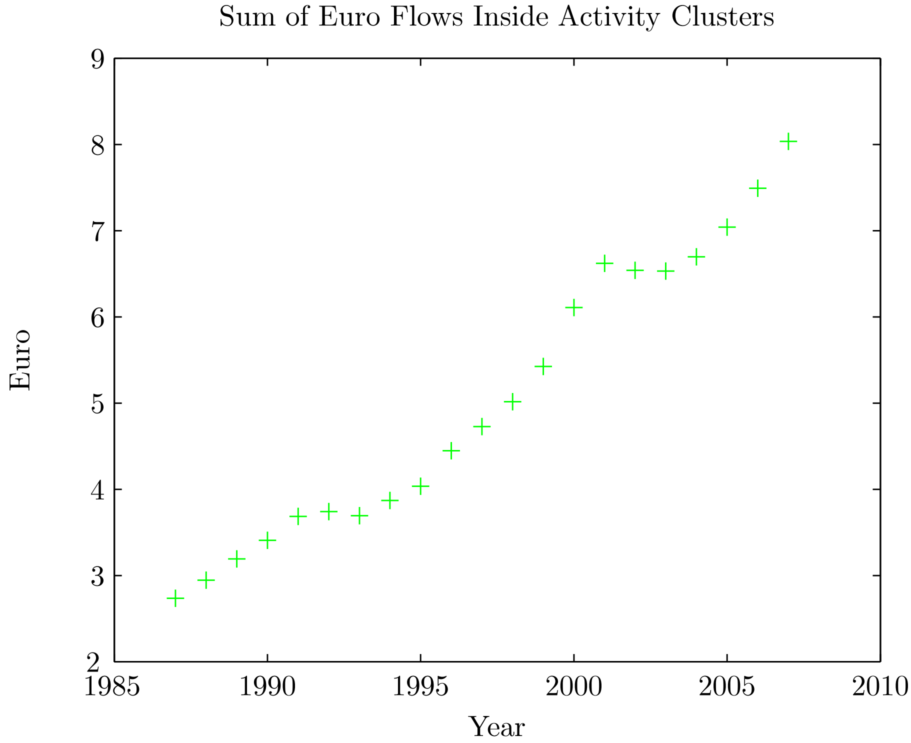

Figure 4.6: Total internal euro flows within the activity clusters for each year, in ten billion euro.

4.4 Proposed Multi-Dimensional Framework for Studying Complex Networks

The proposed method of studying Complex Networks involves investigating three dimensions of information over time:

- Topology - Topology refers to the unweighted structure of connections among nodes. We examine the topological characteristics of the network over the 21 years and study the changes of this property over the time period.
- Link Weight Distribution - Link weight refers to the association of a weight to each link. This property of the network and its evolution over the 21 years is investigated in multiple ways.
- Node Weight Distribution - Node weight refers to the association of a weight to each node. This is a fairly new concept and is being explored in this paper in the context of the sector network for the first time.

The above introduced framework is depicted in figure 4.7. First, each of the three metrics, or dimensions, is investigated independent of the others. Their distributions

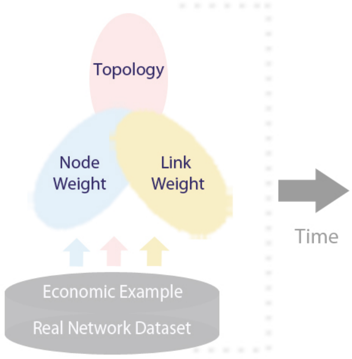

FIGURE 4.7: Proposed framework for analyzing the network.

are investigated cumulatively over 21 years. That is, the data for each metric over 21 years is taken together and the distribution examined. Next, the change of each metric over each of the 21 years is observed. This depicts the evolution of these metrics over time. Since these network metrics reflect the nature of the complex network, the study reveals the trend of the network evolution over the 21 years. Thirdly, correlation studies are conducted between pairs of each of these three metrics. This gives us a perspective on whether or not there are correlations between these network properties. To check for correlation, correlation coefficient and scatter plots reflecting assortative nature are examined. Assortativity [28] is a property wherein nodes show a preference to link with other nodes which are similar in a certain node property. This node property may be degree, node weight or node strength. A network that is assortative in node degree, for instance, has nodes that tend to link up with other nodes which have a similar level of degree. In such a network, high degree nodes tend to link up to other high degree nodes and vice versa. The same applies for networks that are assortative in other metrics, like link weight.

Note: Colour bars appearing on the side of graphs, with numbers from 2 to 22 depict year numbers. As a property of Matlab's colorbar function, the numbers are hard coded. Year 1 refers to 1987, year 21 to 2007. All other numbers fall in the range respectively.

Topology Study

Topology is the first of the three dimensions in studying a complex network over time. This measure is, so far, the most thoroughly researched in literature.

Figure 4.8 shows the number of links in the network over the 21 years. The total number of links between nodes shows an upward trend over the years. The increase in the number of links indicates that the number of trans-sector transactions has increased steadily over

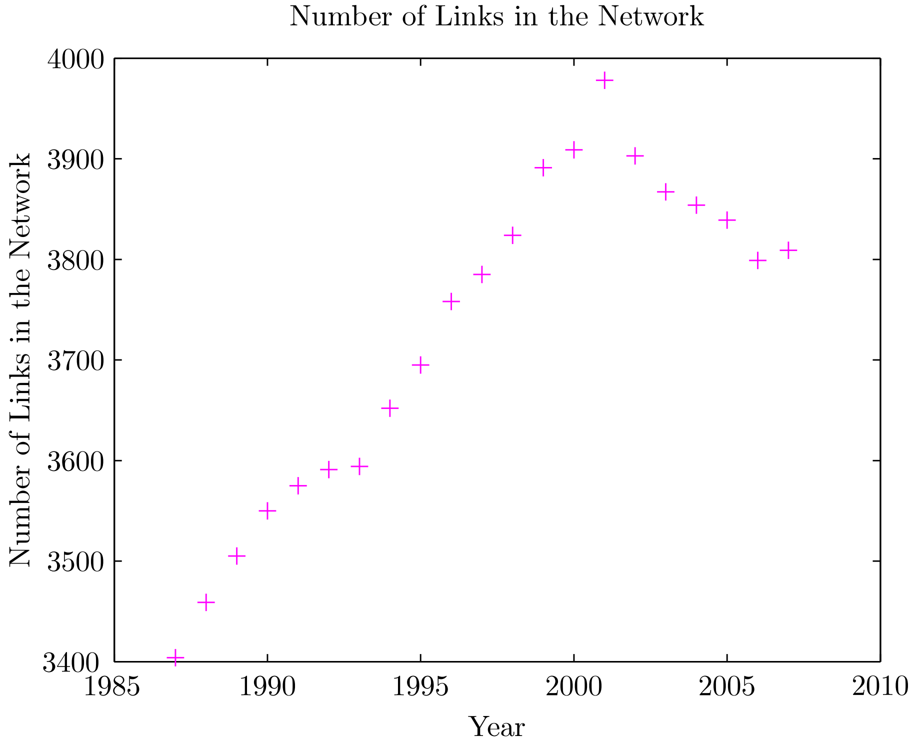

Figure 4.8: Evolution of Number of Links in the Network

the 21 years. As seen in this diagram, coincident with the crash of the Internet Bubble, there is a steady drop in the number of links in the network.

The primary implication of such a growth in the degree is increasing collaboration with other activities. This is interesting as it is in accordance with today's emerging economic practice of vertical disintegration [30]. As more and more companies and organizations specialize in specific activities, other companies prefer to outsource that activity to specialists. The increase in degree supports the trend of specialization of knowledge, division of labour, outsourcing activity and vertical disintegration. Our observation, therefore, indicating this increase in transactions, supports the idea of increasing vertical disintegration of organizations in today's economy.

Figure 4.9 depicts the degree distribution of the network. This reflects the density of the 21 network instances cumulatively. It is found that when studied on a per-year basis, the degree distribution shows no recognized properties. This may be because of the low number of data points.

The complex network at hand is a very dense network, with many nodes being connected to many other nodes. Also, there exist some nodes which act as hubs and are connected to a large number of nodes. This is reflected well in figure 4.9. We see a small number of nodes with a very high degree on the right hand side of the image, having degree 100 to 104. These are the hub nodes.

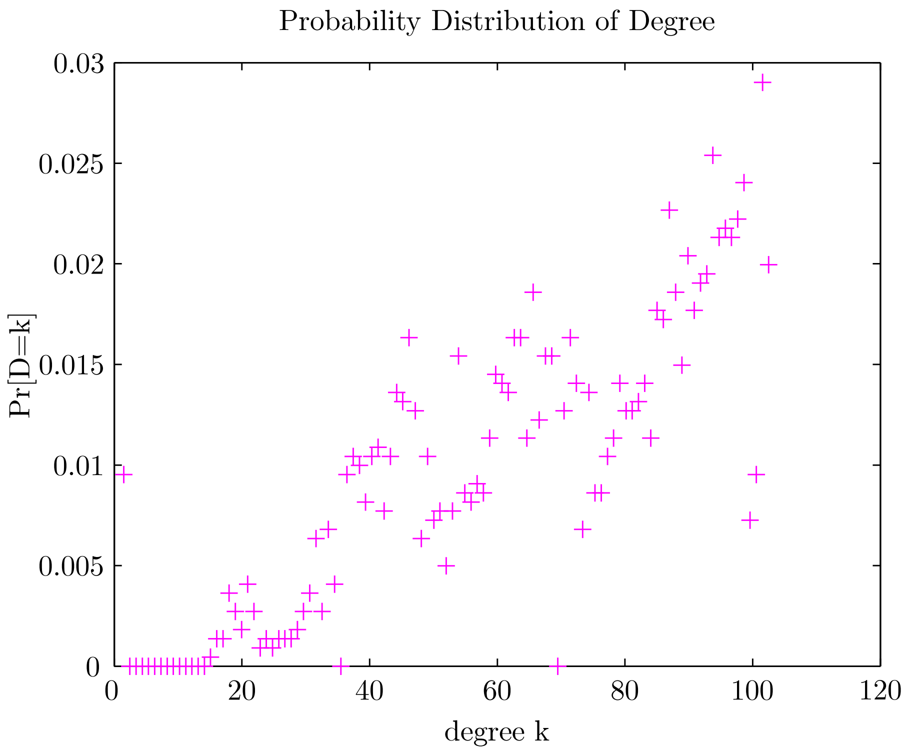

FIGURE 4.9: Degree distribution $Pr[D = k]$ over 21 years

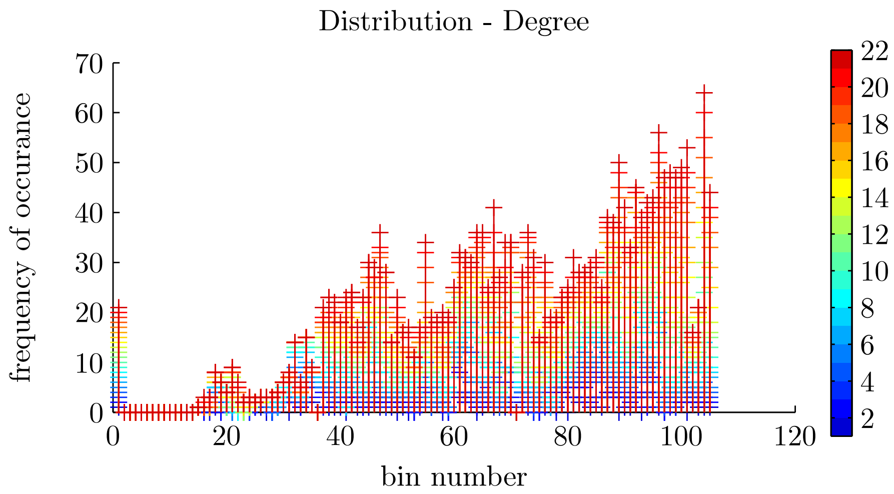

FIGURE 4.10: Degree distribution $Pr[D = k]$ over 21 years, depicting the contribution of each year

The diameter of a network is the maximum distance between any two nodes in that network in terms of the number of links traversed or the number of hops between source and destination. The presence of central nodes makes the distance between any two nodes in this network at most 2. Thus, the diameter of this network is 2. This supports the idea that euros flow efficiently between any two activity clusters via at most one other cluster.

In figure 4.10 the same degree distribution information as figure 4.9 is depicted, with the

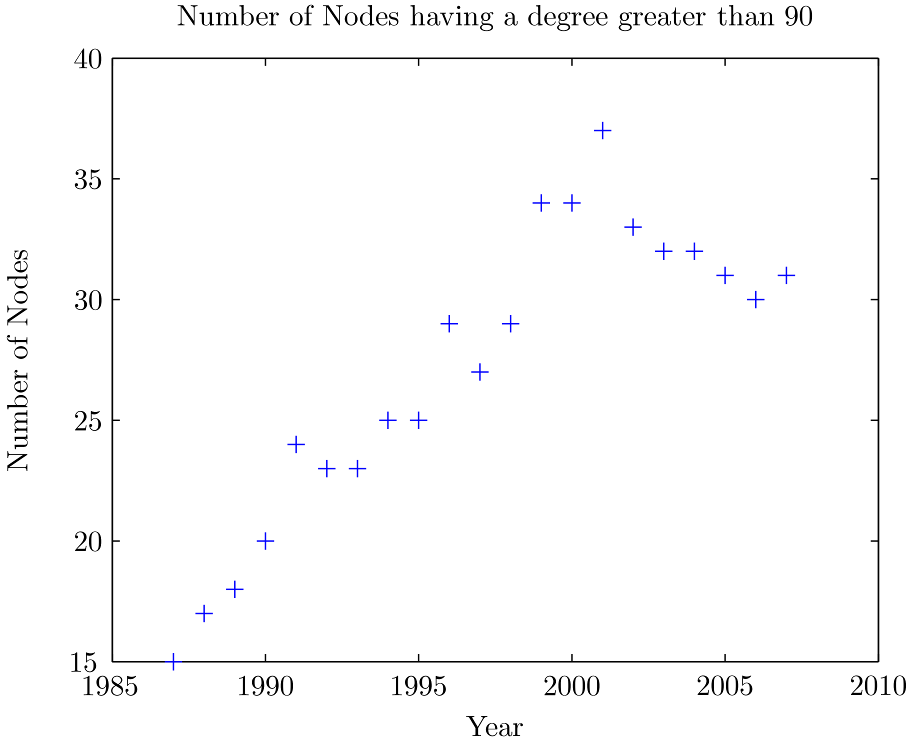

FIGURE 4.11: Number of nodes having degree greater than 90 over the 21 years.

addition of information regarding every year's contribution to this degree distribution. This is done by accumulating the number of nodes over the years with each degree value. In this diagram, looking closely at the higher order degrees, we see that in the more recent years, there is a larger increase in the number of nodes having high degree. That is, in recent years, a greater number of nodes are seen with high degrees (between degree values of 90 and 104) than in earlier years. Figure 4.11 details this trend. The number of nodes in 2007 having degree greater than 90 is double the number having such a high degree in 1987. Between these years, there was a peak instance when the figure was even higher. This reflects the increase in the number of hubs in the network over time.

The next step taken in the study of the network topology was an examination of the degree assortativity of the network nodes. Assortativity has been elucidated in the paper by Newman[28] in 2003.

Figures 4.12 and 4.13 depict the degree assortativity of the network. As seen in both figures, our network is disassortative in node degree. The assortativity value of node degree for each year is negative, indicating that nodes of our network are disassortative in nature. In figure 4.13, assortativity is studied using Correlation method. This also reflects disassortativity in degree.

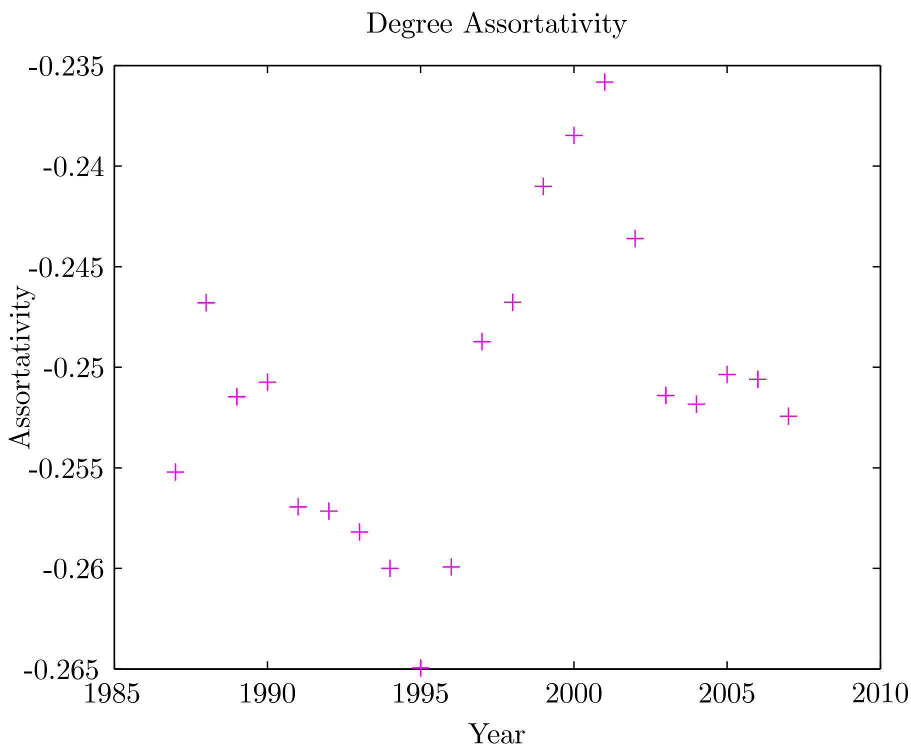

FIGURE 4.12: Assortativity of Node Degree.

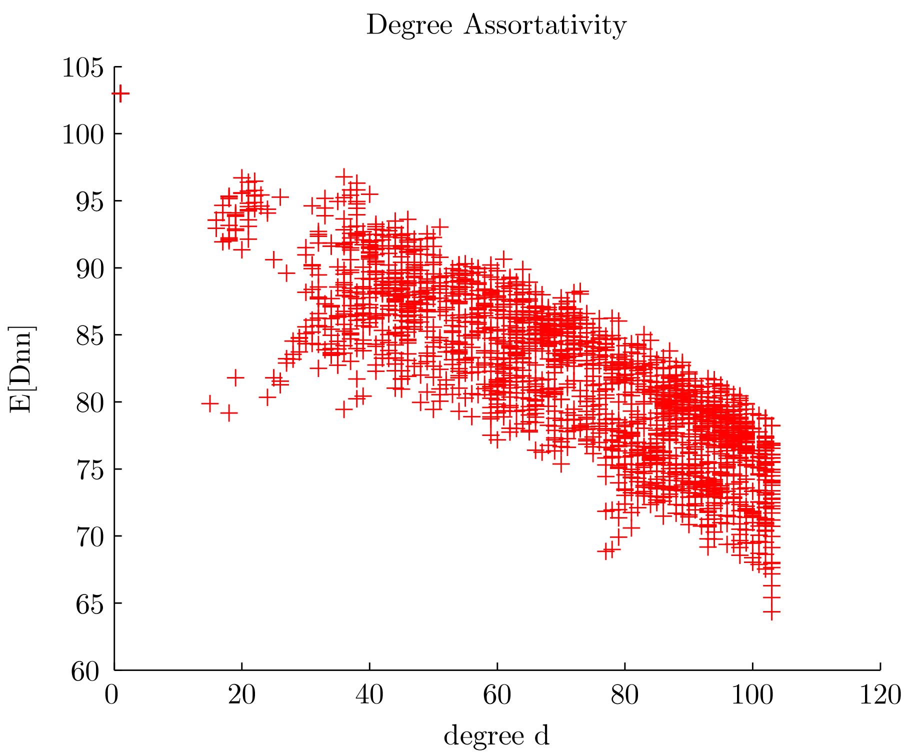

FIGURE 4.13: Scatter plot of the degree d of a node and the average degree of its direct neighbours $E[D_{nn}]$

In the first figure 4.12, the Pearson co-efficient [28] is calculated for the degree of the nodes for each individual year. The Pearson Coefficient, r, is a standard correlation coefficient. For Pearson's coefficient, the value of r lies in the range $-1 \leq r \leq 1$, with $r = 1$ indicating perfect assortativity and $r = -1$ indicating perfect disassortativity. In figure 4.12 r is negative throughout, depicting a disassortative nature.

Figure 4.13 is a scatter plot depicting the 21 instances of the network cumulatively in one plot. On the X axis, the degree of a node corresponds to, on the Y axis, the average degree of its neighbours. Thus, this graph considers the degree of a node and the average degree of its neighbours for each of the 21 years and plots them as 21 different points. This is done for all 105 nodes. The points plotted on the graph together, depict a disassortativeness in degree.

This observation is in agreement with ongoing research on community structures. Recent work [31] reveals that community structures reflecting real world networks tend to be disassortative in degree. Community structure is in its essence similar to the Holarchy in a Holon Network. For example, users form a network. A community is a holon which is representative of a subset of that network, on a higher abstraction level. Then, there exists a network of communities on the higher abstraction level. This is also an accurate description of our data set structure, where a group of activity clusters are aggregated into one representative sector on a higher aggregation level. Thus, the observations of our network properties are coherent in comparison with that of community structures.

In figure 4.14 we see the same information as depicted in figure 4.13, the degree assortativity, except that this plot also includes the contribution of each year to this data via colours. The pink colours represent nodes in the recent years of the range and the blue colours represent nodes in the early years of the 21 year dataset. We observe that over the 21 years, the trend in degree has remained disassortative. But towards the recent years, we see a more narrow and constrained distribution in the higher regions of the graph. We also observe that during the earlier years, there was the presence of nodes of degree between 30 and 40, having neighbours of average degree between 80 and hundred. This seems to be missing in the later years. This could be result of the tendency of nodes to acquire a higher degree, which is coincident with the observation that the number of links, on average, increases over the years.

Link Weight Study

The second metric used in this study is the link weight. As elucidated in section 4.2, all links in our network have a link weight and are non-directional. The figure 4.15 depicts the link weight distribution of the network under study.

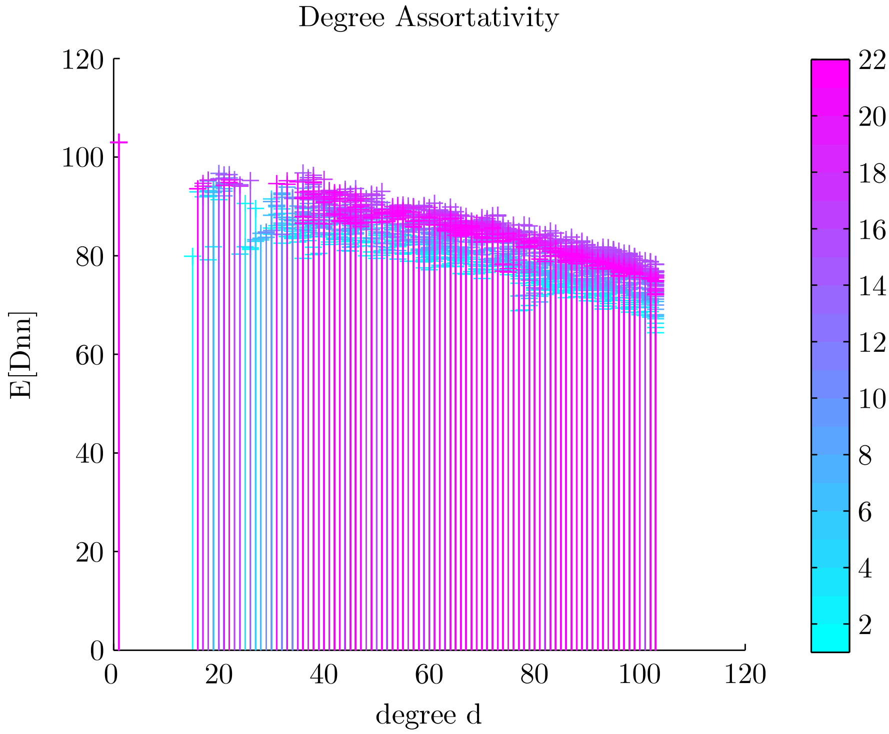

FIGURE 4.14: Scatter plot of the degree d of a node and the average degree of its direct neighbours $E[D_{nn}]$ depicting the contribution of each year.

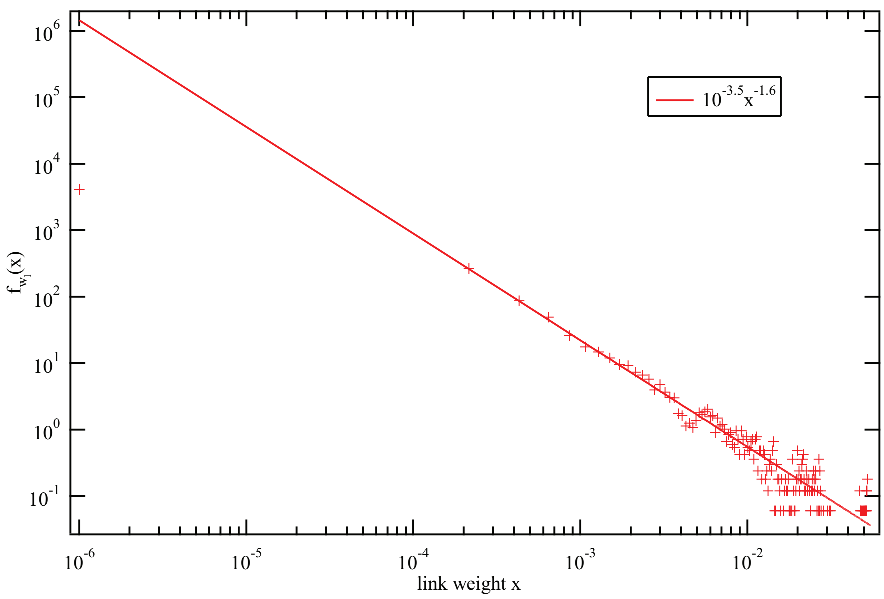

FIGURE 4.15: The probability density function, $f_{w_l}(x)$, of link weights.

The link weights of our network demonstrate a power law distribution [29]. That is, the probability distribution function of the link weight is such that the probability of occurance of a certain link weight is a negative power of the link weight itself. Thus, a few links possess a large link weight while many have much smaller link weights. This is observed in several real world networks [31]. The power law distribution can be given by $Pr[D = k] = ci^{-\tau}$, where $c = 1/(\sum_{i=1}^{N-1} i^{-\tau})$ is a constant.

Next, we study the assortativity of nodes based on link weights. The nodes of our network have been characterized by the nature of the incident link weights. The sum of all link weights connected to a node i in one year is designated s_i. That is, $s_i = \sum_{j \epsilon N(i)} w_{ij}$. Therefore, it's a measure of the amount transacted by the node i. The average link weight incident to a node i is s_i/d_i. From here on in, this measure is referred to as *Node Strength*. An alternative term used for the same measure is *average link weight around a node*.

In the assortativity test, we check for similarity of node strength between those nodes connected to each other by a link. We do this by running a cross correlation test on the node strengths of all nodes connected to each other by links in each year. The correlation study results are presented in figure 4.16. As we can see, the network shows a positive link weight correlation in each year. This gives us the assortativity of the nodes based on their average node strengths.

As depicted in figure 4.16, there is a positive link weight correlation in our network. In a highly dense network, with positive link weight correlation, a high link weight w_{ij} implies that other links incident to nodes i and j have to also have a high link weight value.

In figure 4.17, we examine the variance between the link weights around a node over the 21 years. The variance of the link weight around a node decreases until 2004 and slightly increases thereafter. Despite this, the overall trend is decreasing. The inference from this observation is that nodes increasingly distribute their spendings evenly. This could be an indication of a growing inclination among activity clusters to balance financial transactions among co-operating clusters than concentrating all resources toward a small group of co-operators[14]. For instance, a telecom company increasingly co-operating with different types of transport service providers, administrative service companies and support organizations would typically reflect an increase in degree. It is only important for the telco to have access to the resources, the organization doesn't need to own them. The idea of increasing co-operations and balancing transactions with all co-operators as opposed to concentrating them on a few partners, supports the idea of

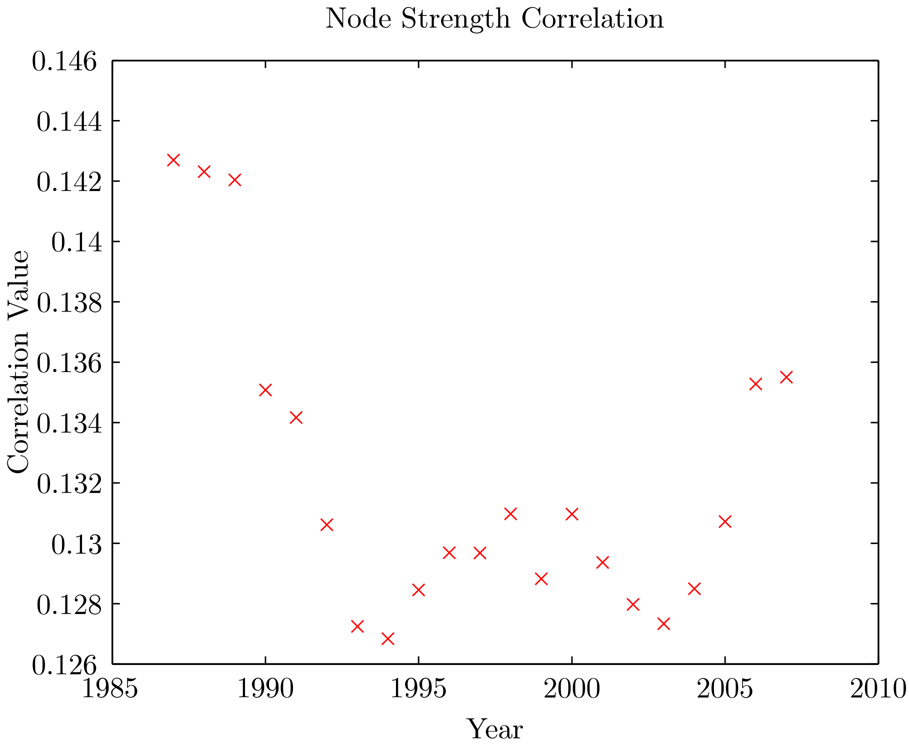

Figure 4.16: Correlation between the node strength of a node and that of the nodes around it.

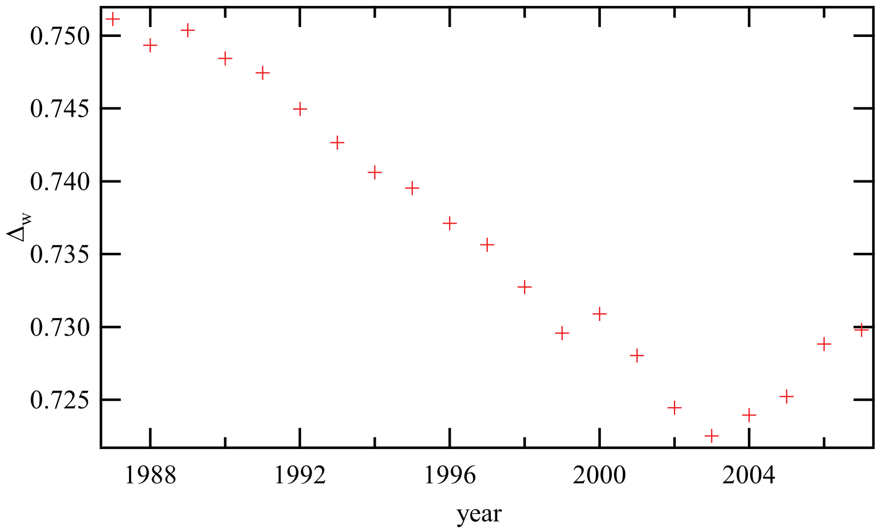

Figure 4.17: The link weight correlation around a node of the network over 21 years.

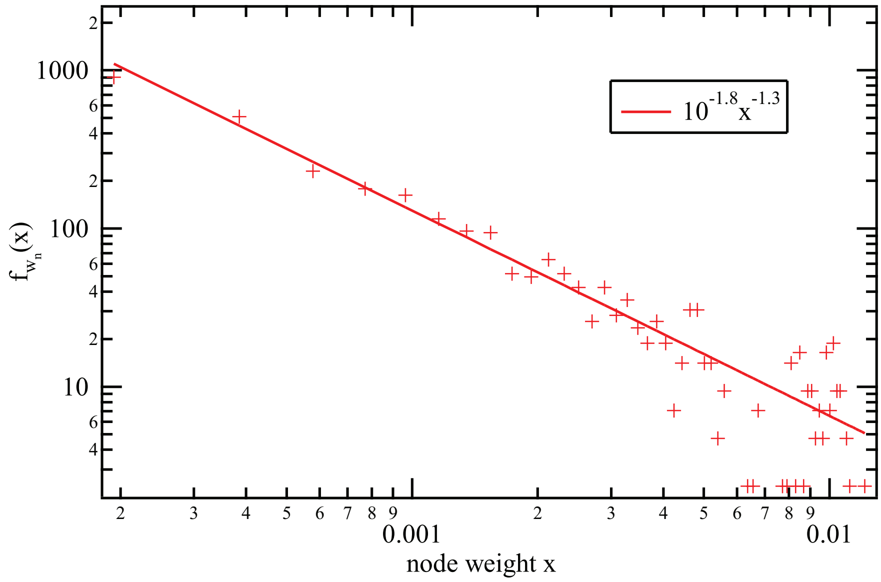

FIGURE 4.18: The probability density function, $f_{w_n}(x)$, for nodes of all 21 years together.

vertical disintegration. The slight increase in the variance of link weights around a node occurs directly after the internet bubble crash.

Node Weight Study

In figure 4.18, we see the node weight distribution of the network, cumulatively, with all 21 years. The network displays a power law distribution.

Figure 4.19 depicts the assortativity of the Node Weights over 21 years. We find that the Node Weights are disassortative in nature. Thus, high weight nodes tend to link to other nodes which have low node weight and vice versa. In figure 4.20, we see the same information as depicted in figure 4.19, with the addition of information regarding the contribution of each year to this distribution. As we can see, the distribution is more or less constant over the 21 years and remains disassortative in nature. There are no significant periods of change that are immediately visible.

Topology and Link Weight Study

Figure 4.21 depicts the correlation between degree, d, and the node strength, s_i/d_i. The positive correlation depicted in this diagram implies that a cluster having a high number of transactions with other clusters tend to exchange a large amount of money in these co-operations.

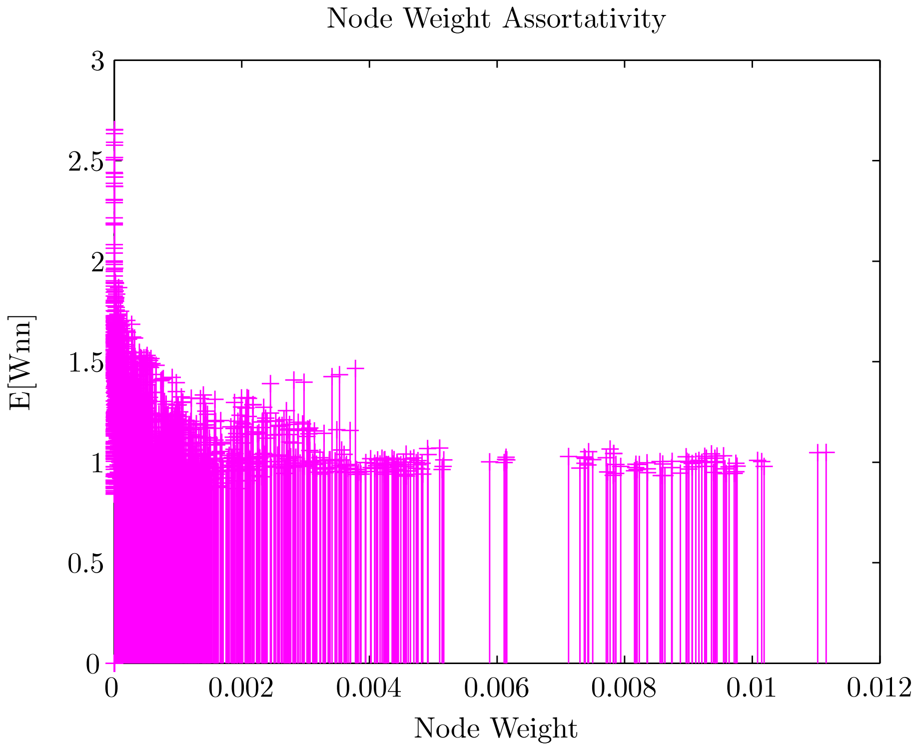

FIGURE 4.19: Scatter plot of node weight and the average node weight of its direct neighbours.

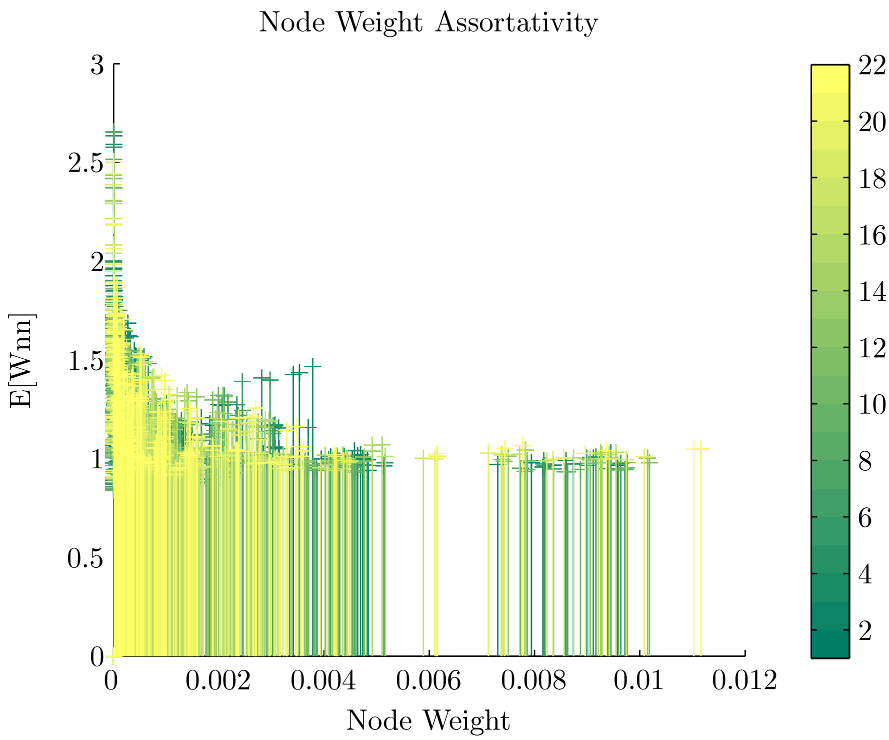

FIGURE 4.20: Scatter plot of the node weight and the average node weight of its direct neighbours, depicting the contribution of each year.

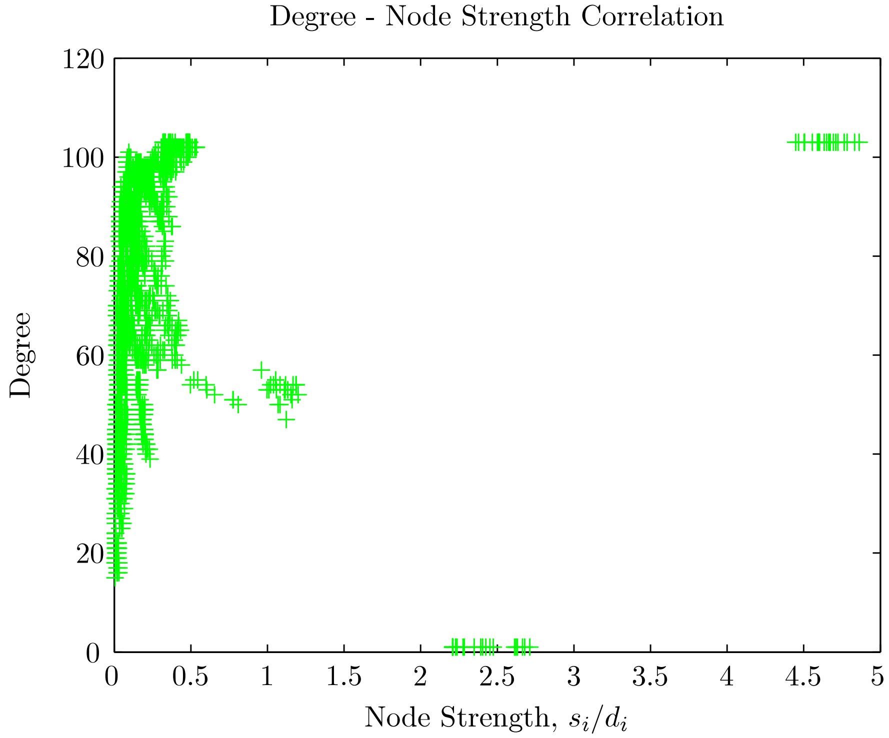

FIGURE 4.21: Scatter plot of degree d and node strength s_i/d_i of each node in the network over 21 years

Topology and Node Weight Study

Figure 4.22 depicts the relationship between the degree and node weight. It depicts all the 21 network instances cumulatively. The graph shows a positive correlation between the degree and node weight of nodes. We observe that clusters of weight 0.006 and higher are connected to almost all other clusters. This is interesting since it indicates that clusters with more interactions with other clusters show a propensity to have more internal euro flow.

In the last section, we observed that high degree nodes tend to transact a large amount of money in co-operations. Further study is needed to determine if high connectivity and high external transaction lead to large amount of internal flows in high degree nodes.

Node Weight and Link Weight Study

Figure 4.23 depicts the relationship between node weight and node strength. We can see an approximate positive correlation between the two. This is intuitive after observing the trends between degree with node strength and node weight.

In summary, the network is disassortative in degree and node weight, but assortative in node strength. Nodes and links tend to show assortative behaviour in relationship to

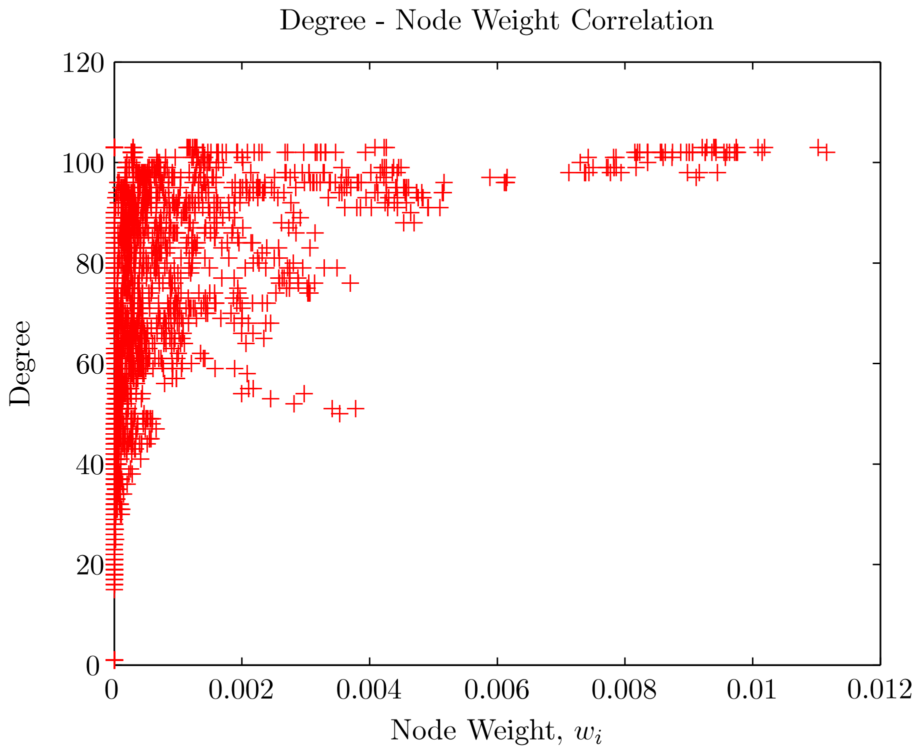

FIGURE 4.22: Scatter plot of degree d and node weight w of each node in the network over 21 years

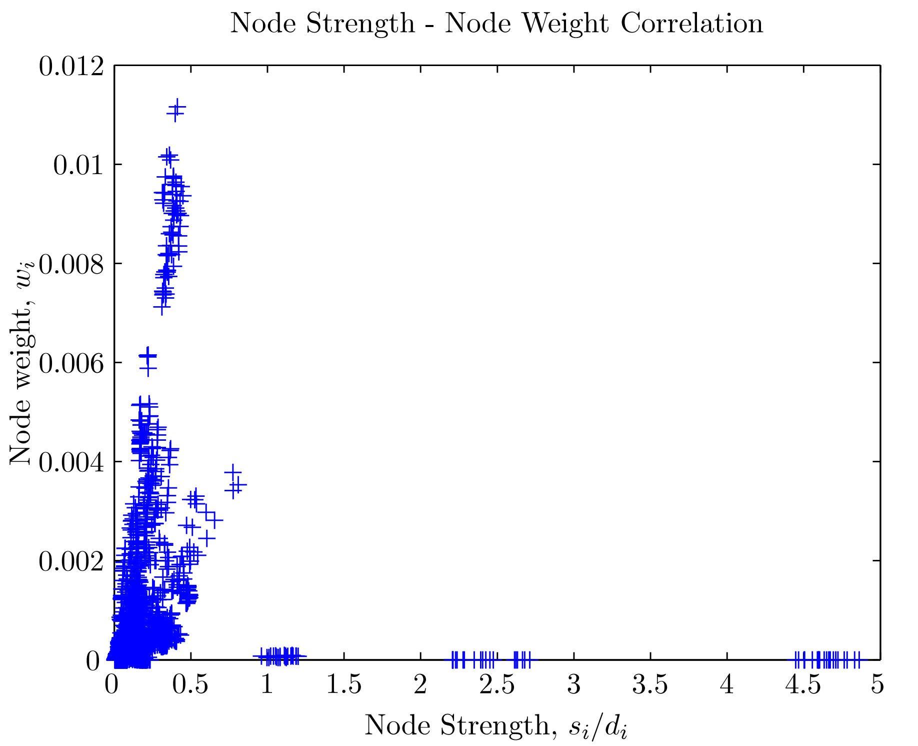

FIGURE 4.23: Scatter plot of node strength s_i/d_i and node weight w of each node over 21 years

each other. That is, nodes show no preference to connect with nodes of similar degree. Nodes connect to other nodes irrespective of high, low or equal degree. This may well be a consequence of the empirical nature of the network. Nodes also do not show any clear preference for other nodes of similar node strength. This may be a result of the fact that there are multiple hubs in the network, to which many nodes of low node weight connect. Node strength is assortative, indicating that nodes show a marked preference to transact with other nodes that have similar node strength.

4.5 Sector Specific Dynamics

In the obtained dataset from the Statistics Netherlands, the activity cluster telecom also includes the activity of the Postal organizations. Thus, it is essentially Telecom and Post. From hereon in, the term *telecom node* refers to the activity cluster that comprises of both telecom and postal organizations.

The telecom node is a hub in the sector network. Figure 4.24 depicts the trend in degree of telecom over 21 years. As seen in the figure, telecom connects the majority of nodes, supporting its capability, when considered along with its functional ability, to play a central role in trans-sectoral transaction processes. Figure 4.25 depicts the Telecom node weight over the past 21 years. Figure 4.26 depicts the node strength of Telecom over the past 21 years. Figure 4.27 refers to the income of the telecom node over the past 21 years. Here again, we can see a clear coincidence with the burst of the internet bubble. Figure 4.28 depicts the amounts of euro flowing inside the telecom activity cluster over the 21 years. The steep rise of the node weight values in the second half of the nineties coincides with the introduction of competition in the Dutch telecom sector.

In figures 4.25 and 4.26, we observe the time variation of the node weight and node strength respectively, of the telecom activity cluster. It is explained in the following sections that the trends in node strength and node weight vary for each node individually, though the income of each node displays a congruent trend over the years.

Figure 4.29 depicts the expense of households on telecom each year. This is different from the nature of certain other activity clusters, such as the computer services activity cluster, which shows a pattern of rising share of income from the household sector over the twenty one years.

In figure 4.31, we see the income trends of the 2 fastest growing activity clusters, along with the income trend of the telecom. These 2 are Computer Service and Employment Agencies. Telecom lies within in the top 10 per cent of the fastest growing sectors.

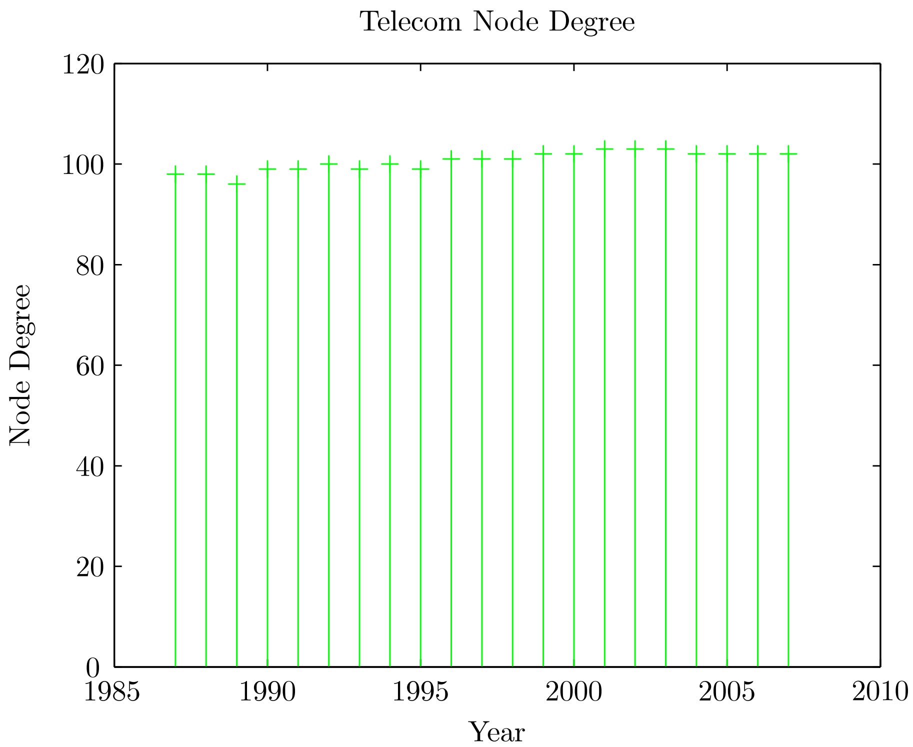

FIGURE 4.24: Degree of Telecom node over 21 years

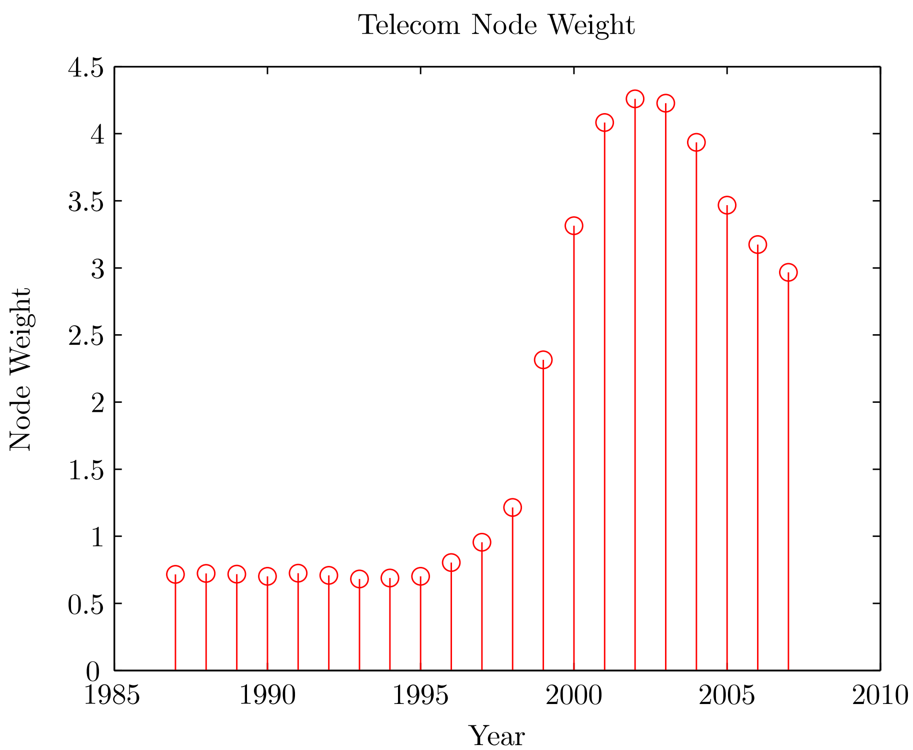

FIGURE 4.25: Telecom node weight over 21 years

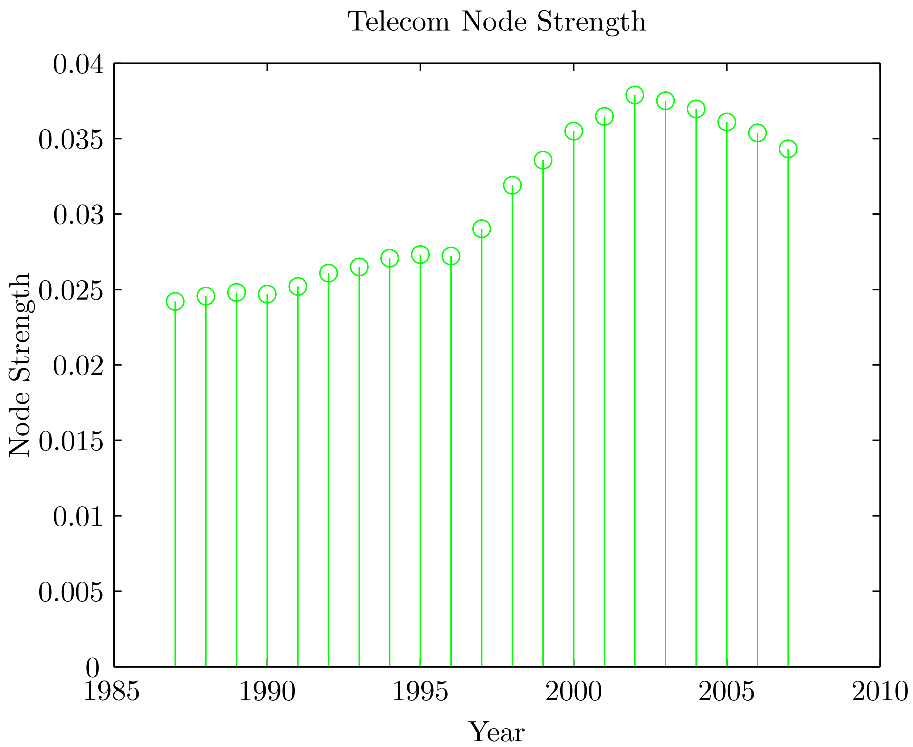

FIGURE 4.26: Telecom node strength over 21 years.

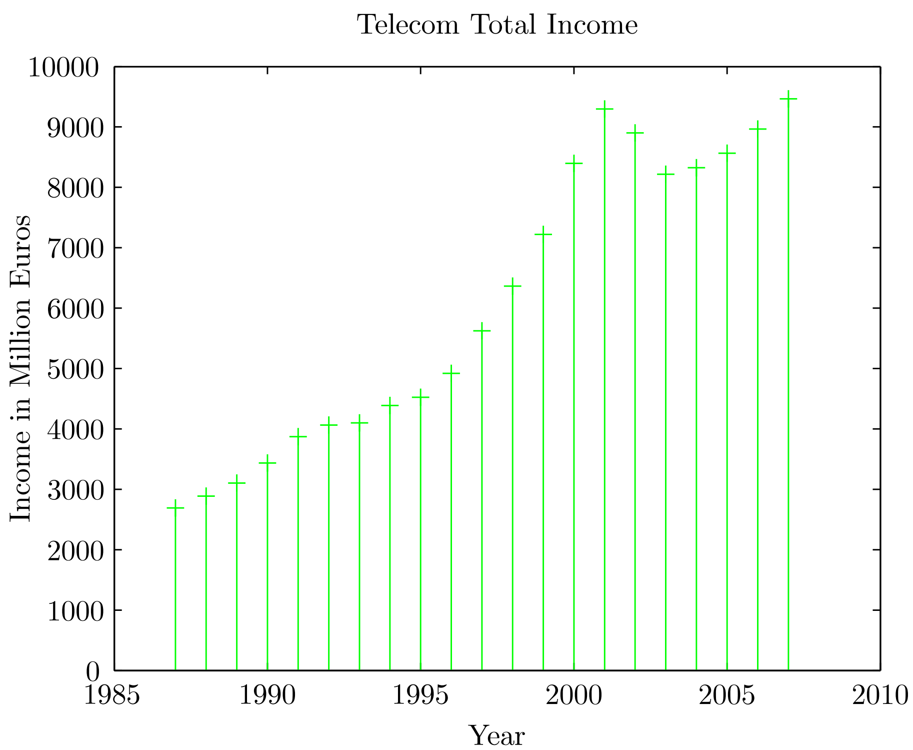

FIGURE 4.27: Telecom Income over 21 years.

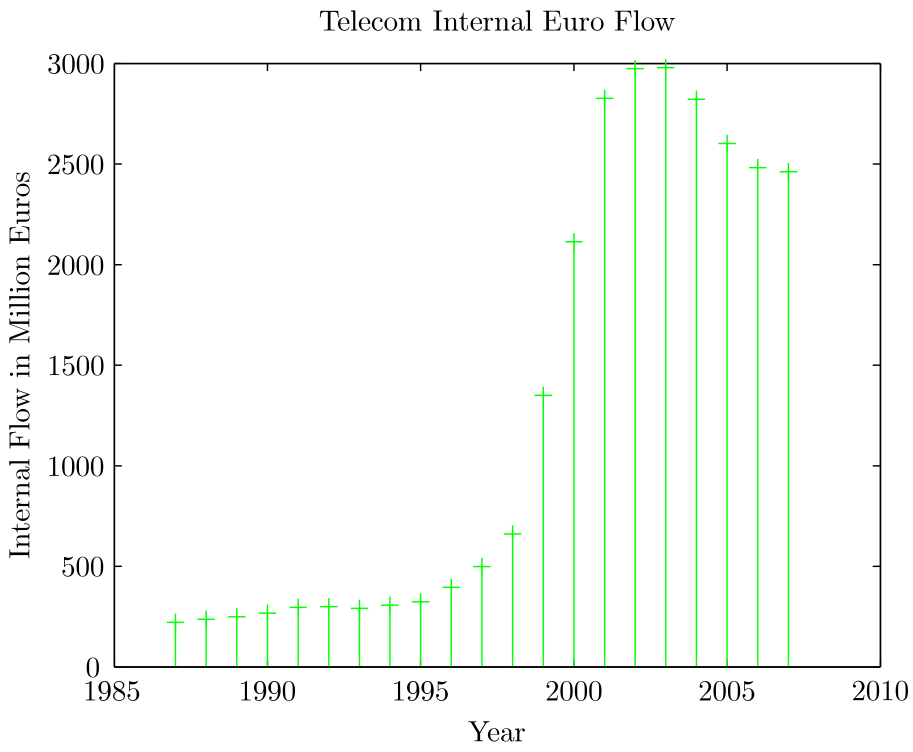

FIGURE 4.28: Telecom internal euro flows over 21 years.

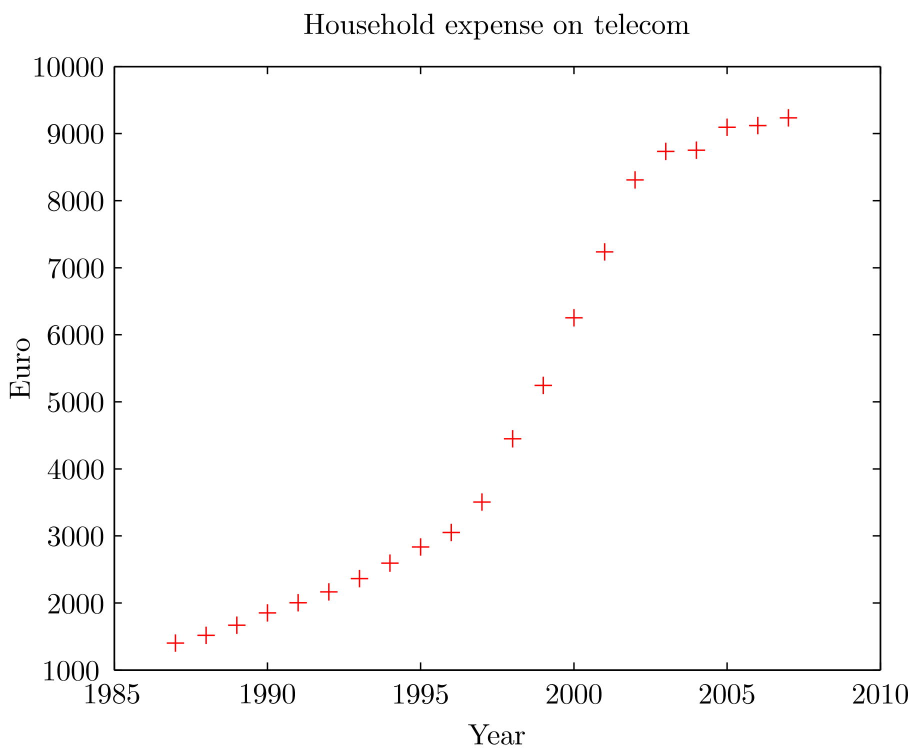

FIGURE 4.29: Expenses of household on telecom in million euro

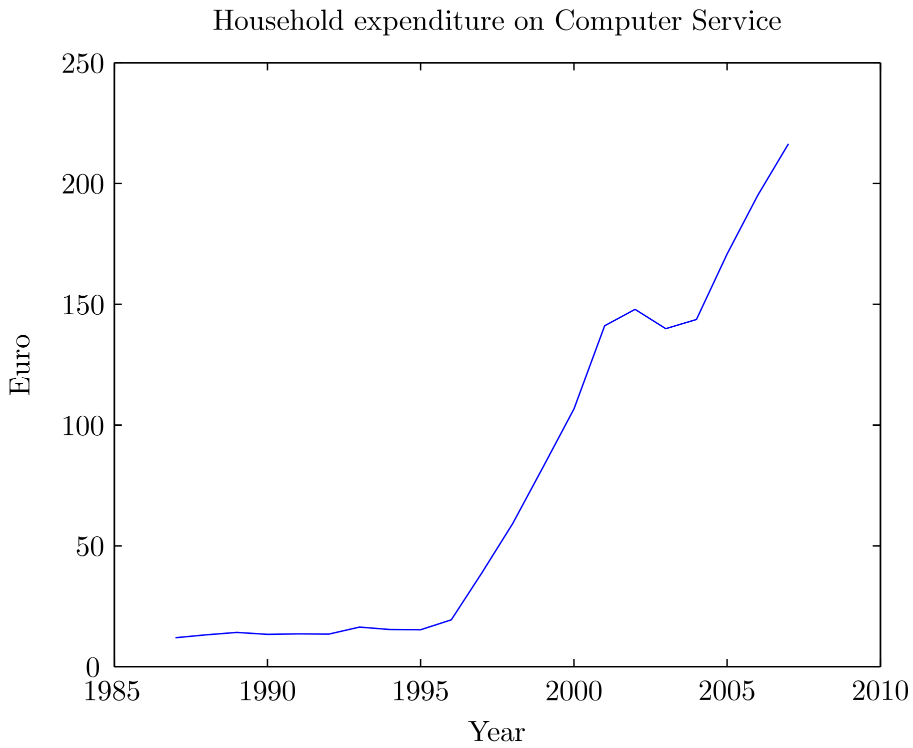

FIGURE 4.30: Expenses of household on computer services in million euro

Telecom is the eleventh fastest growing activity cluster over the 21 years studied. It is observed that the overall trend of each cluster's total income behaviour has remained congruent But the specific dynamics of each sector is different. Here, in figure 4.31 we can see that the income trends for all the nodes follows a congruent trend. The individual trends of each of these activity clusters vary in different respects. For example, in figure 4.32 the node strength trends of the same nodes are elucidated as in figure 4.31. Since the node strength of a node is a reflection of the amounts transacted by the node, variations in this trend between nodes reflects the ways in which the amount of transactions of different nodes has changed. The same applies to figure 4.33 where the node weights of the same nodes are depicted, and 4.34 where the degrees of the same nodes are compared. Here, we see the difference in the way the nodes interact with their neighbours over time. While the overall contribution of the transactions between activity clusters remains around ninety percent of total yearly transactions(as seen in figure 4.5), the individual transaction trends of activity clusters are different from each other.

Note: The activity cluster entitled Labour Recruitment in the figures 4.31, 4.32, 4.33, 4.34, 4.35 and 4.36 includes the activities of both labour recruiting organizations and organizations involved with the provision of personnel. The name is shortened so as to remove overlap of legend with graph points.

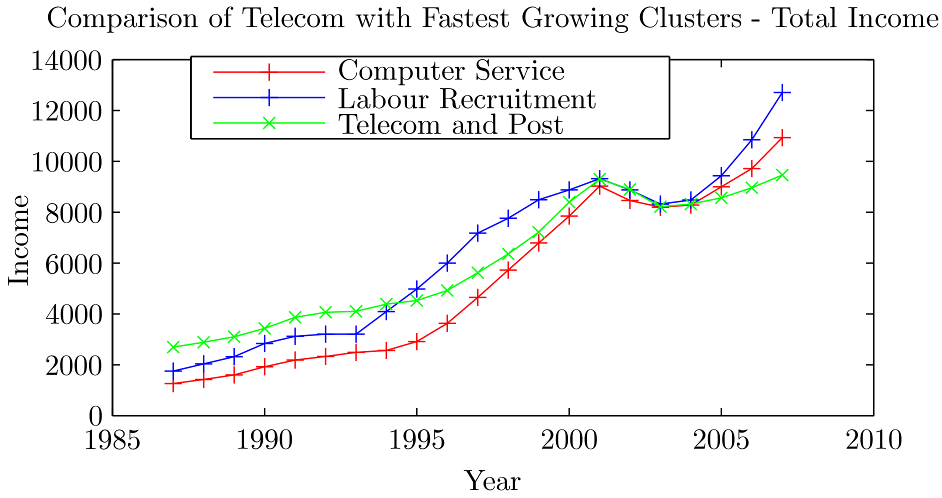

FIGURE 4.31: Telecom income compared to the incomes of the top two fastest growing activity clusters.

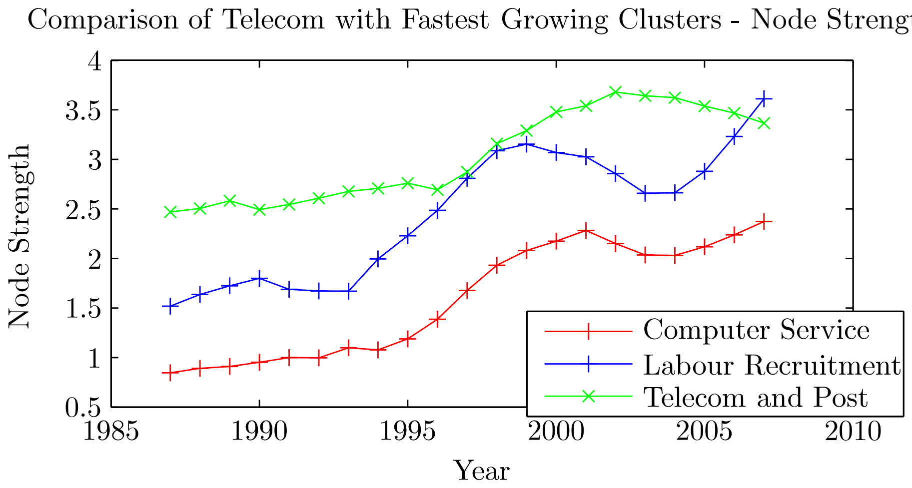

FIGURE 4.32: Variation of Telecom's Node Strength compared to the Node Strength of the top two fastest growing activity clusters.

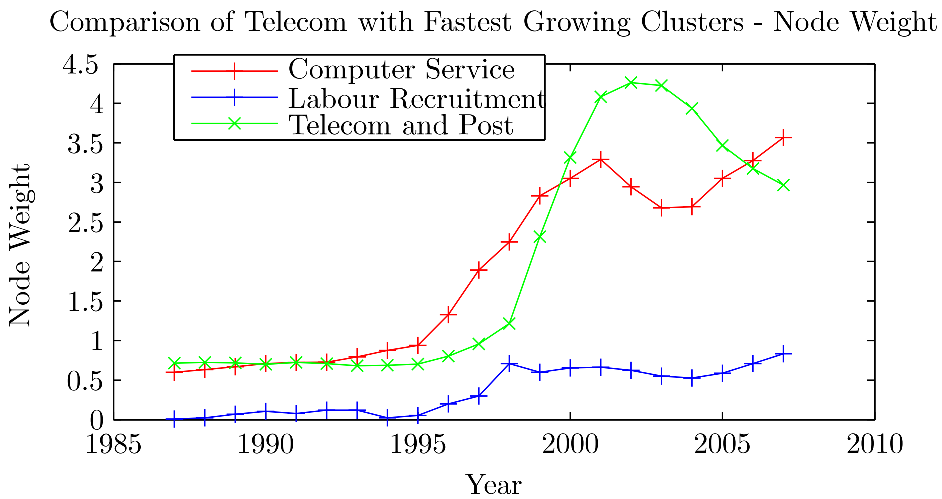

FIGURE 4.33: Variation of Telecom's Node Weight compared to the Node Weight of the top two fastest growing activity clusters.

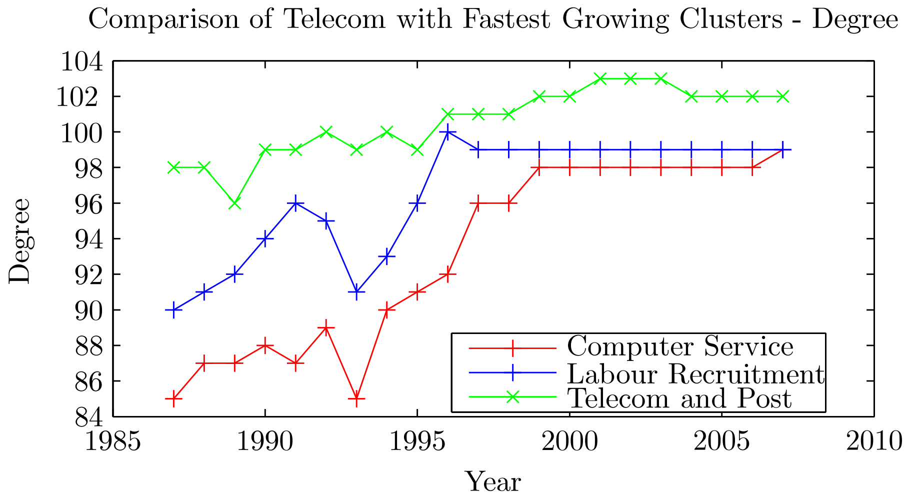

FIGURE 4.34: Variation of Telecom's Degree compared to the Degree of the top two fastest growing activity clusters.

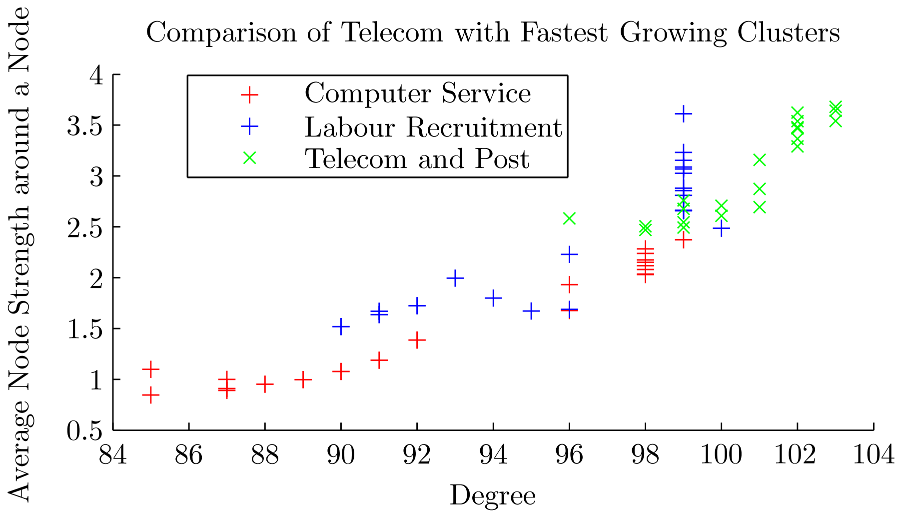

FIGURE 4.35: Comparison of the Average Node Strength vs. Degree Scatter Plots of Telecom along with the fastest growing activity clusters.

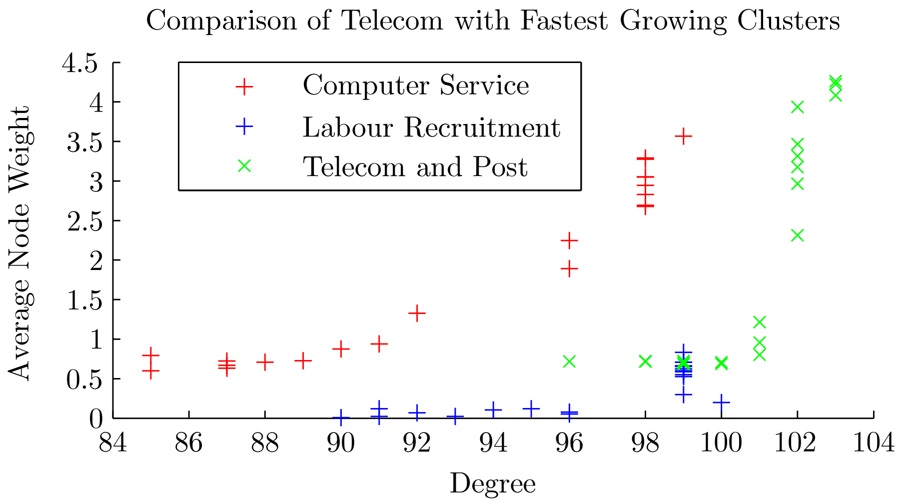

FIGURE 4.36: Comparison of the Node Weight vs. Degree Scatter Plots of Telecom along with the fastest growing activity clusters.

In figures 4.35 and 4.36, we see that the assortativity trends of degree and node weight, and, degree and node strength of Telecom and Computer Service are congruent.

Summarizing Observations

All the sectors are sub-divided into activity clusters. In this section, information detailing the euro transactions between the activity clusters, is studied. The data gives information over 21 years on a per year basis. This is together modelled as an evolving network of activity clusters over 21 years. There are 105 activity clusters in the network, as defined by the National Accounts Department of Statistics Netherlands. The name and composition of each of the 105 nodes remain constant over the period of 21 years examined. Each node is composed of a network in the lower level, which consists of interacting organizations grouped together on some criteria defined by the Statistics Netherlands. The nodes are defined similarly but are composed of different sub-networks. Each year, a fixed amount of money traverses the links between these nodes. These amounts vary only on a year-to-year basis.

The presence of at least one directional transaction between two nodes is considered to be a link. To allow ease of mathematical examination, the links are modelled as weighted, undirected links. The weights of the links are equal to the sum of the euro flow between the nodes, neglecting the direction of the flow.

The euro flow amounts are corrected for inflation in order to make the yearly transactions comparable. It is found that inflation only slightly distorts the steady rise in the total amounts of money flowing in the network.

There is a steady rise in the total amount of money circulating in the network. The above observation is especially interesting in light of the fact that in all of the examined years, transactions *between* activity clusters contribute to approximately ninety percent of the total economic transactions, that is, $\sum_{i \neq j} w_{ij}$. By observation, $\sum_{i \neq j} w_{ij} \approx 0.9$ and $\sum w_i \approx 0.1$.

It is observed that the network is very dense. At the sector level, the network forms almost a complete graph.

It is also observed that coincident with the crash of the Internet Bubble is a drop in the total amount of euro flow in the network. Similarly, coincident with the crash of the Internet Bubble is a large drop in the number of transactions in the network.

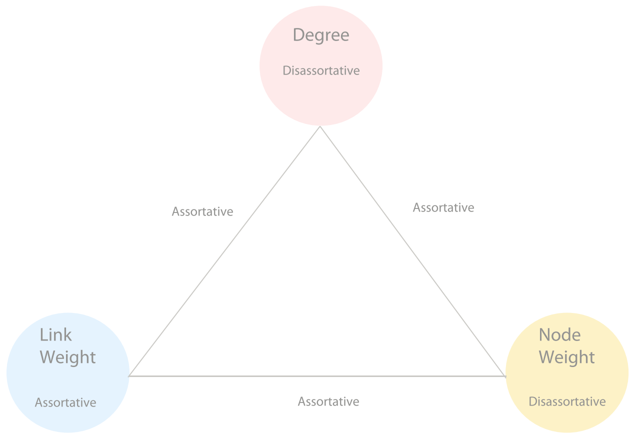

FIGURE 4.37: Schematic representation of the results of the assortativity experiments on the network.

Despite a fluctuation in the number of links in the network, there has been a doubling in the number of high degree (degree greater than 90) nodes in the network over the 21 years.

A three dimensional model is proposed to examine the network characteristics. A fourth dimension, that of time, is added to this model to track the evolutionary pattern of the network.

The following observations are a result of the study of the network based on the proposed model. The network is disassortative in degree. This is coincident with the nature of social networks. Thus, nodes do not show any marked preference for other nodes which have a degree of the same order as theirs. Instead, nodes connect to other nodes which have low degree as well as other nodes which have higher degree. The link weight distribution and node weight distribution, both display power law behaviour. This is also coincident with the nature of social networks [29]. Link weight studies show assortative properties. That is, the nodes which exchanged large amounts of money in one transaction, tended to exchange high amounts of money in all their transactions. Over the years, nodes increasingly distribute their spendings evenly. Node Weight is disassortative in nature. Nodes are not explicitly partial to other nodes which have the same order of euro flow within itself. High degree nodes exchange a large amount of money in individual transactions with other nodes. High degree nodes show a tendency to have a large amount of euro flowing within themselves. These tendencies observed in the nature of interactions between nodes is depicted in figure 4.37.

It is also observed that Computer Service has been the fastest growing activity cluster over the past 21 years. Household has been the strongest hub of the sector network consistently over the past 21 years. Though Computer Service's income from the Household has increased rapidly over the past 21 years, the income of Telecom from Household has dropped to fifty percent of its initial value in 1987.

We observe that individual activity clusters have unique patterns in degree, transaction amounts and amounts of money within themselves, over the years. But taken collectively, in each year, we find that the ratio of the observed total amount of transactions between the activity clusters, divided by the total amount in the network, $\sum_{i \neq j} w_{ij}$ is close to a constant. By observation, $\sum_{i \neq j} w_{ij} \approx 0.9$ and $\sum_{i} w_i \approx 0.1$

Chapter 5

The Telecom Transport Network

5.1 Introduction

The evolution of an individual sector has details and idiosyncrasies that are hidden from view when studying innovation from a national perspective. "...one could explain important characteristics of innovation that the macro-environment has not clearly shown by focussing down the camera to look at the actors..." [32] Thus, it's important to focus in on the sector in order to identify the evolution of its innovation.

Telecom plays a key role in both intra-sector and trans-sector innovation, as mentioned in chapter one [5]. The objective of this part of the thesis is to study the evolution of the telecom transport network so as to understand what drives changes in it and how it is in itself influenced by changes. Research is done to track changes in the telecom network, since the network is the functioning tool of the telecom sector.

By observing changes in the telecom transport network, we wish to determine a set of drivers that cause the network to change. The motive behind such a model is to aid network designers and standardization bodies, giving the former a formal basis in accounting for the factors driving change in future design of transport networks.

5.2 Literature Review

In this study, we look at the telecom sector from a very specific perspective. We look at the changes that occurred in telecommunication transport network technology over the years from 1987 to 2010. A study of literature was done to understand the currently identified nuances of evolution. Though there is intensive contention and limited consensus on the validity of any one theory, the literature study brought out the essential forces being considered in the study of evolution.

In his editorial in [10], Witt states that "the principles of variation, selection and retention are abstract reductions of conditions that are domain specific for evolution in nature." He concludes that creating an abstract analogy of these principles in the evolution of economics does not necessarily rigorously and/or exhaustively define the evolutionary process in the latter domain in hierarchical detail.

In their paper [11], Hodgson and Knudsen discuss whether generalized Darwinism is applicable in the evolution of social systems at all. They surmise that the principles of Darwin are necessary in the evolution of social systems, but not sufficient, since these principles give an abstract idea and not a system-specific detailed view, of the process of evolution. The authors argue first that in the social domain, like the biological domain, the question of how variety and replenishment of this variety came about is valid and significant. Though attempts have been made to address this in the biological domain, it is yet to be addressed in the different social domains. Variation, is the first essential principle of Darwinism. The second argument by the authors is that "there must be some mechanism that ensures that some such solutions (replication of habits, customs, rules and routines) endure and replicate; otherwise, the continuing retention of useful knowledge would not be possible." This is their case supporting the second Darwinian principle of inheritance. Finally, the authors argue for the principle of selection. They clarify that "Selection refers to the mechanisms that bring about the survival of some variations rather than others, often reducing variety." The significance of selection is brought out by their argument that *"Innovation is about the creation of new variation; selection is about how they are tested in the real world. Through selection, a set of entities, a population will gradually adapt in response to the criteria defined by an environmental factor."*

Hodgson and Knudsen state that "Darwinian modes of explanation are necessary" to address the growth and development of evolving populations, but they also state: "to say that two sets of phenomena are similar in general terms does not imply that they are similar in detailed respects... Darwinian theory is a general explanatory framework into which particular explanations and empirical details have to be placed."

The two authors define what they mean by the term *complex system* - these are not simple, mechanical systems but ones that involve a variety of entities that interact with one another. They state that "such complex systems produce some outcomes that are not willed by any individual entity and have properties that do not correspond to any individual entity taken alone." They further elucidate, retaining generality, that these systems involve populations whose members are “similar in key respects, but within each type, there is some degree of variation, due to genesis, circumstance, or both.” Examples of these include social entities such as customs, rules, routines and institutions. The authors highlight that these entities exist in an environment of which they are a part, and face a problem of “local and immediate scarcity.” These and other properties described in the paper, give an image of the system under study. The above specified properties tally with the sector network as well as a sector holon(and it’s underlying network).

In essence then, the basic darwinian evolution principle may be applied to the system on hand.

In their work [8], Dosi and Nelson discuss existing ideas in the domain of evolutionary economics. The part of their paper, most relevant to this study, lies in the section entitled *Evolutionary theory: principal characteristics and applications in the social domain.* Here, they elucidate some of the characteristics of the term *evolutionary* social studies. They describe two main characteristics of such studies and four “concrete principal building blocks of an evolutionary theory.” The two main characteristics of evolutionary study are, one, a dynamic analysis of the movement over time of a particular thing and two, an explanation of the elements that generate this variation. Of specific interest to this study, they describe what is meant by “unit of selection and the mechanism and criteria of selection.” The unit of selection manifests itself in the social domain as demand. Evolution, then is toward satisfying this demand, that is, towards supply. This concept is further discussed later in this chapter in the context of the telecom transport network.

A review of literature to check for the existance of a model for sector specific studies was undertaken. It was found that most sector based innovation studies used a fundamental approach proposed by Bell and Pavitt [33].

The work of Westphal, et al [34] and Malerba and Mani [32] are two of the most famous examples of this. From their work, it is seen that technology change, innovation and growth of technological capability are interlinked. Bell defines technological capability as the “capacity to manage technology and to implement technical change” [35]. Figueiredo also includes the knowledge of humans active in the sector, the techniques involved and production, while referring to Bell’s former definition [36]. Research of technological capability (often pertaining to a sector [34]) has been evolutionary in nature [37].

The theory that *technology change is not an isolated process* is used to explain the evolution of firms and their innovative behaviour. Innovative behaviour over time, results in the firm accruing technological capabilities[32]. The ability of an organization to transact technological knowledge, as well as deliver innovation, results in technological change. Towards this end, it is necessary that the organization interact with surrounding organizations such as regulatory bodies, research and development organizations, universities and supplementary organizations, to transact technology, resulting in enhancement of their own technological capability. Thus, in this trans-sector process, we see that technological change is a consequence of increasing technological capability and innovation. The evolution of technological capabilities and it's subsequent technological changes, therefore, ought to reflect upon the innovativeness of any organization.

Our objective is to track the evolution of a part of the telecom sector. Typically in literature, sectoral systems have been studied in two ways. In the first, there is a comparitive study between one or more sectors in multiple geographic locations[38],[39]. This comparison are sometimes based on R and D as a percentage of GDP, shares of patenting, similarities in specializations, qualifications of work force, etc. The second method is to study one particular sector of one particular country within the national network [40]. The evolutionary view is holistic in nature. "The evolutionary perspective also considers that firms evolve over time when they attempt to adapt themselves to their environment. This adaptation process has implications for the path of technological capabilities accumulation, which is related to the main characteristics of the innovative activities within firms... Following this perspective, technological capabilities refer to the dynamic and competence building activities firms undertake to generate new products ,processes and services." [32]

Bell and Pavitt introduced three domains in which technology change of a sector can be studied - Product, Production Process and Organizational Process. Either completely new technology or incremental technology may be introduced in any of these three domains. These same three domains can also be introduced in the study of Technological Capability[33]. These studies show that the technology changes in Product, Production Process and Organizational Process give a perceivably complete overview of the technological changes in organizations.

Marques and Oliveira [32] classify Technological Capability based on Innovative Capability (further divided into Advanced and Intermediate Capabilities) and Routine Capabilities (further divided into Pre-Intermediate and Basic Capabilities). The authors classify Technological Changes into three levels - High, Middle and Low Impact.

In our study, some of the possible Technological Capabilities include product functionality, volume of services being supported and available technology. Other possible areas of impact that influence technological capacity include operational feasibility. Several changes are desired in telecom which may or may not be completely feasible. Consider the migration of telecom networks to Next Gen Technologies. This is not possible to complete fully because of unfeasible trade offs between the value generated by existing infrastructure and it's rate of depreciation.

To examine the impact of the identified drivers, it is useful to follow the study of Marques and Oliveira, where the impact of the technological change is ranked. This system allows us to detect during the study itself, whether or not it is possible to rank the impact of changes occurring in the network. If they do, the model also allows us to judge the relative importance of each of the drivers and how they impact the network.

Typically in literature, Technology Capabilities and Change is studied for a whole sector - as opposed to examining only the functions of the sector or the tools of the trade of the sector. The models developed for such studies have a scope that is much wider than the scope of this study.

A review of the different telecom models is found in the work of Zuniga [4]. This study discusses the advantages and disadvantages of the different models as well as their suitability in different situations. These models include the OSI, eTOM and FCAPS, among others. Different business models are discussed too. The STOF Model and the Portfolio Model are compared. This study has a clear depiction of the Portfolio Model and its applicability to telecom operators. It also has a clear elucidation on the different functions of the Telecom sector.

Next, a review is conducted to define the term - Transport Network. For this study, where an examination of the fundamental drivers of change is undertaken, such a model is required that captures the structure of network in terms of the network's functions, without delving into overwhelming details. Toward this end, the Recommendations from the International Telecommunication Union, the G.805[41], G.809[42] and the G.800[17] standards are studied. The G.809 Recommendation proposes a functional architecture for a connectionless network. The G.805 Recommendation describes a similar architecture for the connection oriented network. There are several similarities between these two Recommendations. This is interesting in light of the fact that both these Recommendations take a Functional view of the networks, which resulted in essentially similar nuances in both cases.

The G.800 proposes a unified functional view of the transport network architecture. The ITU G.800 definition of a network is technology independent in nature. The recommendation uses a layer system to depict the transport infrastructure of a telecommunications system. Each layer has the same fundamental and simple function of transport. Each layer looks exactly like every other layer and differs only in the type of signal transported, that is, the format of the information carried. There may be any number of layers stacked on top of each other.[17]

The layered structure allows for scalability and mapping onto any other networking standards, such as OSI. This system of multiple layers is interesting since it makes the telecom network setup transparent. It also makes the setup flexible and adaptable to the changing demands made upon network. For instance, keeping the IP layer intact, the services running over IP can be continuously run while the layers under IP are changed to cope with issues such as volume of traffic and quality of service. An example is the design of certain technologies with a particular product or type of data in mind. SDH technology was designed with voice traffic in mind. This allows circuit-like connections to function in a synchronous manner. This technology was sub-optimal for data networks. To improve this scenario, IP and ATM are encapsulated in SDH. To examine events like these, it is necessary to be able to seperate and identify the individual technological entities and drivers of change. Since the model proposed by the Recommendation is transparent and allows the dynamic decoupling of layers, it is well suited for a study where individual drivers need to be examined.

The Recommendation also elucidates some of the demands made upon the network. There is a section describing the nature of data being transferred by the network and the nature of the connections supported by the network. Data of three different types can be encountered by the transport network. These are, one, data which is ordered in time and sequence, two, data that is ordered only in sequence and three, unordered data. Data may be bursty or continuous in nature. Apart from the nature of the data, the connections may be of a point to point nature, a point to multi-point nature, multi-point to point nature, or a virtual private network.

During the process of the study, it is found that solely a functional description is insufficient and therefore, resource elements and technological elements are also taken into account.

A summary of the salient points from literature follows.

The object of the above study is the telecom transport network. This network supports a group of value added services. These are used by a group of end users. The network is run by a telecom operator who supplies functionality to customers. These elements are part of the environment in which the network operates. The network is constrained by scarcity in its environment, such as scarcity of money and technological capability.

By nature, networks are part of a social environment and therefore, their evolution follows darwinistic principles at a fundamental level. The examination of the evolution of a social system has to reflect the dynamic nature of the system over time, that is, the actual changes that the network has gone through. It also has to identify the factors that cause the change, that is, what drives the changes in the network.

In the biological domain, there is a creation of variety. Only those individuals from this variety that meet the demands of the environment survive. This is the selection process. So, there is the presence of variety and a selection process to prune it, in the environment. Similarly, in networks, there are some demands upon the network from its environment. To meet these demands, the network has to take a certain form. This form is determined by the nature of those demands. This is the selection process in networks. When these demands change, the network has to take one out of several possible paths of evolution to meet these demands. The network keeps evolving to meet those demands. Therefore, evolution is a process of demand and supply in networks.

The demands made upon the network could be by multiple entities. These entities may even have conflicting needs and motives. This is the character of selection criteria in social systems.

Actors in an environment can also influence the environment. This often causes changes in the drivers that influence the actors. Thus, the process is bi-directional. In our study, we choose to confine the examinations to a one-directional nature. We examine only those factors from the environment that affect our network and do not study the effect of the network on the actors. Nor do we examine the motives of change in the actors themselves. This limitation of scope is due to time restrictions.

To put networks and their evolution in a social context, we consider the Holon Model and the Portfolio Model. This is elucidated in the following section.

Finally, a definition of the network under study is undertaken. Though the study mainly involves knowledge mining via expert interviews and discussions, intensive basic study of the existing system, via documentation owned by the network operator, was required to understand the terminology and existing setup of the system.

5.3 Context of Study

To be able to identify the drivers operating on the network, it is required to look at a larger picture where all the influences on the network are made visible. A model comprising of the actors in the environment around the network is required. Such a model is depicted in Figure 5.1. This model is known as the Holon Model.

The social and economic environment of a country is modelled as a network of sectors. To allow for simplification of the complex system, while retaining a holistic view, we apply the Holon Model to this network. The sector network is the topmost network depicted in Figure 5.1. The second layer in this figure represents the activity cluster level, which is

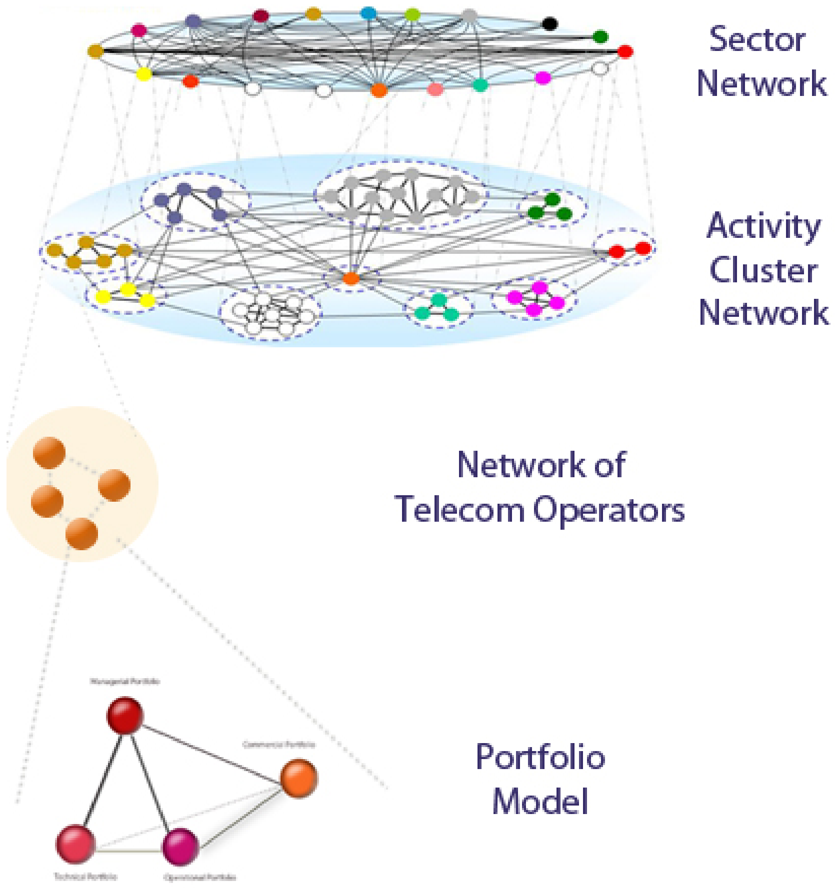

FIGURE 5.1: Hierarchical model depicting the context of this study.

the detailed view of the sector level above. The activity cluster level was investigated in the previous chapter. Consider the communication sector which is a holon on the sector network level. We can open this up to examine its constituents. One of the constituents is the telecommunication activity cluster. The constituents of the telecommunication holon form the third level of the hierarchy depicted. On looking inside the telecommunication holon, we see multiple telecom operators, when viewed from the subject perspective. These operators are holons too. They interact with each other and form a network. On opening up an operator holon, we see that there are multiple activities. There is management, operation, technology and commercialization. This further network inside the operator holon is known as the Portfolio Model, Figure 5.2 [4]. The transport network forms an integral part of the portfolio of a telecom operator.

The portfolio model identifies four discrete entities that make up the portfolio of a telecom operator. First, a Managerial Portfolio, which focusses on the governance of the organization, includes the activities involving legal affairs, regulatory affairs, corporate strategy and human resource management, among others. Second, a Commercial Portfolio that is composed of organizational entities involved in marketing and service

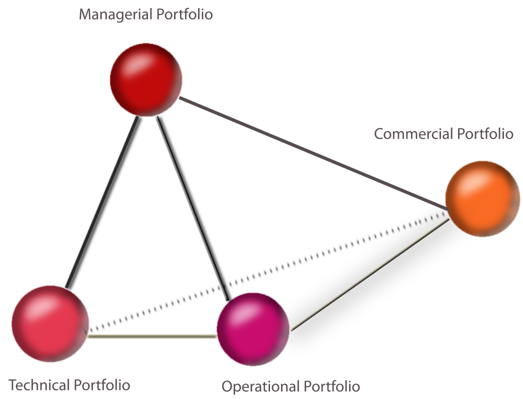

FIGURE 5.2: The Portfolio Model

bundling activities. Third, an Operational Portfolio that is process centric, involving entities that maintain and manage the network, install equipment, plan capacity, etc. And finally, a Technical Portfolio that comprises of the telecom infrastructure in place - this includes the telecom transport network and the expertise of employees.[4].

The portfolio model depicts all the functional units in a Telecommunications organization. It provides a high level view of all the vested interests surrounding the basic function of *transferring* bits. This high level view allows a simplification of the complex scenario. It allows us to identify the functions of each entity and their respective roles in influencing each other. It is therefore well suited for this study.

The proposed model of the Drivers for Network Evolution is complementary to the Portfolio Model. The portfolio model is in accordance with the Holon Model. The telecom transport network, which is a part of the technical portfolio of the Portfolio Model, is one of the tools for the functioning of the telecom holon.

In this part of the thesis, we examine the drivers of change for the telecom transport network alone. We first determine the factors that change in this network and then the factors that drive this change. The study has been made via meetings and discussions with experts.

5.4 Components of Network Evolution

From literature, we know that evolutionary studies describe the development of the object of study over time and identify the elements which generate variation in the population [8]. It has been well established in literature that at an abstract level,

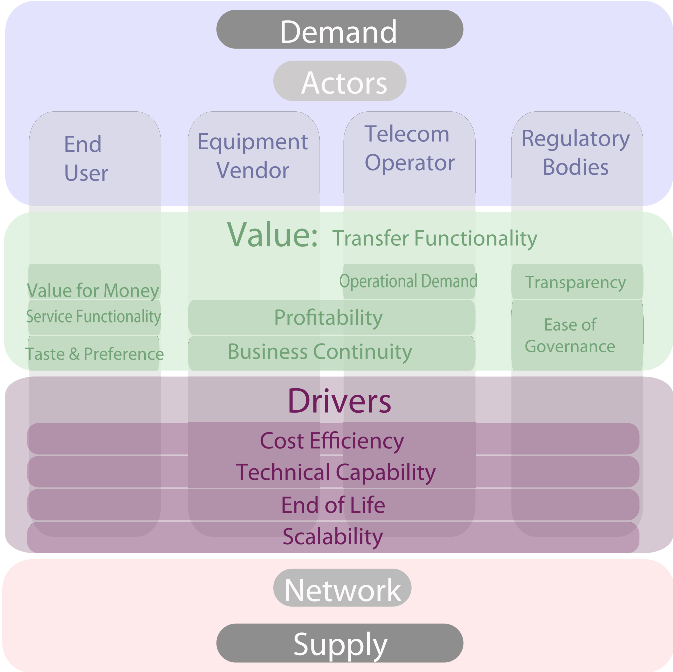

FIGURE 5.3: Model depicting the Drivers of Change in Networks, leading to network evolution.

Darwinistic principles describe evolution in social systems. In essence, then, there is reproduction, leading to a new population - *variation*. Some of these survive, while others do not - *selection*. Selection happens based on certain selection criteria, which may vary from environment to environment. And finally, *inheritance* of customs or regulations. This study is a modest attempt in examining the first two properties for telecom transport networks. The study comprises of an examination of the variation in a generic way and the drivers that enforce selection.

In social institutions, selection criteria manifests itself as demand. The fundamental function of the network is Transfer. The network supplies this functionality to society. This demand for transfer is the value to users since it serves their individual purposes. The supply of transfer capability, to cater to a changing societal demand, manifests itself in the form of the value of the network.

There are multiple sources of societal demand. These are depicted in Figure 5.3. Demands on the network are primarily made by four actors: end users, equipment vendors, the telecom company itself and by Government and regulatory bodies. This is consistent with literature. In the work of Dosi and Nelson [8], the authors state that in social systems "one typically observes a multiplicity of selection environments affecting the probability of growth and survival of each organization...Indeed, it happens in biology and even more so in social dynamics that the objects of selection are not single elementary traits but structures of much higher dimensions in which they are nested."

In the following, we examine some of the demands on the telecom transport networks.

End users are the individuals, businesses and secondary, licensed operators who make use of the network offered by the incumbent (or primary) network owners. They have vested, personal and individual need-based demands from the network. These three types of end users have some common motives but make demands of the network in extents which are unique to each specific type of end user. For example, the individual end user and a small business may have entertainment needs or simply data transfer needs. Their demands are mostly upon service functionality. End users require that their perception of value for money is satisfied. They also demand services that fit in with their tastes and preferences. For a secondary, licensed operator, the demands are slightly different. These operators do not directly own the network. Usually, they are secondary operators, licensed to control a certain portion of the network which is owned by a primary telco. These operators require profitability in their business with an ability to provide the most fashionable capabilities to the end user, according to changing tastes and preferences. The definition of value for money for these operators essentially translates into cost efficiency and business profitability. That is, the cost per bit for the user versus cost incurred by the secondary operator has to prove profitable to the secondary operators. They also have certain technological tastes and preferences. They may prefer a certain technology, just as an individual end user prefers a certain technology. They also have specific technical requests such as the compatibility of switches, platforms, etc. This is a much more detailed and rigorous demand in preference. This is an example where the technological demands of the secondary operator are more extensive than the end user.

All end users require that the network be scalable. End user demands are met by the network in the form of its service functionality. These users need a certain functionality at a cost that they perceive to be cost efficient. If a certain capability offered by the network meets the requirements at an affordable price, at a time when the tastes and preferences of the end users are amenable to it, the volume of instantiations of that capability increases. This increase in instantiations needs to be supported by the network. That is, scalability of the network is required. Also, when a certain capability offered by the secondary operator is profitable and successful, the operator may require the network to be scalable to a larger volume of consumers.

At times, end users demand the continuation of a service that has reached its end of life. Similar to the end user, the secondary operator may also demand certain capabilities to be supported by the network, which may have reached its end of life. The telco, at this point, needs to make a business trade off regarding transition from the old technology platform to a new technology platform that supports the existing capability as is, or in a modified form. These are the key demands made by the individual end users, business consumers and secondary operators on the network, causing the network to evolve.

The second actor in the environment of the network is the equipment vendor. Equipment vendors provide the equipment with which the network is built. Their effect is especially prominent on the End of Life situation in networks. If vendors decide to discontinue a certain technology, the operator is left with no option but to shift to another technology. The vendor's choice of technology inherently affects the scalability, cost efficiency, end of life and technical capability of the network.

The third actor in the Demand scene is the telco itself, who owns the network. The main objective of the telco is to achieve business continuity and profitability. The telco influences the same drivers, cost efficiency (cost per bit), technological capability, scalability and end of life, as is the wholesale operator. The telco, also has to consider operational limitations when designing a network. In an end of life scenario, the telco is forced to migrate from the old system to a new technology. With growing demand, the network has to prove to be scalable. Since new technologies are increasingly more scalable, the scalability and technical capability of the network go hand in hand. Cost efficiency is imperative to maintain profitability.

The fourth actor in the Demand scenario is the Government, taking the form of regulatory bodies. These bodies wish to implement a transparency in operations while maintaining ease of governance. Regulations impact the cost efficiency, technical capability and end of life of technologies for networks. This actor plays an important role in determining the evolution of the network since the rules laid down have legal import.

As seen here, the different actors who make demands on the network have varying higher order motives. Again, this is consistent with literature. In the work of Dosi and Nelson[8], the authors describe how social systems have multi-dimensional selection criteria. They also elucidate that these selection criteria, or, what we refer to in this study as *drivers of change* in transport networks, may be different and possibly conflicting.

To distill the drivers of change then, from the above discussion; we see some recurring factors that seem to drive change in the network. This is proposed as analogous to the second characteristic of evolutionary studies as mentioned by Dosi and Nelson [8]: selection criteria. The fundamental factors that affect change in the network are listed below:

- Cost Efficiency
- Technical Capabilities

- End of Life
- Scalability

These drivers are inter-related. Their relationships are illustrated with examples and arguments below.

As already mentioned, the essence of telecom's function is the transfer of bits. Everything starts and ends with the demand for this functionality. We can conclude then, that there is a fierce drive to evolve to serve increasing demand. At the same time, there is no increase in demand if there is no promise that it can be supported. Demand, then, is an influenced driver. It is, in itself, subject to conditions such as availability of technology and the cost of the technology. This is illustrated in the example of the Video Phone first introduced by AT&T in the 1980s. The technology was available then, but the service was not successful. Today we see the use of video along with telephony. The cost of the service is affordable and the technology exists, a demand is created. Thus cost is related to volume, volume to demand and demand to cost in a cycle. If all the forces in this chain come forward, then, a technology service becomes viable to the customer.

This cycle is broken by technologies such as GSM. Such killer applications gave consumers increased accessibility and ease of use. Initially, GSM too was affordable only to an elite set of users. With technological progress, the cost of use decreased, bringing it closer to a larger audience.

Other factors which also influence the technical capability of the telecom sector include the end of life of technologies, changes in the ownership of resources, changes in network management capabilities, etc. In an end of life scenario, the network developed based on a certain technology is phased out. This could be caused by several factors. One, a certain technology may be set up for a particular service which is not in much demand. Telcos cannot afford to allow under-usage of infrastructure as this would lead to a low ROI. Two, a certain technology may not be supported anymore by a manufacturer. Three, a certain technology may not be able to meet the demands of volume or Quality of Service, in which case it may need to be replaced by a better technology. Once a platform or a network has reached its end of life, the operator has no choice but to replace it with a current platform or network technology. Thus, end of life is a significant driver in the evolution of networks.

The increasing demands of society result in a need for scalability. A technology which does not support easy scalability is less preferred by the network owner than an easily scalable one. With this increasing demand for scalability, new innovations and inventions result in technological change. That is, often technical capability and scalability go hand in hand.

The above mentioned drivers illustrate only a part of the forces acting on a network. Other drivers too play an important role in the evolution of the network over time. Cost of management or maintenance, cost of operations or operational limitations often play a decisive role in the introduction of new platforms, technologies and network capabilities. If cost of operation is too high or the existing operational portfolio cannot support a certain new addition to the network, at a reasonable cost, then the change may not be introduced in the network.

Different situations will result in different drivers playing a more emphatic role in network evolution.

The demand on the service functionality offered by the network can take the form of demand on:

- Connection Type
- Type of Data
- Volume of Data
- Reach
- Quality of Service

All of the four different actors in the demand scenario make different extents of these above types of demand. The end user demands are different from the demands of a large organization such as a bank, whose demands are again different from the needs of Mobile Virtual Network Operator (MVNO) or Value Added Service (VAS) providers. For instance, where an end user wants certain specific capabilities with a certain level of security at a certain speed in a certain specific location, to establish communication, a secondary service provider wants the same functions, types of data transfer, volume capacity and reach at a much larger level. This isomorphism in the demands and drivers, with varying extents of influence each, brings out the plurality of the Holon Model and elucidates how the Holon Model can act as a blueprint for the telecom transport network.

Transport Network Evolution Study

In this section, a schematic overview of the evolution of the telecom transport network over the past 21 years is presented, viewed in the perspective described in previous section. The following is a distilled version of the information gathered, designed to bring into perspective, the rationale behind the findings of the study.

Ten years ago, the Public Switched Telephony Network (PSTN) and Synchronous Digital Hierarchy (SDH) constituted almost the entire telecom network. These were voice services. Over the past ten years, data has been added to the voice centric network. PSTN has morphed into a Next Generation Network (NGN). In terms of the transport network, we went from SDH to SDH plus packet transport. Copper has been enhanced with DSL technologies to support data traffic. Coax got an upgrade with DOCSIS. Bandwidths went up to 64 kbps, but remained less than 100 kbps. Now, networks are moving towards FTTH and Fast Internet with real broadband capabilities, greater than 100 Mbps. This allows fast streaming video and more moving parts. When we study the demand for video components between eight and ten at night, we notice a large surge. This puts a high demand on the resources. To serve this demand, we need higher bandwidth in the core. This is because of the presence of the content in the core. We also need more bandwidth in the core, which then requires fibre in the core.

There are changes observed in the type of data in demand over time. Data went from predominantly voice, to data, to predominantly video. The factor of increase in bandwidth in the transition from voice to data is smaller than the factor of increase in bandwidth in the transition from data to video. This plays a determining role in introducing change in the network. In the predominantly PSTN and SDH era, high levels of statistical multiplexing were used to satisfy the demand for bandwidth. In PSTN, resources were held for users for a fixed period of time. This is not possible to sustain.

Limitations faced when this change occurred are listed below:

- Use existing infrastructure, spread assets - leading to the introduction of a new layer in network.
- Resource limitations - leading to change in resource layer.
- Adaptation to new layer - leading to change in resource layer.

Thus, ideally, cost efficiency, technological capability and demand have to come together simultaneously for a network service to be successful in a market. Increasingly, in the current situation of the network, machine interactions are taking place over the network. Man-machine as well as machine-machine interactions will be a new dimension in the network and may place different types of demands upon it altogether.

Over the past ten years, there has been a huge resource changes from copper to optical fibre. When initially introduced in the '90s, SDH was installed directly on fibre. On the other hand, Plesiochronous Digital Hierarchy (PDH) service was started on copper and moved on to fibre. PDH 2Mb, 8Mb were all on copper twisted pair. The PDH 34 Mb of the early '80s was on fibre as was the 140 Mb and 565 Mb. There does exist an electrical version of SDH which is even lower in cost but it's usually used for internal networks such as within an organization. Today, operators plan to introduce Glass Boxes, which are more in number than the 1300 end offices but less than the number of existing street cabinets. This action is expected in addition to complete copper replacement. The fibre network opens the road into the future since the capacity of copper stops somewhere.

Increasing data rates over copper infrastructure intended for voice was made possible by advanced encoding technologies. The early fibre technologies started by using Synchronous Transport Module (STM) 1/4/16/64 etc. Today, the core network has been using fibre for about fifteen years and the metro has been using fibre in the last phase, with SDH in fibre.

Since fibre started with 100Mbps to 1Gbps, this smart encoding layer was unnecessary. Encoding techniques previously used on copper are appearing today on the optical high speed networks to get higher and higher bit rates on the core side of the network. The same techniques are also used on the wireless networks, to go beyond what they can provide so far. Wireless operators wish to stretch upto 1-2Gbps on the micro wave link. When the 10Gbps bandwidth was encountered, there were technical difficulties with transporting the signal through the fibre. There was a 10Gbps optical problem and the fibre couldn't transport the wavelength. AT&T and others tried to fix this by using multiple channels of lower wavelength, such as Nx2.5Gbps. Nortel found a solution to get 10Gbps over the fibre first. Later, different types of fibres supporting this wavelength were found. But Nortel already had a market lead and created a hype for fibre. Around 2000, 40Gbps was developed because of cost of optical transmitters and receivers for 10Gbps was higher. It was also found that 100Gbps over some fibres is easier to transport than 40Gbps. But the cost of 100 Gbps components was greater than four times the cost of 40 Gbps components. In the year 2000, Optical Transport Network discussions were initiated for fibre transport. By 2001, The first Recommendation for the NNI was approved. In 2002, the second Recommendation and in 2003, the third Recommendation was produced. After this, there was a quiet period where minimal activity took place on OTN. The hype cycle had reached it's low. In the quiet period, some limited OAM was implemented. During this time, there were even doubts regarding bandwidth demand. Question were asked if in fact, there was a large bandwidth demand, let alone a growing one.

Around 2008, with the large scale demand for both Web Video and VOD, it was confirmed that there is a greater and increasing demand for bandwidth. This was reflected by the growing number of wavelengths used. Thus, switched OTN was introduced which could deal with a large number of wavelengths.

As we can see, the factors of resource limitations, monetary efficiency and nature of the data transported, have played a critical role in shaping the evolution of the fibre network. The low cost of copper and high cost per use of fibre has supported the sustained use of copper. Advances in electrical technology to get high speed on copper has helped its cause tremendously. The electrical version of Gigabyte Ethernet, for example, is the most used for interconnect technologies. Generally, the rule of thumb for pricing is that 4xBandwidth corresponds to 2.5xPrice. But when we use fibre for Gigabit Ethernet, it turned out to be 5xPrice. Thus, Fast Ethernet, Gigabit Ethernet and 10Gig Ethernet are all implemented on copper today for the end user due to low cost compared to fibre implementation.

Network Design Dilemmas: Relations between Network Change and the Drivers for it

In this section, are listed some of the network design considerations. This includes the demands, limitations and choices faced by network architects when designing the network. This illustrates some of the drivers of change that act on the network and their resulting changes. This is a concise version of some of the information gathered from expert interviews.

- When a new technology is introduced, a new technological layer is introduced in the existing network. In this layer, we implement the new technology and adapt it to existing technologies. Existing technologies and infrastructure is used to encapsulate and carry the information of the new technology layer. There is no direct replacement of any existing layer. This is because of the long time for ROI (around 20 years) on telecom infrastructure. Also, new technologies have to be tested and perfected before investing in a parallel, dedicated infrastructure for them. The fundamental idea is to spread the assets. **Cost efficiency: driver of change.**
- To allow support of the new Technologies by the old infrastructure, the higher layer and lower layer data has to be formatted in a way compatible with the new layer. New Connection Paths (CP) implementing adaptation, encapsulation/de-capsulation function, multiplexing, labelling and encoding/decoding functions are introduced above and below the new layer. *Change in layering* to achieve **cost efficiency**

- Soon, convergence between these technologies is needed. Today, the trend is towards convergence on one technology again. The telecom network began as a single technology network. When the packet network got optimized, under the IP layer, different technologies were used. SDH, frame relay, ATM and now Ethernet MPLS are used under IP. Why do we find a need for converging? Convergence is required to facilitate volume growth. Initially, a large number of subscribers joined the internet. Each took increasingly more bandwidth. Now attemps at volume optimization are being made and the more recent technologies make the most value for volume. The volume, users and usage per user is increasing. So to overcome technology capability limitations and to implement cost effectiveness, convergence is needed. **Societal demand and cost efficiency** act as drivers of change here.

- SDH was designed with the voice network in mind. Frame relay was designed for packet as well as data networks, allowing for the incorporation of both packet switching and circuit switching technologies. So it was better suited for a packet switched network than SDH. Both of these were encapsulated in existing infrastructure. With the advent of ATM and Ethernet, the direction is increasingly towards a packet switched (cost effective), optical transport network. Again here, there is a *Change in the network layering* to achieve **cost efficiency**

- Networks are started small and allowed to grow with the number of customers. This is because the setup of a transport network involves a large amount of initial investment. If a new format becomes popular, for example, the way Ethernet became popular, a new infrastructure needs to be built for it. This makes costs of operation very high. Operators will be forced to give away more for less cost or counter problems with new technology discovered. *Topology change* to accomodate **cost efficiency** is reflected here.

- In the case of Supervised Peer-to-Peer Overlay Networks (SPON), the network became tough to maintain since there were very few subscribers. One solution is to increase the capacity of each Optical Line Terminal (OLT), moving the chunk of the capacity to core. This way, the metro equipment becomes more passive, involving less switching, and operates more like reach extenders. *Change in capacity* lead to change in **cost efficiency** which in turn lead to *Change in topological location of functions.*

- Today, operators want to get rid of Tier one offices (Metro access offices). To do this, they need to get rid of underlying infrastructure such as copper wires since they run through the building. *Change in geographical location of functions* due to requirements of **cost efficiency**.

- In the transport network architecture, a large multi wavelength core is broken up into multiple smaller OTUs. These may be divided up further into higher order ODUs and lower order OTUs. OTUs may be further divided into MPLS Label Switched Paths (LSP) and VLANs or MPLS PseudoWires. From 2005-2010, 40Gbps Ethernet was implemented over STM256 running under OTN3. The next step now is the use of ODU4 over OTU4 to carry 100 Gigabit ethernet and a multiplex of lower order ODUs, or to implement 2x40 Gigabit ethernet. In the future, a 400 Gbps or a 1 Terabit per second ODU5 or OTU5 is envisioned to carry a future 400 Gbps or 1 Tbps ethernet. Here, *Topology* decisions are made on the basis of **cost efficiency**. Operators want to get maximum efficiency out of each wavelength used. This is subject to the slot capacity of transport systems. This is the factor of **technology capability**.

- A switch essentially has multiple slots of different capacity each. There are a limited number of ports and slots on a rack. This is a limitation of **Technology Capability.** Each connection in the network, depending on the required capacity, is instantiated differently. The rates of switching between connections has an effect on the efficiency of the technology being used. These switching rates, also called backplane rates, play a crucial role in determining if a new technology can be supported efficiently or not. Backplane signals are multiwire connections (16 parallel wires) and have one to one association with the rate of transmission. Backplane rates are dependant on the integration density of the silicon processors. The developments in the silicon technology allow us to get the increased bandwidth using the same volume of space occupied by the switch as previous generation technology. This is expected to be around 4xBandwidth increase each 3 years. If newer, high demand higher layer services are directly mapped onto resources, scalability issues arise. Thus, scalability of a network is subject to **technology capability**.

- Solution to the scalability issue: A network has at least two layers: a resource layer and a service layer. This is the minimum configuration. By introducing a multiplexing layer, also called a tunnel layer, in between, we can map services to a tunnel and a tunnel to a resource. The multiplexing layer is essentially a path layer between the service supporting layer and the transmission media layer. This addresses the scalability issue by allowing flexibility of resource allocation. The service layer of one layer will be the tunnel of a higher layer. If the service supporting layer, for instance, has one million services. The transmission media layer does increasingly stronger encoding to allow faster bit rates over copper wire. Thus, the solution to the scalability issue is subject to **Technology Capability**. It is important to notice here that service switching and tunnel switching will reflect in the resource layer where the actual hardware reside. For instance, if a 0.5Gbps service is mapped onto a 20Gbps port, resource is wasted. So, a cable is used to connect the two different capacity racks of 0.5Gbps and 20Gbps, allowing efficient resource allocation. This changes the resource layer.

- But how is the path layer to be implemented in the network? In a network there are boxes interconnected by fibre. These boxes may be Service aware or Path aware. At the edges of the network, the boxes are service aware. At the core, they are Path aware. In the core, only LSPs are used for routing purposes and not on the IP streams per se. This allows scalability. It saves memory and resources and makes the network financially viable since it requires less investment. It also makes the network *faster* and allows for a better *Quality of Service.*

- Limitations of resources, for example, faced during transition from voice to data instigates change in the network resource layer. Data had to be transferred over existing voice channels. This was possible over phone lines. But simultaneous voice and data was not possible. So, a splitter was introduced at the user end that splits the channel into two frequency separated channels - one carrying voice and the other data. Now the first channel connects to the PSTN switching technology cloud, while the second connects to the packet switching IP cloud. Here there is a *Change in capacity*, a *change in the format of information* and a *change in topology* due to **social demands** and **technological capabilities**.

- As the number of services increases, administration problems are encountered. Port allocation problems, for instance, are typically of an operational limitation situation. This example reflects the influence of **operations demand** on the resource layer.

- Another factor that influences evolution of resource technology is Power. The same volume of switch space used in the 1990s for 450 Mb capacity network is now used for a 256 Terabyte (Cisco's latest switch announced) capacity network in 2010. This has been enabled by enhanced **technology capability**.

- Evolution is reflected in the presence of network intelligence and moving of intelligence into the network. Voice switching was first done manually by operators. Soon, to provide **Quality of Service** and to maintain **cost efficiency**, this intelligence was moved into the network. The *network intelligence* grew. The PSTN switches had switching intelligence and customer records. But these functions were soon moved upwards into the network. There was a *topological as well as geographical change in the location of functions.* This is subject, also to **technology capability**.

- The presence of video in the core puts a high demand on large core bandwidth. Should the content be placed closer to the user, the required bandwidth at core will reduce, but there will be an increase in the OPEX, since maintenance is expensive. Also, manpower price is increasing while bandwidth price is decreasing. This was a design dilemma. **Cost Efficiency** affects the *topological and geographical location of functions* in the network.

Network Changes

An examination of the information presented above reveals the elements of the network that change over time. One, the geographical reach or footprint of the network has changed. With increasing acceptance and demand for some network functionalities, and with phasing out of some others, the geographical reach of the network increases, or decreases, respectively. Two, the access types supported by the network has changed over time. Access types refer to the possibility of establishing both wireless and wired connections. Three, the format of information the network is capable of carrying has changed over time. Initially, voice was the main type of information the network was designed to support. With increasing demand for data, support for packet transport became imperative. Today, the demand for video is on the rise. It is expected that in the future, machine interactions will pose further new requirements of the network. Four, with the new types of data and service functionality, the connection types supported by the network has changed. Point to point connection based services have been enhanced with capability for multi-point to point connections, for instance. Simultaneously, five, the quality of service offered by the network has changed over time. It is now possible to have very high quality connections as well as best effort connections and intermediate level service guarantees. Six, as one of the results of the plethora of technological options for implementing the network, the robustness of the network has changed over time. Where there is a very dense network today, aiding robustness, it is possible to have best effort service, which does not guarantee a reserved resource for a connection, allowing possibility for failure.

Seven, with this increasing demand for network functionalities, the bandwidth capacity of the network has risen. It has been met by the use of increasingly complex multiplexing algorithms and newer transport technologies. Simulataneously, eight, the density of the network has changed. This, of course, is not only synchronous with the demand for some network functionalities but also with the phasing out of others. Also as a result of these phenomena, is the change in the network topology, which is the ninth element of network change. Change in topology is accompanied by, ten, network layering changes. With the continuous introduction and removal of network layers (to introduce or remove a network functionality and/or a network technology), eleven, the addressing systems used in the network has shows changes. This is subject to the operational and administrative management that runs the network. At key points in the evolution of networks, the operational and administrative management system has also had to morph. This is the twelfth network property that changed over time.

Thirteen, the partitioning of network domains has been dynamic in nature. This is subject to ownership and regulation issues. Fourteen, to satisfy all the demands made on the network, the technology in hardware and software used to implement the network changed over time. Today, with the focus on sustainable energy solutions, the energy consumption of the network is coming into focus in the design of hardware systems. This is the fifteenth element of change in the network. The geographical location and topological location of functions in the network have changed with changes in technology, requirement for quality of service and number of connection instantiation in the network. The two types of change in the location of network functions are the sixteenth and seventeenth elements of change in the network. For much the same reason as the movement of network functional location, the presence or absence of content in the network has also changed, eighteen. As a result of increasing content and capability within the network, the extent of network intelligence has changed over time. This is the nineteenth identified element of change in networks.

5.5 Valorization

Evolution strives toward fulfilling the needs of the environment around an actor. The demands made by the environment on the sector network, as is the nature of every environment on an actor, are increasingly complex in nature.

To meet the demands by the environment around the sector network, we need to create more variation in the network. This stimulates the selection process. Towards this end, the Smart Home is envisioned as a place where multiple players come together and interact in a trusted environment. In this way, the Smart Home can catalyze the evolution of the sector network and the innovation processes therein enabling Smart Living.

So far, the transport network has remained at the transfer-only functionality level. In light of the needs of the smart home concept, this needs to transcend to meet further complexity such as incorporating new features and sniffing the right transactions [7].

Chapter 6

Conclusions

The objective of the study is to examine the evolution of networks. The motive behind this is to lay a foundation for evaluating these networks in the face of the trans-sector innovation process. Two networks are studied, the sector network of The Netherlands and the telecom transport network. Since both these networks show a hierarchical nature, have entities on multiple layers that communicate with each other, and have a need for an intrisic, detailed view as well as a holistic system view, both the networks reflect the holon model. Both networks have also been evolving over time. From literature, a study of evolution should have two elements necessarily. One, a study of the actual change over time of a particular system; and two, an explanation of what creates this change. This study tries to incorporate these components.

It is found in literature that darwinistic principles are followed in the evolution of social systems at a fundamental level, though these principles may be insufficient in explaining the evolution in detail, comprehensively, for all systems that exist. The systems described involve social rules, regulations, etc. The descriptions of the systems is found to match the two networks under study. Accordingly, the networks exist in an environment. This environment tends to have a scarcity of resources. The environment makes demands on the networks and the networks make demands back on the environment. In this study, we constrain ourselves to the influence of the environment on the network.

The network, like the social system in literature evolves to meet the demand in the environment. Out of multiple possible forms (variety), it takes one particular form. By definition, innovation is a means of creating variety. Whereas selection is the *mechanism that ensures the survival of some variations rather than others,* which operates because of the scarcity of resources present in the environment. Selection processes occur on the existing variety and that system which supplies the demands of the environment in the optimal way, survives. Thus, evolution translates into a process of matching supply and demand. Literature states that social systems typically have multiple sources of demands and these may be possibly contradictory in nature. This effect is seen in our results.

Initiating the examination of the networks, it is found that there is first a need to characterize and understand the sector network before evaluating its evolution. Towards this end, a model is proposed wherein the nature of the network is evaluated over time by three separate measures. This four dimensional model is applied to data about the network over twenty one years, thereby extending it to four dimensions. This study resulted in the creation of a paper, due to be submitted for publication in 2010.

In the study, we observe that approximately ninety per cent of the total economic transactions (of euros) each year and over 21 years, are transactions between activity clusters and only ten per cent are internal transactions. We conclude from this that the majority of the transactions in each year are between activity clusters.

We also observe in our study that nodes (activity clusters) do not show any marked preference for other nodes in terms of degree. In the network, nodes connect to other nodes which have low degree as well as other nodes which have higher degree. This is coincident with the nature of social networks.

The link weight distribution and node weight distribution of the network, both display power law behaviour. This is also coincident with the nature of social networks. Therefore, our network of activity clusters shows properties similar to that of social networks.

The activity cluster network is disassortative in degree and node weight, but assortative in node strength. Nodes and links tend to show assortative behaviour in relationship to each other. That is, nodes show no preference to connect with nodes of similar degree. Nodes connect to other nodes irrespective of high, low or equal degree. This may well be a consequence of the empirical nature of the network. Nodes also do not show any clear preference for other nodes of similar node strength. This may be a result of the fact that there are multiple hubs in the network, to which many nodes of low node weight connect. Node strength is assortative, indicating that nodes show a marked preference to transact with other nodes that have similar node strength. Assortative nature between degree and node strength indicate that an activity cluster having a high number of transactions with other clusters tend to exchange a large amount of money in these co-operations. Assortative nature between degree and node weight of nodes indicates that activity clusters that have a greater number of transactions tend to have a larger internal euro flow. Figure 6.1 depicts these relationships.

It is observed that there has been an increase in the number of undirected links over the years. Simultaneously, the amount of money in transactions has increased. It is also

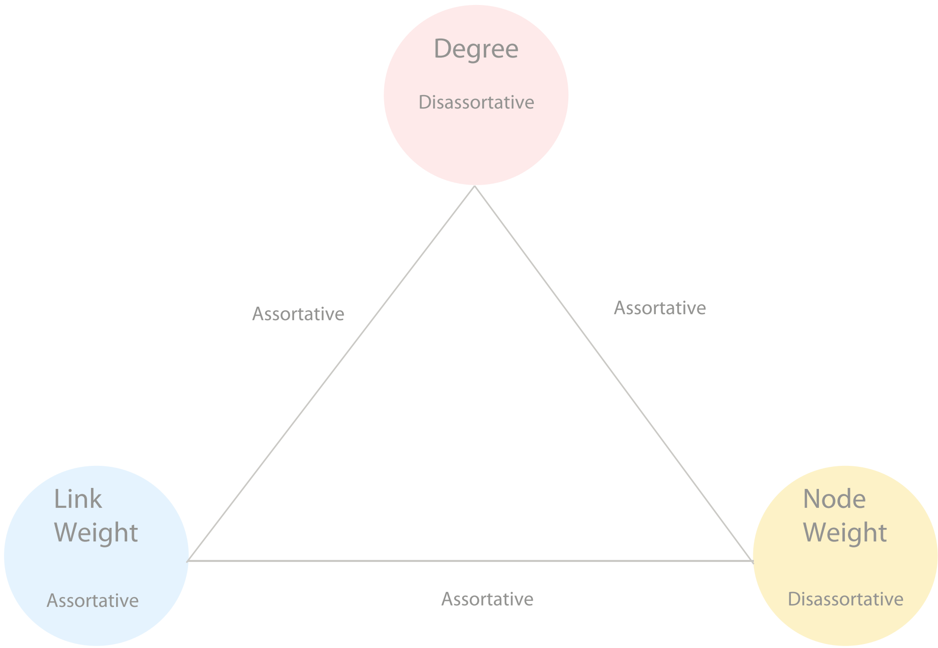

FIGURE 6.1: Transactions nature of the network.

observed that the link weight around a node is increasingly equal over the twenty one years (despite being inflation accounted). This observation indicates that activity clusters are spreading out transaction amounts more equally among their neighbours. That is, activity clusters transact increasingly equal amounts of euro in all their transactions rather than transacting only high values with a preferred, small group of partners.

The above observations also support the theory of innovation proposed by C.K.Prahalad and M.S.Krishnan [30]. The theory states that innovation is motivated by a globalization of resources. To innovate, say the authors, organizations only need *access to resources* and not *ownership*. They claim that organizations with a highly vertical structures are increasingly becoming obsolete. Organizations are now choosing to outsource to a large extent and retain only access to, not ownership of, resources. These resources are now global. Prahalad and Krishnan [30] state that this disintegration of the vertical stovepipe and the globalization of resources is a prime source of innovation.

The observations here are twofold. One, with globalization of resources, there is an increase in the probability of access to resources. Since selection takes place under scarcity of resources, when there is an enhanced accesibility of resources, there is creation of more variety. This holds true for the sector network and the transport network. It addresses the scarcity faced by the system in the environment. Two, interaction translates into a larger number of variations that are created, thereby increasing the chances of successful survival.

Innovation, then, is a means to increase the chances of survival. Since trans-sector innovation supports this possibility, an atmosphere that fosters such innovation is now required to implement the same. The Smart Home environment is envisioned as this atmosphere. As observed too in the study of the sector network data, the household sector is the prime hub in the sector network. Thus, it is likely to become the major inflection point in the twenty first century. The many possibilities of the Smart Home could prove to be a catalyst in fostering the trans-sector innovation process.

Next, the telecom transport network is examined. First, It is found that at a fundamental level, the transport network follows the principle of supply and demand in evolution. This closely reflects the basic darwinian principles, which is true of the evolution mechanism of social systems. There are several possible architectures for networks, this is *variety.* The environment around the network makes some demands from the network, this is *selection.* The design process ensures that the most optimum solution is chosen, keeping in mind the demands of the environment,*supply.* In short, *There is a demand made on the network, which is a selection process for its survival. The network satisfies this demand to offer a certain functionality, as supply. As the demands from the network's environment change, so does the nature of the network. At a basic level, the network follows darwinistic principles.* Second, like the evolution of social systems, our network too has multiple actors in the environment around it, making demands of it. Thirdly, some of these demands, like the ones on social systems, can be opposing in nature. Therefore, our system follows in some trends, the evolution of social systems.

Finally, a driver model is proposed that elucidates the demands made upon the telecom transport network by the environment around it. This model only depicts the drivers of change that are motivated *by the environment, on the network.* Knowing that the network can also have effects on its environment and the actors therein, there is every chance that there are influenced drivers in the environment. This would require a seperate and more detailed study.

6.1 Recommendations

1. In light of the study of the sector network, several future possibilities exist.

    (a) It is interesting to examine the data from the national accounts department of other countries to check for similarities and to examine the network, retaining the directional nature of the links completely.

(b) An examination of the nature of the network by looking at the inverse of the topology; that is, by analyzing the links which do not exist, may yield properties so far unnoticed. This may allow insight into the character of the network.

(c) It is also possible to apply existing clustering algorithms at the aggregation level of activity clusters, to check the yielding higher level network. This network may or may not tally with the sector network as defined by the Statistics Netherlands. The extent to which it does or does not tally, would reflect on the method of classification of activity clusters into networks. Therefore, this will prove insightful in the design of a methodology to classify national activity.

2. Several interesting future questions arise in the domain of the telecom transport network also.

   (a) The proposed driver model for change in telecom networks is not claimed to be entirely complete. Primarily, of course, the influence of the network itself on the environment could be examined. An interesting cycle of influenced demand and supply may emerge, completing the picture of evolution of networks.

   (b) A very interesting and promising future study would involve the isomorphism of the driver model. An examination of the applicability of this model to other systems in other sectors would valorize an isomorphic nature. Some of the underlying principles in the network may prove transferrable to other sectors.

   (c) As seen in this study, the changing demands on the network, may be on the quanitity (number of instantiation in the context of the network) or the quality (service functionality in the context of the network). But sometimes, the demand on quantity may prove so large that a qualitative change would be required. This then poses the question, how far do quantitative demands translate into qualitative ones? How does this drive change in a network?

   (d) Also, there may exist other less important drivers of change in the network that have not surfaced in this study. A more detailed examination of the changes in the network and their drivers may reflect these missed out factors.

   (e) It is interesting to study how the property of inheritance may be depicted by network evolution. For instance, it may prove insightful to examine the methods of of technological research based organizations on the changes in the network. Are principles in these fields retained in the design of technology for new networks, may be a question to be answered.

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Appendix A. List of 105 Activity Clusters

Node Number	Node Name (Translated from the Input Output table, Statistics Netherlands)
1	growing crop outdoor
2	greenhouses
3	animal production
4	other agriculture
5	gardening and agriculture specific services
6	forestry and hunting
7	fishing and aquaculture
8	extraction of oil and natural gas
9	mining other resources
10	processing and preserving meat
11	processing and preserving fish, crustaceans and mollucs
12	processing and preserving of fruit and vegetables
13	manufacure of dairy products
14	manufacture of prepared animal feeds
15	manufacture of other food products n.e.c.
16	manufacture of coffee and tea
17	manufacture of beverages
18	manufacture of tobacco products
19	manufacture of textiles
20	manufacture of confection
21	manufacture of leather and related products
22	manufacture of wood, cork and plaiting materials
23	manufacture of pulp, paper and paperboard
24	manufacture of corrugated paper,paperboard &containers of paper and paperboard
25	publishing and printing
26	reproduction of recorded media
27	processing of coke and refined petroleum products
28	manufacture of basic chemicals
29	manufacture of anorganic chemical products
30	manufacture of refined petroleum products
31	manufacture of fertilisers and nitrogen products
32	manufacture of chemical end products
33	manufacture of rubber, synthetic rubber and plastic products
34	manufacture of construction materials
35	manufacture of basic metals
36	manufacture metal products
37	manufacture of machinary and equipment
38	manufacture of household related machinary and equipment
39	manufacture office machinary and computers
40	manufacture of other electrical machinary and equipment
41	manufacture of audio, video and telecommunications equipment
42	manufacture of medical, measure and control equipment
43	manufacture of motor vehicles
44	manufacture of ships
45	manufacture of railway, aircraft and aerospace related vehicles
46	manufacture other transport means
47	manufacture of furniture
48	other manufacture of goods n.e.c.
49	recycling preparation
50	electricity, gas, steam and air conditioning supply
51	water collection and distribution
52	preparing building sites

Node Number	Node Name (Translated from the Input Output table, Statistics Netherlands)
53	civil utilities construction
54	ground, water and road construction
55	construction installation
56	finalising building construction
57	renting construction machines
58	motor vehicles wholesale trade
59	motor vehicles retail trade
60	car service and gas stations
61	wholesale trade
62	retail trade
63	accommodation and food service activities
64	public transport
65	transport of goods
66	transport via pipelines
67	sea transport
68	river transport
69	air transport
70	services for land transport
71	services for water transport
72	services for air transport
73	travel agencies
74	post and telecommunications
75	banking
76	insurance
77	financial support companies
78	real estate exploitation
79	other real estate
80	renting mobile goods
81	computer services
82	research
83	legal consultancy
84	engineers and architects
85	advertisement and promotion companies
86	labour recruitment and provisional of personnel
87	cleaning of buildings
88	other business services
89	common central government administration
90	common decentral government administration and municipalities
91	other government administration and social insurances
92	defence
93	primary education
94	secondary education
95	tertiary education
96	medical services
97	care for well-being
98	private companies environmental care
99	governmental environmental care
100	culture, sports, recreation, radio and television
101	gambling
102	other services
103	household services
104	goods and services n.e.c.
105	household

Appendix B. Source Code

```
% Program to computer parameters:

alldegree=zeros(105,21);
allnw=zeros(105,21);
allns=zeros(105,21);
allalw=zeros(105,21);
sum_lw_around_node=zeros(105,21);

alltotaldeg=zeros(21,1);
%the above does not include self loops.
yeardata_diag=zeros(105,105);
yeardata_nodiag=zeros(105,105);
Name1='.xls';

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    yeardata_diag = xlsread(Name);
    yeardata_nodiag=xlsread(Name);
    r = k-1986;
    sigma_all=0;

    % calculating sigma_w = sigma_all
        for i=1:105
            sigma_all=sigma_all+yeardata_diag(i,i);

            for j=1:105
                sigma_all=sigma_all+yeardata_diag(i,j);
            end

        end
        sigma_all

    % removing diagonal elements
    for i=1:105
        for j=1:105
            if(i==j)
                yeardata_nodiag(i,j)=0;
            end
        end
    end
```

```
    % calculating degree
        for i=1:105
            for j=1:i
                if((yeardata_nodiag(i,j)~=0)|(yeardata_nodiag(j,i)~=0))
                    alldegree(i,r)=alldegree(i,r)+1;
                    alldegree(j,r)=alldegree(j,r)+1;
                    sum_lw_around_node(i,r)=sum_lw_around_node(i,r)+yeardata_nodiag(i,j)+yeardat
                    sum_lw_around_node(j,r)=sum_lw_around_node(j,r)+yeardata_nodiag(i,j)+yeardat
                    allns(i,r)=allns(i,r)+yeardata_nodiag(i,j)+yeardata_nodiag(j,i);
                    allns(j,r)=allns(j,r)+yeardata_nodiag(i,j)+yeardata_nodiag(j,i);
                end

            end

        end
     % normalizing node strength
     for i=1:105
         allns(i,r)=allns(i,r)/sigma_all;
     end
     % calculating total number of connections in each year

        for i=i:105
            alltotaldeg(r)=alltotaldeg(r)+alldegree(i,r);
        end

     % calculating average link weight around a node
        for i=1:105
            for j=1:105
                if(alldegree(i,r)~=0)
                    allalw(i,r)=sum_lw_around_node(i,r)/alldegree(i,r);
                else
                    allalw(i,r)=sum_lw_around_node(i,r);
                end
            end
        end

     % calculating node weights
        for i=1:105
           allnw(i,r)=yeardata_diag(i,i)/sigma_all;
        end

%       % calculating node strength
%          for i=1:105
%              for j=1:105
%                  allns(i,r)=allns(i,r)+yeardata_nodiag(i,j)+yeardata_nodiag(j,i);
%              end
%              allns(i,r)=(allns(i,r))/sigma_all;
%          end

end


-----
%Program to examine the degree distribution of network
```

```
deg_trial=zeros(1,1155);
r=1;

for i=1:105
    for j=1:21
        deg_trial(1,r)=alldegree(i,j);
        r=r+1;
    end
end
 max(deg_trial)
[n_deg,xout_deg]=hist(deg_trial,105);

figure()
plot (xout_deg,n_deg,'m+')
title('Probability Distribution of Degree')
xlabel('degree k')
ylabel('Pr[D=k]')

k=zeros(1,105);
r=0;

cc=colormap(jet(21));

for i=1:21
    k(1,:)= k(1,:)+hist(alldegree(:,i),105)
    hold on
    stem(k(1,:),'Marker','+','Color',cc(i,:));
end
hold off

title('Distribution - Degree')
xlabel('bin number')
ylabel('frequency of occurance')
colormap

-----

%Calculating Node Strength

ns_trial=zeros(1,2205);
r=1;
m=0;

for i=1:105
    for j=1:10
        ns_trial(1,r)=allns(i,j);
        r=r+1;
        if(m<allns(i,j))
            m=allns(i,j);
        end
    end
end

m
```

```
[n_ns,xout_ns]=hist(ns_trial,64)

% figure()
% bar(xout_ns,n_ns)

k=zeros(1,64);
for i=1:64
    k(i)= (i-1)*0.0062+0.0062;
end
p_ns = n_ns/(0.0062*105*21);

figure()
plot(k,p_ns,'--','marker','o')
title('Probability Distribution of Node Strength over 21 years')
xlabel('Node Strength')
ylabel('Probability of Node Strength')

-----

%Calculating Node Weight

nw_trial=zeros(1,2205);
r=1;
m=0;
slopes=zeros(1,2);

for i=1:105
    for j=1:10
        nw_trial(1,r)=allnw(i,j);
        r=r+1;
        if(m<allns(i,j))
            m=allns(i,j);
        end
    end
end

[n_nw,xout_nw]=hist(nw_trial,32)
r=zeros(1,32);
for i=1:32
    r(i)= (i-1)*0.0003+0.0003;
end

% X=[[1:32]' ones(32,1)];
% y=log(p_nw);
% x=1:length(y);
% Y=y'
% slope(1,:) = inv(X'*X)*X'*Y;
% yref=slope(1,1)*x+slope(1,2)

figure()
bar(xout_nw,n_nw)

p_nw = n_nw/(0.0003*105*21);
figure()
plot(r,p_nw,'--','marker','o')
```

```
% hold on
% plot(x,yref);
title('Probability Distribution of Node Weight over 21 years')
xlabel('Node Weight')
ylabel('Probability of Node Weight')
hold off

-----

% Calculation of  Node Strength as well as the Assortativity of Degree.

Name1='.xls';
deg_ass=zeros(1,21);
allns2=zeros(105,21);
r=0;

for i=1:21
    for j=1:105
        allns2(j,i)=allns(j,i)/alldegree(j,i);
    end
end


for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    excel_year=xlsread(Name);
    r = k-1986;
    l=0;

    % removing diagonal elements
    for i=1:105
        for j=1:105
            if(i==j)
                excel_year(i,j)=0;
            end
        end
    end

    % declaring temporary variables
    avg_deg_prod=0;
    avg_deg_sum=0;
    avg_deg_sum_sq=0;

    % calculating assortativity. step 1 = find the total sum, product, sum of squares, etc
    for i=1:105
        for j=1:i
            if((excel_year(i,j)~=0)|(excel_year(j,i)~=0))

                l=l+1;

                avg_deg_prod   = avg_deg_prod + (alldegree(i,r)*alldegree(j,r));

                avg_deg_sum    = avg_deg_sum + (alldegree(i,r)+alldegree(j,r));
```

```
                avg_deg_sum_sq = avg_deg_sum_sq + ((alldegree(i,r)^2)+(alldegree(j,r)^2));

            end
        end
    end



     % calculating assortativity. step 2 = calculate average
    avg_deg_prod=avg_deg_prod/(l);
    avg_deg_sum=avg_deg_sum/(l)
    avg_deg_sum_sq=avg_deg_sum_sq/(l);

    sq_avg_deg_sum = avg_deg_sum^2;


    % calculating assortativity. step 3 = find the assortativity for that
    % year and assign it to the right position in the main array

    deg_ass(1,r)=((4*avg_deg_prod)-(sq_avg_deg_sum))/((2*avg_deg_sum_sq)-(sq_avg_deg_sum));

end

k = 1987:1:2007;

deg_ass

figure()
plot(k,deg_ass,'m+')
title('Degree Assortativity')
xlabel('Year')
ylabel('Assortativity')

-----

%Second test for assortativity of degree

sum_deg_around_node=zeros(105,21);

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    yeardata_diag4 = xlsread(Name);
    yeardata_nodiag4=xlsread(Name);
    r = k-1986;

    for i=1:105
        for j=1:i
            if((yeardata_nodiag4(i,j)~=0)|(yeardata_nodiag4(j,i)~=0))
                sum_deg_around_node(i,r)=sum_deg_around_node(i,r)+alldegree(j,r);
                sum_deg_around_node(j,r)=sum_deg_around_node(j,r)+alldegree(i,r);
            end
        end

    end
```

```
end

for i=1:105
    for j=1:21
        if(sum_deg_around_node(i,j)~=0)
        sum_deg_around_node(i,j)=sum_deg_around_node(i,j)/alldegree(i,j);
        end
    end
end

dd=colormap(cool(21));

for i=1:21
    hold on
    stem(alldegree(:,i),sum_deg_around_node(:,i),'Marker','+','Color',dd(i,:));
end
hold off
    title('Degree Assortativity')
    xlabel('degree d')
    ylabel('E[Dnn]')
colorbar

figure()
for(i=1:21)
    hold on
    scatter(alldegree(:,i),sum_deg_around_node(:,i),'r+')
end
title('Degree Assortativity')
    xlabel('degree d')
    ylabel('E[Dnn]')

-----

%Examination of Assortativity of Link Weight

%plot(allns2,'x')
nscor=zeros(1,21);
% yeardeg=zeros(1,21);
sum=zeros(105,21);
allns2=zeros(105,21);
expect=zeros(105,21);

for i=1:105
    for j=1:21
        allns2(i,j)=allns(i,j)/alldegree(i,j);
    end
end

allns2

% for i=1:21
%     temp=0;
%     for j=1:105
%         temp=temp+alldegree(j,i);
```

```
%     end
%     yeardeg(1,i)=temp;
%end

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    yeardata_diag3 = xlsread(Name);
    yeardata_nodiag3=xlsread(Name);
    r = k-1986;

    for i=1:105
        for j=1:i
            if((yeardata_nodiag3(i,j)~=0)|(yeardata_nodiag3(j,i)~=0))
                sum(i,r)=sum(i,r)+allns2(j,r);
                sum(j,r)=sum(j,r)+allns2(i,r);
%
            end
         end
    end

    for z=1:105
        for y=1:21
            expect(z,y) = sum(z,y)/alldegree(z,y);
        end
    end

end

nn=colormap(summer(21));

for ss=1:21
    hold on
    stem(allns2(:,ss),expect(:,ss),'Marker','+','Color',nn(ss,:))
end
hold off

%stem(allns2(:,:),expect(:,:),'m+')
title('Node Strength Correlation')
xlabel('s/d')
ylabel('E[s/d]')
colormap

-----
%Examination of Assortativity of Node Weight

sum_nw_around_node=zeros(105,21);

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    yeardata_diag5 = xlsread(Name);
    yeardata_nodiag5=xlsread(Name);
    r = k-1986;
```

```
    for i=1:105
        for j=1:i
            if((yeardata_nodiag5(i,j)~=0)|(yeardata_nodiag5(j,i)~=0))
                sum_nw_around_node(i,r)=sum_nw_around_node(i,r)+allnw(j,r);
                sum_nw_around_node(j,r)=sum_nw_around_node(j,r)+allnw(i,r);
            end
        end

    end

end

for i=1:105
    for j=1:21
        if(sum_nw_around_node(i,j)~=0)
            sum_nw_around_node(i,j)=sum_nw_around_node(i,j)/alldegree(i,j);
        end
    end
end

figure()
nn=colormap(summer(21));

for ss=1:21
    hold on
    stem(allnw(:,ss),sum_nw_around_node(:,ss),'Marker','+','Color',nn(ss,:))
end
hold off

%stem(allnw(:,:),sum_nw_around_node(:,:),'m+')
title('Node Weight Assortativity')
xlabel('Node Weight')
ylabel('E[Wnn]')
colorbar

-----

% Examination of assortativity of nodes in each pair of the three dimensions

plot(allnw(:,:),alldegree(:,:),'r+')
title('Degree - Node Weight Correlation')
xlabel('Node Weight')
ylabel('Degree')

figure()
plot(allns2(:,:),alldegree(:,:),'g+')
title('Degree - Node Strength Correlation')
xlabel('Node Strength corrected to Degree - s/d')
ylabel('Degree')

figure()
plot(allns2(:,:),allnw(:,:),'b+')
title('Node Strength - Node Weight Correlation')
xlabel('Node Strength corrected to Degree - s/d')
ylabel('Node weight')
```

```
-----

% Checking for number of high degree nodes ( degree>90)

number = zeros(1,21);

for i=1:21
    for j=1:105
        if (alldegree(j,i)>90)
            number(1,i)=number(1,i)+1;
        end
    end
end

    k=1987:1:2007;

    figure()
    plot(k,number,'b+')
    title('Number of Nodes having a degree greater than 90')
    xlabel('Year')
    ylabel('Number of Nodes')


-----

%Checking effect of Inflation

x = [-0.2, 0.9, 1.0, 2.6, 4.0, 3.7, 2.1, 2.7, 2.0, 2.1, 2.2, 2.0, 2.2, 2.6, 4.5, 3.4, 2.1, 1.2,

p=zeros(1,21);

p(1) = 1+ x(1)/100

for i=2:21
    j=i-1;
    p(i)= p(j)* (1+x(i)/100)
end
q = double(p)

k = 1987:1:2007;

figure()
plot(k,q,'--','Marker','o')
title('Inflation Trend')
xlabel('Year')
ylabel('Total inflation against euro value of 1987')

figure()
plot(k,totalcashflow,'r+')
hold on
plot(k,totalcashflowun,'g+')
hold off
title('Absolute Value Euro Transaction vs Inflation Accounted Values')
xlabel('Year')
```

```
ylabel('Euro Value')

-----

%Comparing the total euro flow, with and without inflation

totalcashflowun=zeros(1,21);
Name2 = 'u.xls'

for k=1987:2007
    Namex = [num2str(k) Name2];
    Namex
    yeardata_diagp = xlsread(Namex);

    r = k-1986;
    temp=0;

    %calculating total cash flow
   for i=1:105
       for j=1:105
           temp=temp+yeardata_diagp(i,j);
       end
   end

   totalcashflowun(1,r)=temp;
end

-----

%Calculating transaction growths

l=1;
transactions_amt = zeros(11025,21);
vector = zeros(1,21);
transaction_slopes = zeros(11025,2);

Name1 = '.xls';
for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    temp = xlsread(Name);
    j = k-1986;
    t3d(:,:,j) = temp;
end

for i=1:105
    for j=1:105
        for k=1:21
            vector(1,k)= t3d(i,j,k);
        end
        transactions_amt(l,:)=vector(1,:);
        l=l+1;

    end
end
```

```
% Applying LMS estimation and obtaining slope of growth

X = [[1:21]', ones(21,1)];
for i=1:11025
    y = transactions_amt(i,:);
    x = 1:length(y);
    Y = y';
    transaction_slopes(i,:) = inv(X'*X)*X'*Y;
    yref = transaction_slopes(i,1)*x + transaction_slopes(i,2);
    if(transaction_slopes(i,2)~=0)
        transaction_slopes(i,1)=transaction_slopes(i,1)/transaction_slopes(i,2);
    end

end

%Sorting all the transaction growth slopes
order = [transaction_slopes(:,1),[1:11025]'];
sorted_order = sortrows(order);

-----

%Comparison of growth of sectors and comparison of telecom with fastest growing sector

sec_inc_total=zeros(105,21);
sec_self=zeros(105,21);
sec_inc_slopes=zeros(105,2);
sec_self_slopes=zeros(105,2);

temp=0;
Name1='.xls';

% Input and making matrix of sector_sum_income and matrix of sector_self_investment over 21 year
% Thus, 2 2D matrices

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    sector_with_diag = xlsread(Name);
    sector_nodiag=xlsread(Name);
    r = k-1986;

    for i=1:105
        sector_nodiag(i,i)=0;
    end

    for i=1:105
        sec_self(i,r)=sector_with_diag(i,i);
        for j=1:105
          sec_inc_total(i,r)= sec_inc_total(i,r)+sector_nodiag(j,i);
        end

    end

end
```

```
% Finding the slope of growth of total income for each sector

X = [[1:21]', ones(21,1)];
for i=1:105
    y = sec_inc_total(i,:);
    x = 1:length(y);
    Y = y';
    sec_inc_slopes(i,:) = inv(X'*X)*X'*Y;
    yref = sec_inc_slopes(i,1)*x + sec_inc_slopes(i,2);
    if(sec_inc_slopes(i,2)~=0)
        sec_inc_slopes(i,1)=sec_inc_slopes(i,1)/sec_inc_slopes(i,2);
    end
end

sec_inc_slopes_sec_sorted=[sec_inc_slopes(:,1) [1:105]'];
sec_inc_slopes_slope_sorted=sortrows(sec_inc_slopes_sec_sorted);

% Finding the slope of growth of self investment for each sector

X = [[1:21]', ones(21,1)];
for i=1:105
    y = sec_self(i,:);
    x = 1:length(y);
    Y = y';
    sec_self_slopes(i,:) = inv(X'*X)*X'*Y;
    yref = sec_self_slopes(i,1)*x + sec_self_slopes(i,2);
    if(sec_self_slopes(i,2)~=0)
        sec_self_slopes(i,1)=sec_self_slopes(i,1)/sec_self_slopes(i,2);
    end
end

sec_self_slopes_sec_sorted=[sec_self_slopes(:,1) [1:105]'];
sec_self_slopes_slope_sorted=sortrows(sec_self_slopes_sec_sorted)

k=1987:1:2007

 figure()
 plot(k,sec_inc_total(81,:),'red','marker','+')
 hold on
 plot(k,sec_inc_total(86,:),'blue','marker','+')
 hold on
 plot(k,sec_inc_total(74,:),'green','marker','x')
 r=title('Comparison of Telecom with Fastest Growing Clusters - Total Income')
 s=xlabel('Year')
 t=ylabel('Income')
 h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
 set(h_legend,'FontSize',12)
 set(r,'FontSize',12)
 set(s,'FontSize',12)
 set(t,'FontSize',12)

figure()
plot(k,alldegree(81,:),'red','marker','+')
hold on
```

```
plot(k,alldegree(86,:),'blue','marker','+')
hold on
plot(k,alldegree(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Degree')
s=xlabel('Year')
t=ylabel('Degree')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)


figure()
plot(k,allns2(81,:),'red','marker','+')
hold on
plot(k,allns2(86,:),'blue','marker','+')
hold on
plot(k,allns2(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Node Strength')
s=xlabel('Year')
t=ylabel('Node Strength')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)



figure()
plot(k,allnw(81,:),'red','marker','+')
hold on
plot(k,allnw(86,:),'blue','marker','+')
hold on
plot(k,allnw(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Node Weight')
s=xlabel('Year')
t=ylabel('Node Weight')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)

-----

%Telecom Specific study

sec_inc_total=zeros(105,21);
sec_self=zeros(105,21);
sec_inc_slopes=zeros(105,2);
sec_self_slopes=zeros(105,2);

temp=0;
```

```
Name1='.xls';

% Input and making matrix of sector_sum_income and matrix of sector_self_investment over 21 year
% Thus, 2 2D matrices

for k=1987:2007
    Name = [num2str(k) Name1];
    Name
    sector_with_diag = xlsread(Name);
    sector_nodiag=xlsread(Name);
    r = k-1986;

    for i=1:105
        sector_nodiag(i,i)=0;
    end

    for i=1:105
        sec_self(i,r)=sector_with_diag(i,i);
        for j=1:105
          sec_inc_total(i,r)= sec_inc_total(i,r)+sector_nodiag(j,i);
        end

    end

end

% Finding the slope of growth of total income for each sector

X = [[1:21]', ones(21,1)];
for i=1:105
    y = sec_inc_total(i,:);
    x = 1:length(y);
    Y = y';
    sec_inc_slopes(i,:) = inv(X'*X)*X'*Y;
    yref = sec_inc_slopes(i,1)*x + sec_inc_slopes(i,2);
    if(sec_inc_slopes(i,2)~=0)
        sec_inc_slopes(i,1)=sec_inc_slopes(i,1)/sec_inc_slopes(i,2);
    end
end

sec_inc_slopes_sec_sorted=[sec_inc_slopes(:,1) [1:105]'];
sec_inc_slopes_slope_sorted=sortrows(sec_inc_slopes_sec_sorted);

% Finding the slope of growth of self investment for each sector

X = [[1:21]', ones(21,1)];
for i=1:105
    y = sec_self(i,:);
    x = 1:length(y);
    Y = y';
    sec_self_slopes(i,:) = inv(X'*X)*X'*Y;
    yref = sec_self_slopes(i,1)*x + sec_self_slopes(i,2);
    if(sec_self_slopes(i,2)~=0)
        sec_self_slopes(i,1)=sec_self_slopes(i,1)/sec_self_slopes(i,2);
    end
```

```
end

sec_self_slopes_sec_sorted=[sec_self_slopes(:,1) [1:105]'];
sec_self_slopes_slope_sorted=sortrows(sec_self_slopes_sec_sorted)

k=1987:1:2007

% figure()
% plot(k,sec_inc_total(81,:),'red','marker','+')
% hold on
% plot(k,sec_inc_total(86,:),'blue','marker','+')
% hold on
% plot(k,sec_inc_total(74,:),'green','marker','x')
% r=title('Comparison of Telecom with Fastest Growing Clusters - Total Income')
% s=xlabel('Year')
% t=ylabel('Income')
% h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
% set(h_legend,'FontSize',12)
% set(r,'FontSize',12)
% set(s,'FontSize',12)
% set(t,'FontSize',12)

figure()
plot(k,alldegree(81,:),'red','marker','+')
hold on
plot(k,alldegree(86,:),'blue','marker','+')
hold on
plot(k,alldegree(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Degree')
s=xlabel('Year')
t=ylabel('Degree')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)


figure()
plot(k,allns2(81,:),'red','marker','+')
hold on
plot(k,allns2(86,:),'blue','marker','+')
hold on
plot(k,allns2(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Node Strength')
s=xlabel('Year')
t=ylabel('Node Strength')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)
```

```
figure()
plot(k,allnw(81,:),'red','marker','+')
hold on
plot(k,allnw(86,:),'blue','marker','+')
hold on
plot(k,allnw(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters - Node Weight')
s=xlabel('Year')
t=ylabel('Node Weight')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)

k=[1987:1:2007];

figure()
scatter(alldegree(81,:),allns2(81,:),'red','marker','+')
hold on
scatter(alldegree(86,:),allns2(86,:),'blue','marker','+')
hold on
scatter(alldegree(74,:),allns2(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters')
s=xlabel('Degree')
t=ylabel('Average Node Strength around a Node')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)

figure()
scatter(alldegree(81,:),allnw(81,:),'red','marker','+')
hold on
scatter(alldegree(86,:),allnw(86,:),'blue','marker','+')
hold on
scatter(alldegree(74,:),allnw(74,:),'green','marker','x')
r=title('Comparison of Telecom with Fastest Growing Clusters')
s=xlabel('Degree')
t=ylabel('Average Node Weight')
h_legend=legend('Computer Service','Uitzendbureaus en arbeidsbemiddeling','Telecom and Post');
set(h_legend,'FontSize',12)
set(r,'FontSize',12)
set(s,'FontSize',12)
set(t,'FontSize',12)

-----
```

Ancillary Figures

In Figure 2, we examine the distribution of the node strength of a node i against the average node strength of all the nodes connected to node i. This is a scatter plot depicting the node strength of a node on the X axis, against the average of the node strengths of all the neighbours of the node. This plot reflects the 21 years' data cumulatively. This was an experimental approach to analysing the node strength correlation characteristics. Three clear regions are seen in the graph. The large cluster in the middle of the graph is what typically would be shown by nodes that transact large amounts of money with fewer clusters. The small cluster on the bottom right of the graph shows nodes having high node strength, with neighbours having low average node strength. This graph needs further investigation to prove insightful.

In Figure 3 we see the information depicted in Figure 2 with the addition of the information regarding the contribution of each year towards this correlation. We see that over the years, the distribution has shifted slightly, though there is no marked change in the nature of the distribution.

Figures 4 and 5 depict the probability distribution of link weights for the first ten years' network instances taken cumulatively and the last eleven years' network instances taken cumulatively, respectively. It is an interesting question to ponder if they have power law behaviour in these time aggregates since they did show such a behaviour when all 21 years were considered together. As of this data set, there are insufficient data points to conclude this. Further investigation is required to reflect on the nature of the network based on this distribution. Similarly, the probability distribution of node weights over the first ten years cumulatively and the last eleven years cumulatively is depicts in figures 6 and 7. Again, the question may be asked whether in these time aggregates too, the networks show power law behaviour in node weight distribution.

In these graphs, it is possible to experiment with the bin sizes and analyse the resulting graphs for power law behaviour. The graphs depicted here use 64 bins. Increasing the number of bins is one way to increase the number of instances. On the other hand, if bin sizes are too small, there may be increased noise in the graph. If bin sizes are very

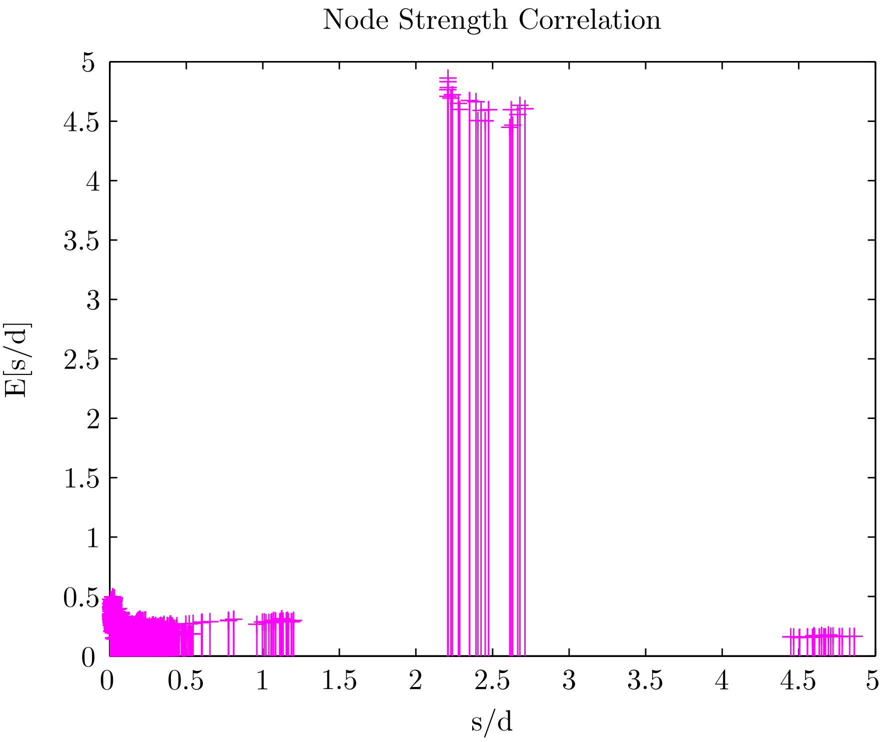

FIGURE 2: Scatter plot of the node strength of a node i, s_i/d_i and the average node strength s_j/d_j of all nodes in the neighbourhood of node i.

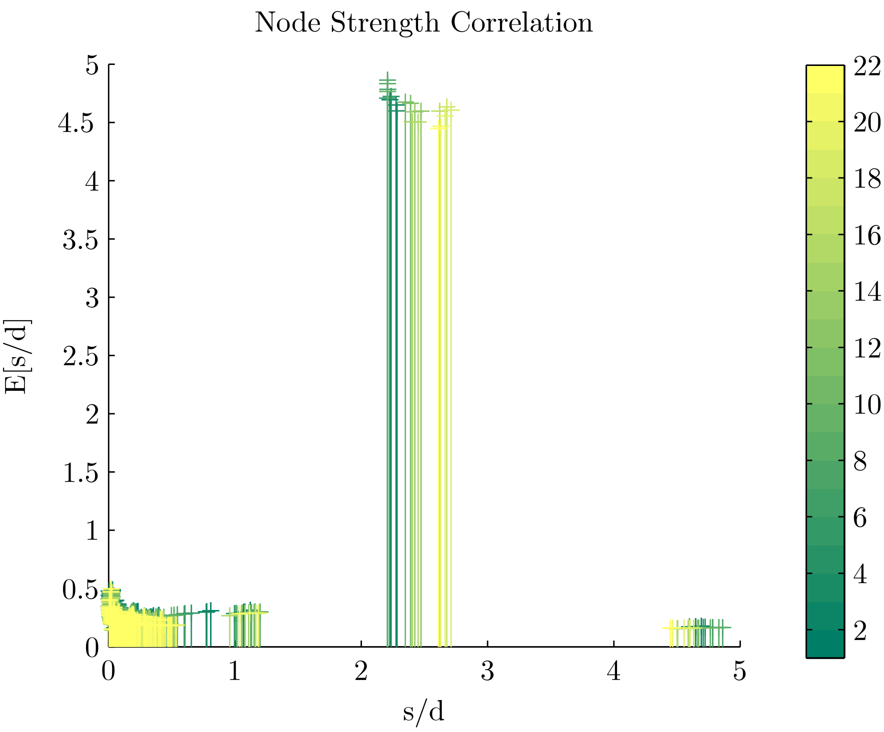

FIGURE 3: Scatter plot of the node strength of a node i, s_i/d_i and the average node strength s_j/d_j of all nodes in the neighbourhood of node i, depicting the contribution of each year.

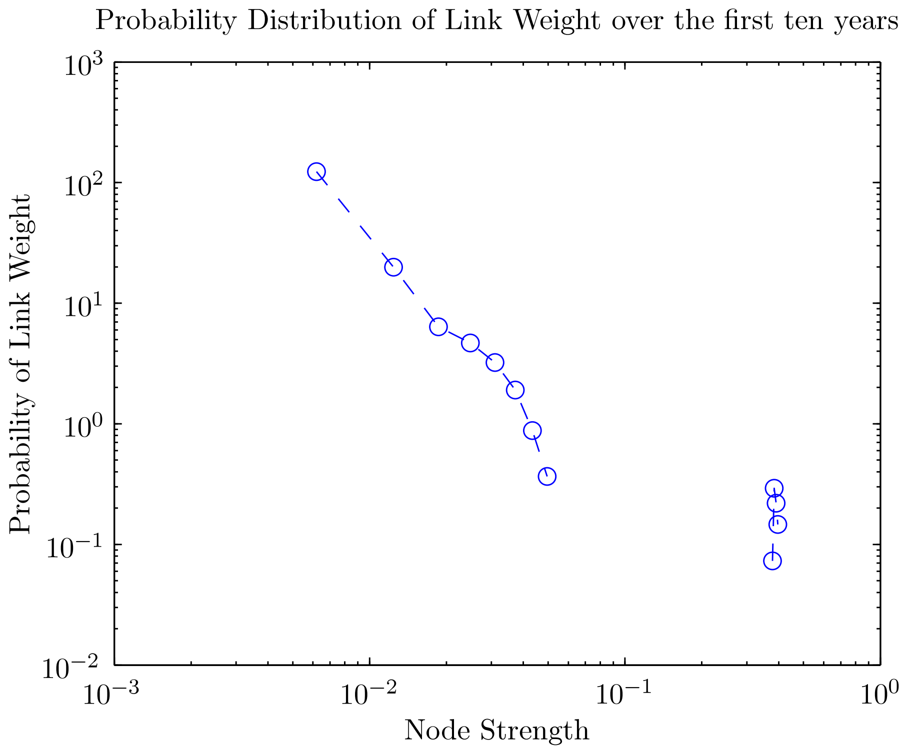

FIGURE 4: Probability Distribution of the Link Weight of the first ten years' network instances

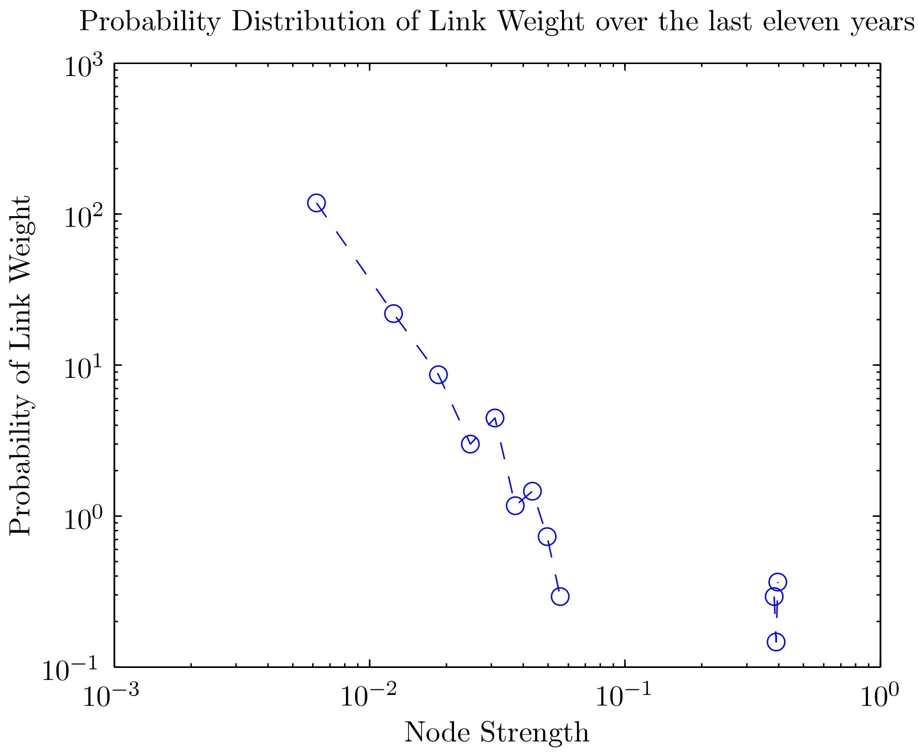

FIGURE 5: Probability Distribution of the Link Weight of the last eleven years' network instances

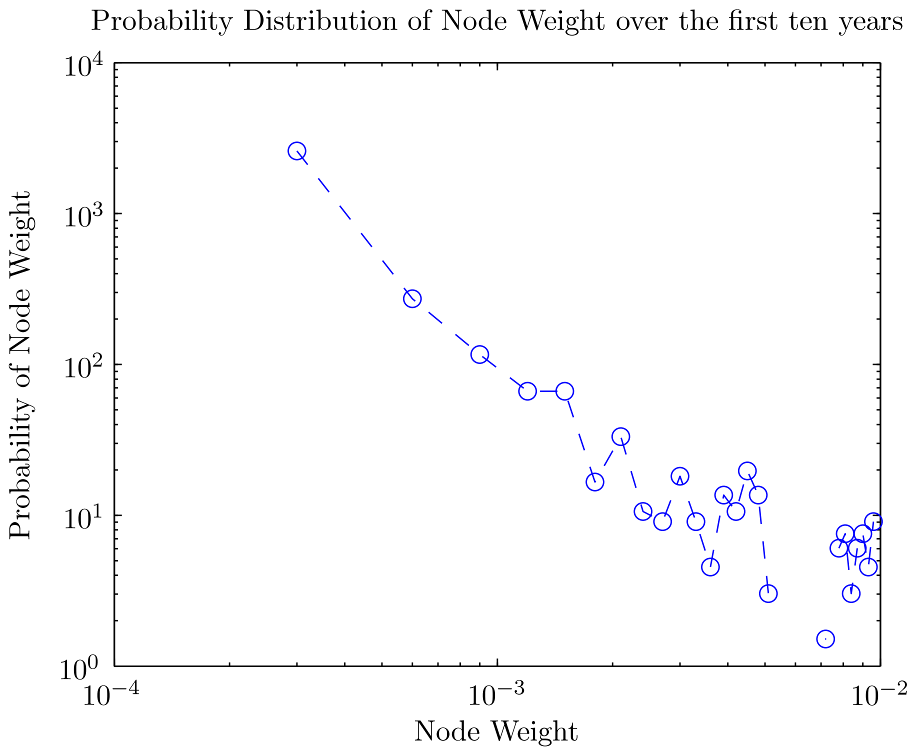

FIGURE 6: Probability Distribution of the Node Weight of the first ten years' network instances

large, the number of instances in the graph are too low to make a distribution. It has to be well pondered what the size of a bin could translate into in terms of a real world transaction between activity clusters. A trade off has to be made.

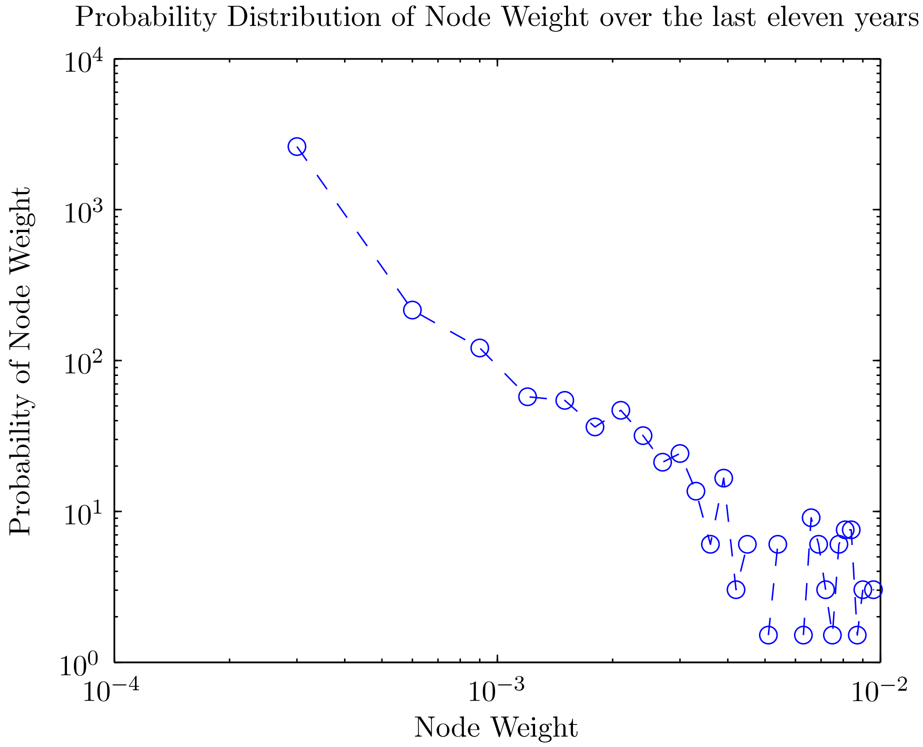

Figure 7: Probability Distribution of the Node Weight of the last eleven years' network instances