Flexibility for a Resilient System

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By

Vivek Anand Asokan
47-136828

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Advisor: Professor Masaru Yarime
Co-Advisor: Professor Miguel Esteban

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ABSTRACT

In this study the authors wish to introduce a new concept into the field of sustainability science and the study of resilience. This study looks to answer two questions: why is flexibility needed and what flexibility actually is.

Researchers from different fields have contended that flexible systems should have an inherent capacity to absorb shocks and perturbations so that a given system is able to maintain its essential functions. In this paper, the authors introduce the concept of flexibility as a measure of resilience. Flexibility as a concept has been used in the field of economics, engineering and biological systems. The authors reviewed literature from these fields before demarcating the characteristics of a flexible system that can be implemented in sustainability science.

The authors then go on to propose a conceptual framework incorporating flexibility as a characteristic while designing complex systems. Robustness and innovation are both identified as being important for a system. While robustness is important in the context of the present, innovation becomes important in the context of future. However in the event of an unknown externality, the authors contend that the flexibility of a system is crucial in maintaining its robustness. Also, that same flexibility is crucial in realizing innovation within that system. To sum up, flexibility as a characteristic leads to both innovation and robustness.

To illustrate the concepts described earlier the authors studied whether an economic system that has a higher contribution of the knowledge intensive service sector to the economy is positively related to economic complexity in that country.

It is widely accepted by scholars working in the field of innovation that technological knowledge creation is evolutionary in nature. It has been proposed that the combination of existing knowledge plays an important role in the creation of new knowledge. This concept can be similarly expanded to ideas, where the generation of ideas is possible by combining existing knowledge. Thus, the combination of existing technological knowledge and organizational knowledge creates novelties and leads to innovation. Numerous examples in the field of biology prove the presence of combination, which results in novelties. In this thesis the author contends that the service sector facilitates this process of combination of knowledge, which results in diverse economic activities.

This interplay is similarly seen in the service sector, which allows the mixing of knowledge from diverse fields, as for example consultancy firms typically employ individuals with different skills sets. This is mainly due to higher chances of diverse ideas combining giving rise to novel ideas and suggestions. The author would like to highlight the flexible role played by the knowledge intensive services. Knowledge intensive service sectors like management consultancy, professional services and technical services allows peer to peer movement of knowledge, allowing for a horizontal flow of information. This is in contrast to the vertical integration of knowledge flow, and can thus facilitate a faster adaption of ideas.

The methodology employed by the authors map the countries' contribution of the knowledge intensive service sector per GDP with the economic complexity of each country. The data for the GDP contribution of knowledge intensive service sector is sourced from OECD and EU database. The Economic Complexity Index (ECI) reflects the diversity and ubiquity of exports of a country, as ECI is based on trade data. A higher ECI reflects higher diversity and less ubiquity of products exported, which is highly desirable. The data for ECI is sourced from Complexity Atlas, where the data is calculated using UNCTAD data.

Results suggest that there is relationship between knowledge intensive services and economic complexity. The knowledge intensive service sector plays an important role in creating avenues for combination of knowledge, which leads to the creation of new knowledge. A correlation analysis showed that technical services played a higher role than the research and development sector in creating economic complexity. The role of imitation is an important contributor in knowledge diffusion vis-a-vis innovation. The role of management consultancy and professional services played an important role in contribution to economic complexity in bigger economies like Germany or the United Kingdom.

It is very important to understand the role played by the service sector in creation of a flexible economy in future. The authors argue that a system with a strong knowledge intensive service sector is crucial for an innovative and robust economy, as they are sites of knowledge combination. This understanding is crucial to design systems in transition. Given the dynamic nature of flexibility, identifying the characteristics system, which leads to flexibility, will add a new dimension to the study of sustainability transitions and help create smoother transitions.

Keywords: Flexibility, Resilience, Business Services, Sustainability, Flexible Systems

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LIST OF TERMINOLOGY: ABBREVIATIONS

IPCC - Intergovernmental Panel on Climate Change

US EPA - United States Environmental Protection Agency

FMS - Flexible Manufacturing System

R &D – Research and Development

GDP - Gross domestic product

OECD - Organisation for Economic Co-operation and Development

ICT - Information and communication Technology

HGT – Horizontal Gene Transfer

DIY – Do It Yourself

MNC – Multinational Companies

WTO – World Trade Organization

ECI – Economic Complexity Index

LIST OF TERMINOLOGY: TERMS

Complexity: A system with many parts, feedbacks, non-linear and linear relationship etc.

Flexibility: The property of a system that promotes change in the system

Socio-Economic: A system with coupled social and economic components.

Robust: Insensitivity of some functionality when the system is exposed to a set of distinct environments

Innovation: Application of new ideas to the products, processes, or other aspects

Modularity: Networks with high modularity have dense connections between the nodes within modules but sparse connections between nodes in different modules

System: A set of connected things or parts forming a complex whole, in particular.

Business Service: Business function and services highly reliant on codified knowledge. The term in the thesis is also interchangeably used with business services Knowledge Intensive Sector/Services

Economic Complexity Index: This index composition of a country's productive output and reflects the structures that emerge to hold and combine knowledge."

1. INTRODUCTION

A recognition of global environmental problems in late half of the 20th century has led to new concepts like sustainable development, sustainability or resilience. These terms have no uniform definition. The terms have been adapted to the local context and have several meanings. At times the terms are prone to be co-opted by existing institutional structures to mean the status quo. In addition, resilience has gained huge traction in the sustainability science field. The discourse on resilience comes from the field of ecology. This discourse is dominated by a handful of institutions. However, recently some researchers from social science have been critical of the resilience literature. They raise significant questions on how these ecological concepts can be applied to social and economic systems. In these researches, it is taken for granted that these ecological concepts are readily adaptable to other systems. (Brown, 2013)

1.1 Sustainability Science – Ontological and Epistemological Considerations

Sustainability Science has been categorized broadly in two fields. They are science for sustainability, which is classified as a tradition discipline, and science of sustainability which is classified as transdisciplinary (Spangenber, 2011). Kauffman identified three characteristics of sustainability science, as follows (Kauffman, 2009),

- Action oriented
- Integrated analysis,
- Transdisciplinary

Traditional research on sustainability focusess on problems solving from a particular perspective (Komiyama & Takeuchi, 2006). Clark identfies the core sustainability program as "understanding the complex dynamics that arise from interactions between human and environmental systems". He further adds that sustanbility science is a "use-inspired basic research" (Clark W. C., 2007). Spangenber (2011) adds that science of sustaianbility should not only add natural science with economics but also with social sciences and humanities. Spangenber emphasises that there needs to be bridging concepts from diverse fields. Reflexivity is an important concept which has emphasised by Spangenber.

> “It requires the acceptance of uncertainty, ignorance and the impossibility of knowing all relevant facts about evolving systems, and that the existence of emergent system properties makes micro-level explanations of macro-level system behavior impossible (in physics and biology as much as in sociology and economics)”

The shift from a curiosity driven approach to a mission oriented approach is highlighted by the above studies. However it is not clear what are the ontological assumptions and epistemological underpinnings of sustainability science. These characteristics can be broadly framed as a discourse in the field of post normal science. However, there is a danger when moving towards transdisciplinary. How can different kinds of knowledge be validated? Spash (2012) contends that it is important to follow realism and reasoned critic instead of getting into the rhetoric of transdisciplinary. (Spash, 2012). Following which, he emphasizes on presenting the worldview or paradigm clearly from others.

In the present thesis, the research paradigm of realism and reasoned critique is followed. The following are the world view followed in the thesis,

Ontological Assumptions

- A holistic approach is needed in understanding the complex reality of our environment and surrounding.
- Socio-ecological system and socio-technical system have the property of emergence and are capable of self-organisation.
- There are complex interaction among the parts, actors and components within a system.
- Humans operating within this system operate with their own values and these can be different from facts.
- Systems are dynamic in nature.
- There is a reality, however, there are multiple perspectives of looking at that reality.

Epistemological Claims

- It is impossible to know all the properties of a system or an objective reality.
- All kinds of knowledge have to be validated and should be open to reasoned critique.
- There is ignorance in our understanding of the environment and our surroundings.

Methodological Statements

- Structured methodological pluralism is required.
- Evolutionary nature of biological sciences and knowledge creation in economic systems has been observed and hence employed in the study.

1.2 Problem Statement

1.2.1 What is the problem?

Some studies from the field of information ecology consider efficiency and resilience as trade-offs (Ulanowicz, 1986). Similarly, theories in the field of manufacturing explicitly mention a trade-off between flexibility and productivity (Gustavsson, 1984) (Son & S, 1987) Recent studies from complexity economics highlight the importance of interconnectivity and diversity in creating pathways, which lead to a system which positively correlates with higher Gross Domestic Product (Hidalgo, Klinger, Barbasi, & Hausmann, 2007). The linkages between the parameters are not properly understood.

1.1 Research Design

It is of paramount importance that these relationships are clarified. Researchers have been pointing out that there certain are similarities between the biological world and social world (Wagner & Rosen, 2014) (Nelson & Winter, 1982).

In the present thesis, the focus is to identify the concepts from biological science and social science to understand terms like resilience, interconnectivity, robustness and innovation. The first part of the study is exploratory in nature. Flexibility is introduced as one of the lens to study sustainable transitions. We employ **inductive inference** to develop a **conceptual framework** to link these concepts. Evidences and observations are used to apply a concept in the domain of socio-ecological system and socio-technical systems. The evidences and observation on concept of resilience are developed from biological science. The evidences and observation on the concept of flexibility are developed from biological sciences and social sciences. The arguments made in this section are probable in nature.

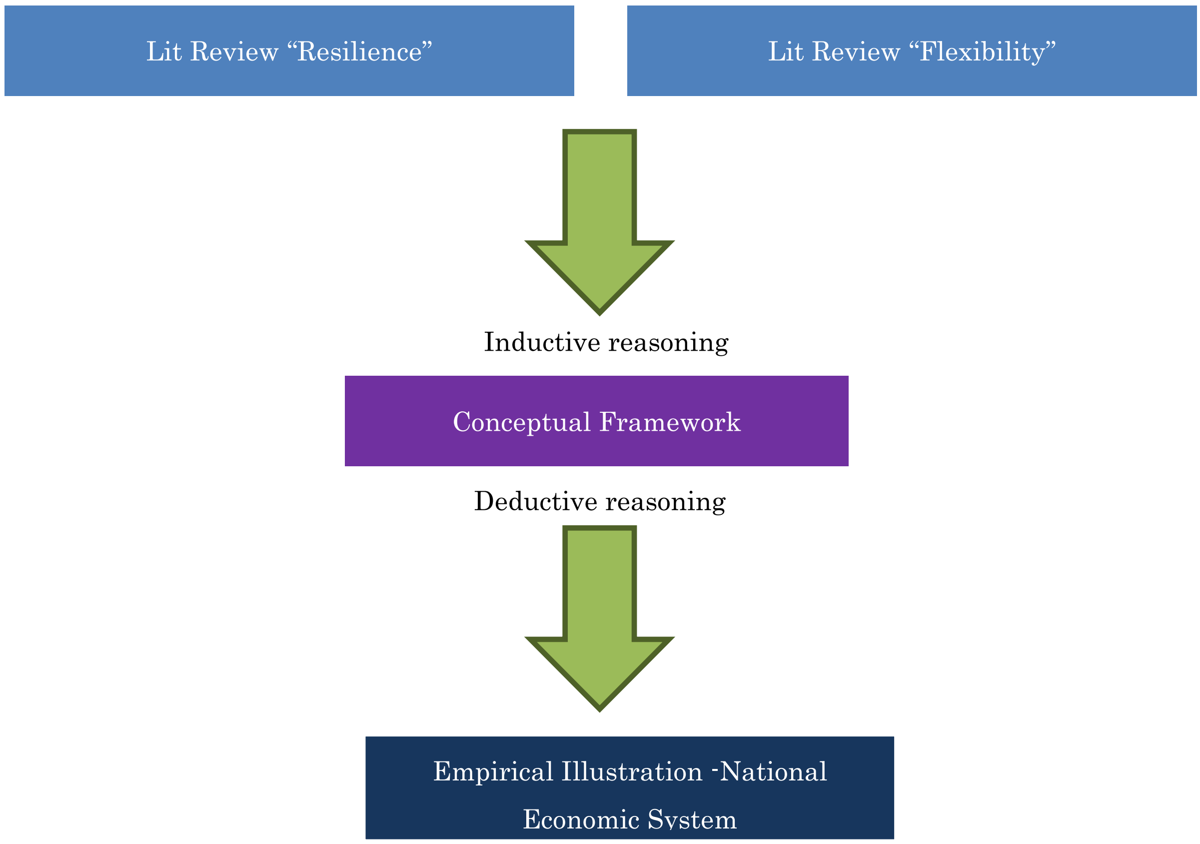


Figure 1 – Research Flow

Finally, an **empirical illustration** involving economic complexity (system) and business services (flexibility) is conducted. This part is used to confirm the proposition to link the importance of flexibility in resilient systems. We employ **deductive reasoning** to inform of a top down logic to validate the concept of flexibility and resilient system.

1.2 Research Tools

In this thesis there are two sections. The first section is exploratory nature. This section involves **literature review** of scholarship on resilience. Based on the investigation and analysis, flexibility is proposed as an essential property of resilient system. Further, the author then conducts a **literature review** on the concept of flexibility. Based on the literature a **c**onceptual framework is proposed which encapsulates the concepts of flexibility and resilience. The second section involves an empirical illustration based on data from economic complexity index and business services. A **correlation analysis** is conducted to show the importance of flexibility in resilient systems. In the illustration, business sector is proposed to contribute to flexibility in an economy.

1.3 Thesis Flow

The flow of presentation followed in the thesis is shown in figure 1. In addition, this subsection lists the subject matter covered in the following chapter.

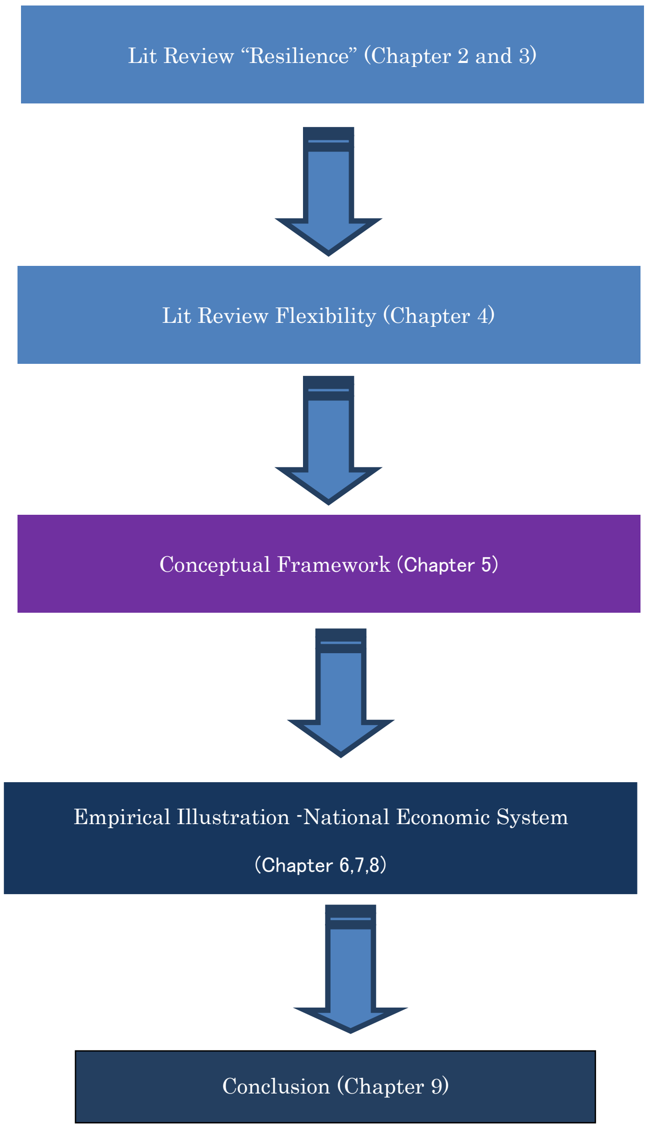


Figure 2- Thesis Flow of the study

Chapter 2 and chapter 3 provide an introduction to the literate on resilience. It focuses on different theoretical conceptualizations of resilience. These studies come from the field of ecology. The chapter covers concepts like engineering resilience, ecological resilience and adaptive cycle. The importance of resilience in providing sustainable solutions is emphasized. To conclude, the chapter indicates the two major components of any resilient system. This chapter 4 looks to answer the question regarding why flexibility is needed.

In the last chapter the author delimits flexibility as a strategy, given the uncertainties and risks faced by system. This chapter 4 looks to answers question regarding what flexibility actually is. The second part of the question is answered based on a review of literature of flexible manufacturing systems, degeneracy, economic flexibility etc. Then flexibility is presented with the framework of resilience thinking. The example of a modular system is cited to show the possibility on how the concept can be applied in a network and systems framework.

In chapter 5 the author introduces the conceptual framework. The mechanism of the model is explained. In the second half of this chapter the author provides the explanation for its applicability in social systems. A case is made for the application of the model for a particular case study of knowledge creation in the economy.

In chapter 6 to illustrate the concepts described earlier, the author checks whether an economic system that has a higher contribution of knowledge intensive service sector to the economy is positively related to economic complexity in that country. To analyze the role of business services, the author maps the contribution of the business services per GDP with the economic complexity of various countries. This is done to estimate the conditions that are suitable for creating higher economic complexity in the system. Then, the author introduces the methods and sources of data used in the empirical illustration.

In chapter 7 the results of the correlation analysis are presented. This is followed by the list of major finding in the study. The findings based on the earlier theoretical concepts are matched with the concepts. The results are compared with the horizontal knowledge flow, role of financial services and importance of imitation and innovation.

The chapter 8 discusses the strategy for the countries with lower economic complexity to gain higher economic complexity. A quadrant approach is conceptualized to identify the countries and the stages of their respective development. The data for global business services trade is used to explain the dependence of countries with a lower economic complexity to gain higher economic complexity through a hub and spoke model.

The final chapter summaries the major result of the study. The focus of the chapter is on the conceptual contributions and the empirical illustration. The significance of the research is portraying flexibility as a characteristic. In addition flexibility can be reflected crucial in creating balance between robustness and transformation potential in the system.

2 RESILIENCE

This chapter covers gives an introduction to the literate review on resilience. It focuses on different theoretical conceptualization of resilience. These studies come from the field of ecology. The chapter covers concepts like engineering resilience, ecological resilience and adaptive cycle. The importance of resilience in providing for sustainable solutions is emphasized. To conclude, the chapter indicates the two major components of any resilient system.

2.1 Types of systems

Cotsaftis contents that there are three elementary types of system classification (Cotsaftis, 2009). They are simple, complicated and complex. He adds that the first two systems (namely complex and complicated) have been studies on laws based on mechanistic representation which were used to study celestial body motion. Simple systems are easy to study as they are isolated systems slightly disturbed by outside influence. A simple system is also one component sub system. Complicated systems on the other hand are a set of subsystems which can be still externally controlled. This includes many artificially created engineering systems.

These objects were simple and had a well-defined trajectory. However, with the ascent of technology and increased understanding of the biological world, systems have been built with interacting components. This leads to internally ruled structures through the process of self-organization and this leads to emergence of new properties. The naturally occurring are more robust. Cotsaftis states that this knowledge can be used to make artificially complicated system more robust. However the emergent and self-organizing properties of different system need not be the same for all the system.

Table 1 Simple, Complicated and Complex System (Cotsaftis, 2009)

Simple	Complicated	Complex
One component sub system	Set of subsystems with components	Set of subsystems with interacting components
Slightly disturbed by outside influence	Externally operated	Self-organising and emergent

In simple language, these three systems can be explained based on the following example as follow, (Glouberman & Zimmerman, 2002)

- Simple system as “following a recipe”
- Complicated System as “Sending a Rocket to the Moon”
- Complex system “Raising a Child”

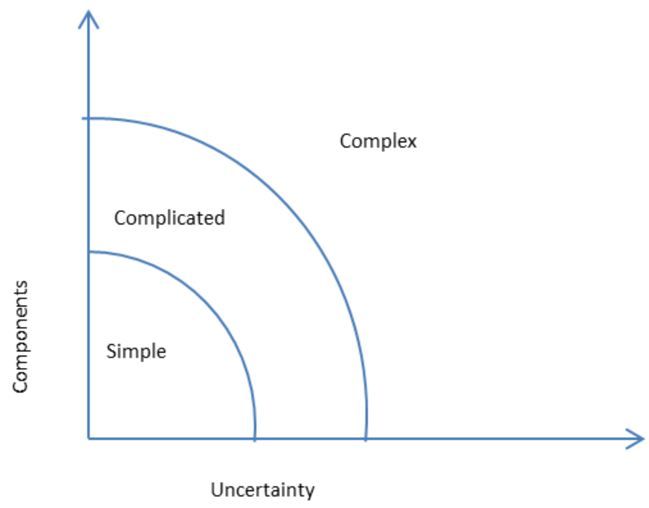


Figure 3 – A simplified graph on Simple, Complex and Complicated System (Glouberman & Zimmerman, 2002)

2.2 Biological and Socio Economic Systems as Complex System in Sustainability Science

The biological world and the socio economic world are filled with single and smaller structures comprising a bigger scheme with multiple structures. The bigger schemes thus make system with multiple components. These multiple components are also interconnected with multiple pathways. This gives rise to a complex system. These arguments have been made by in similar studies (Peter & Swilling, 2014) (Levin, 2006).

Further, Peter and Swilling (2014) identify the following major theories which can be used to study complex system with the sustainability science framework,

(1) Resilience theory;
(2) Decoupling theory;

(3) Transitions to sustainability; and
(4) Behavioral change theories.

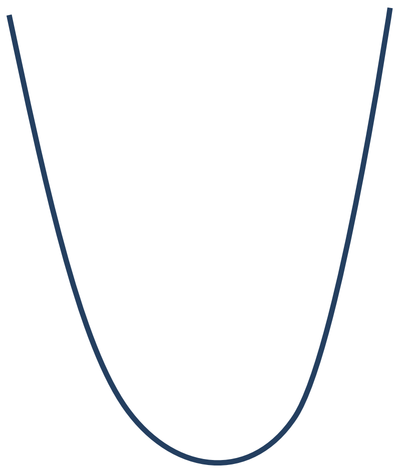
The focus in this paper is on the theory of resilience since it has a wide acceptance in different fields (Thorén, 2014). The number of papers based on resilience in web of science has exploded to 800 in 2013 from 60 in 1993. Also, the papers came from a wide variety of fields like sociology, urology, environmental sciences and ecology, history, anthropology, polymer science, urban studies, materials science and others. Thoren also contends that the concepts abstractness has allowed it to permeate different fields with the possibility of unifying some of them. Hence the concept of resilience has been used in this thesis to study complex systems.

2.3 Resilience and Stability for Social and Economic Systems

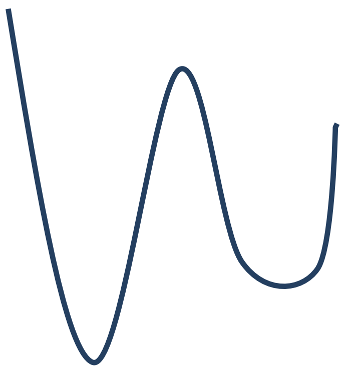
In an uncertain world, our daily lives are prone to certain risks. These risks are important for the government and business to plan their operations. One of the issues is on how to plan and develop our societies given these uncertainties. Do planners follow resilience or stability approach?

Hollings terms stability as “stability, which represents the ability of a system to return ‘to equilibrium state after a temporary disturbance; the more rapidly it returns and the less it fluctuates, the more stable it would be.” (Holling C. S., Resilience and stability of ecological systems, 1973). Similarly, Holling termed resilience as, “that is a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables. ((Holling C. S., Resilience and stability of ecological systems, 1973)”. Following these definitions, it is clear that resilience has a dynamic character. On the other hand, the stability emphasizes returning to a static state.

Scholars have put forth the term “engineering resilience”, which emphasizes the time a system takes to return to equilibrium or a steady state (Holling C. S., Engineering resilience vs. ecological resilience, 1996). This definition of engineering resilience is synonyms with the term elasticity as understood in the field of engineering (McGlade, 2006). This definition is more in line with the definition of “stability”. However, defining resilience as a steady state condition allows it to lose its dynamic character. When applying this concept to a global level, Gunderson accepts that with engineering resilience there is an implicit assumption that there is only one steady state (Gunderson, 2000). This assumption is also shared in different academic disciplines, especially in the field of disaster management (Pendall, Foster, & Cowell, 2010). Some question the fact that given the deplorable condition of certain systems, it is questionable whether they can bounce back to the original system (MacKinnon & Derickson, 2012). This is certainly true in connection with some economic and social systems. The problem with “engineering resilience” is that this concept shapes the discourse in such a way that the view that status quo is considered the best possible state emerges.



Engineering Resilience – Single Basin



Ecological Resilience - Multiple Basins

Figure 4– Engineering and Ecological Resilience (Walker, Holling, Carpenter, & A., 2004)

The second kind of resilience discussed here differs from the first by accepting the presence of multiple equilibrium states. Ecological resilience (as it is called) accepts the transition between multiple equilibrium states such that the system is able to absorb the perturbation. The main parameter measured is the amount of perturbation which the system can absorb. There are researchers who consider “ecological resilience” just like “engineering resilience”, as it does not takes into account the dynamic nature of the resilience (Simmie & Martin, 2010). Ecological Resilience accepts the dynamic nature of the resilience; however this dynamic nature is restricted within the boundaries of these multiple states.

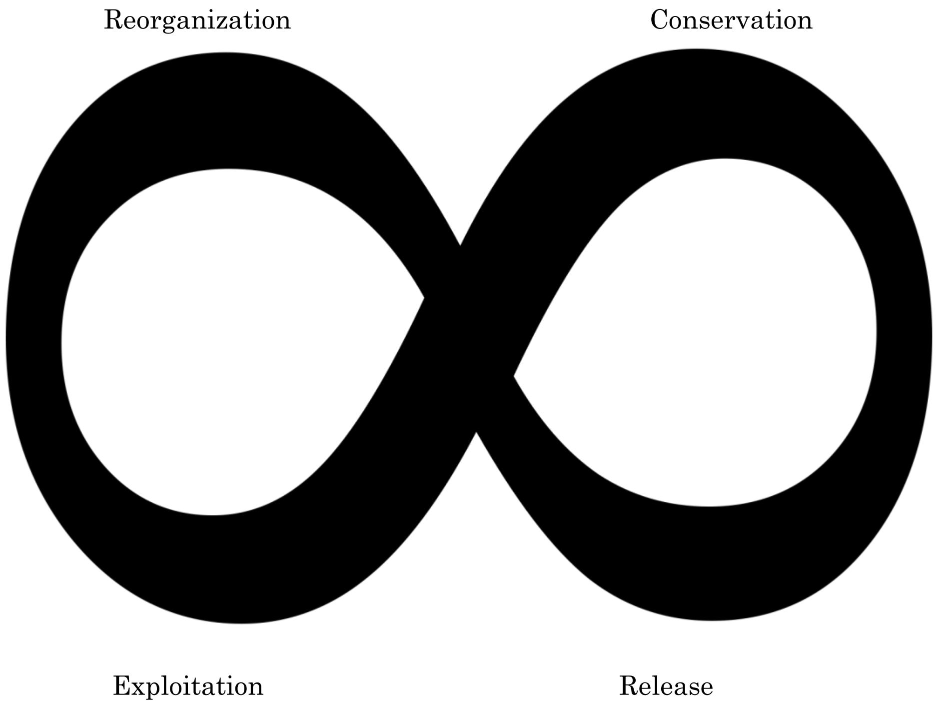


Figure 5- Adaptive Cycle (Pendalla, Foster, & Cowella, 2010) – figure from wiki commons

This idea of continuous change has been incorporated in the resilience literature by Holling and Gunterson (Holling, Gunderson, & Peterson., 2002). They introduced the concept of adaptive cycle. The adaptive cycle has four stages, namely, exploitation (r), conservation (K), release (omega) and reorganization (alpha). The adaptive cycle process in fore loop takes longer time and involves movement from growth to conservation stage. This period is simultaneously also characterized by increased connectedness and stability. After the conservation phase, the system disintegrates in a back loop to the release stage and the reorganizes to reach the growth stage, completing the cycle. However it can be questioned if all the process follows the cycle, especially when applied in the context of social and economic systems. However it is important to note the continuous change and uncertainty a system is prone to.

The above frameworks dominate the discussion on resilience from the field of ecology. It is important to note given the dynamic environments we live in it is not clearly whether we apply the resilience framework developed in the field of ecology. In the social and economic system, a change takes place at fast intervals unlike the biological environment. In this way, it makes it possible to mark equilibrium states or stable condition in an ecological system. However in an economic system like capitalism, it is difficult to imagine equilibrium state or stability. For example, capitalism as a process is driven by creation of new knowledge and this new knowledge always changes (Metcalfe & Ramlogan, 2005). In a dynamic environment, given the change in state of multiple parameters, it is difficult to imagine an environment where equilibrium is possible. Equilibrium is a condition where all the forces are balanced.

Under Capitalism, it is difficult to imagine a system, especially the social and economic system, where an equilibrium state will be achieved. It is difficult to operationalize ecological resilience and engineering resilience framework in dynamic social and economic systems. The adaptive cycle approach shows promise with its dynamic characteristics. However we have to be cautious while applying this to the social and economic system. Under the era of future climate change, it is difficult to predict the uncertainties the social-ecological systems will be facing. It would be important in future to create structures which can face the uncertainty and risks posed by the external and internal forces.

2.4 Competing Ideas from other fields

The field of business has contributed to the scholarship of resilience. Hamel distinguishes two kinds of resilience – strategic and operational. He defines strategies resilience as "continuously anticipating and adjusting to deep, secular trends that can permanently". He adds, strategic resilience is all about having the capacity to change before the case for change becomes desperate obviously. On the other hand the operational resilience refers to "the ability to respond" to the change. The difference between these two models is that the strategic resilience favors anticipation and continues change, which reflects the dynamic nature of the concept. On the other hand the operative resilience is more reactive to the shock or stress (Hamel & Valikangas, 2003). Strategic resilience gives more stress on transformation and change than the operational resilience.

Nassim N Taleb (2012) defined "anti-fragility" as the opposite of fragility, which he defines as "the ability to gain from disorder". He distinguishes anti-fragility from resilience as he contends that resilience encounters shocks or stress and remains the same. On the other hand he emphasizes that the anti-fragility benefits from the stress or the shock. Antifragility behavior refers to the transformation capacity of a system. Evolution is considered as antifragility characteristics where random mutations lead to selections in response to stress or shock in the environment (Taleb, Antifragile: Things That Gain from Disorder, 2012). Nassim N Taleb (2012) also stresses the importance of redundancies in the natural system. He cites presence of two kidneys in the human body as a form of redundancies.

2.5 Relation between Resilience, Adaptation and Sustainability

The information ecological approach makes a clear distinction between resilient and sustainable state. It proposes an idea where a resilient system is not sustainable. However, a resilience system incorporates the character of both adaptation and sustainability. Resilience, sustainability and adaptation are not synonyms, though they have many overlapping characteristics. US EPA defines "sustainability " as the state which creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations (United States Environmental Protection Agency). The temporal scales of sustainability is closely related that of resilience. On one hand the resilience literature talks about maintaining the state function of a system, the sustainability literature on the other hand also stresses the need to maintain the social, economic and other requirements. The social, economic and natural requirements can be considered as state function which shows the similarities between resilience and sustainability. In such a case, it is difficult to consider resilience and sustainability as different. Rather, a resilient system becomes a characteristic of sustainable societies.

The Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC 4AR) defines climate change adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007). Again, there are close similarities between adaptation and resilience. On one hand, the resilience stresses on "absorbing change and disturbance" and adaptation also focuses on adjustments in natural or human system. Resilience terminology incorporates the vibrant significance of both sustainability and adaptation.

2.6 Components of resilience

In 2002, Carpenter suggested the following three possible meanings of resilience,(i) response to disturbance; (ii) capacity to self-organize; and (iii) capacity to learn and adapt (Carpenter, Walker, Anderies, & Abel, 2001). Similarly, Holling (1986) pointed at the importance of renewal, novelty, innovation and reorganization of a system while extending the concept of resilience to a socio- ecological system (Holling C. , 1986). However, Walker and later Folke emphasized the additional critical characteristics of a resilient system under the framework developed by him called "resilience thinking". He noted that adaptability and transformation as important feature of a resilient system (Folke, et al., 2010). Adaptability has been used in resilience literature as defined by Walker as "the capacity of actors in a system to influence resilience" (Walker, Holling, Carpenter, & A., 2004). Walker et al defined transformability as a means of defining and creating new stability landscapes by introducing new components and ways of making a living, thereby changing the state variables, and often the scale, that define the system."

However, traditional view on resilience gives importance to persistence of a system. Folke et al notes the dichotomy between the robustness and resilience, (Folke, et al., 2010), where

> "confusion arises when resilience is interpreted as backward looking, assumed to prevent novelty, innovation and transitions to new development pathways. This interpretation seems to be more about robustness to change and not about resilience for transformation."

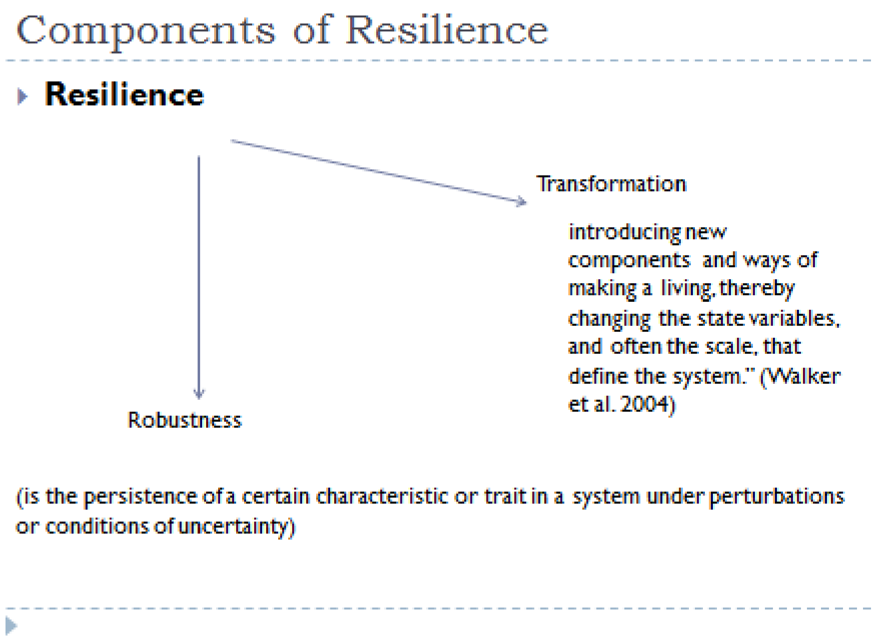


Figure 6– Components of Resilience

By focusing on the backward looking features of the engineering resilience, we neglect adaptability and transformation which reflect the features of ecological resilience. Miller et al (2010), while comparing resilience with the vulnerability framework added that "Similar trends can be seen in the resilience literature, in which empirical work is still interpreting resilience in the narrow sense of return time and recovery, thereby missing the broader use of the concept".

3 ANALYSIS OF RESILIENCE

3.1 Characteristics of Resilient System

The last chapter concludes with the two major components of a resilient system. In this chapter, the focus is on the characteristics of a resilient system. The chapter deals with the issues of interconnectivity and resilience across scales. Flexibility of a system is projected as a solution given the issues of scale and interconnectivity.

3.1.1 Seven Principles of Resilience

The Stockholm resilience center came out with a list of principles which were considered critical for resilience thinking (Biggs, et al., 2012). They are the following,

- Maintain Diversity and Redundancy
- Manage Connectivity
- Manage slow variables and feed backs
- Foster complex adaptive thinking
- Encourage learning
- Broaden participation
- Promote Polycentric governance system

In this section, we will discuss the first four variables, which describe the attributes of the system. One of the important ideas of resilience is maintaining diversity and redundancy. The presence of functional redundancy of the system is attributed to be providing protection to the system. Functional redundancy refers to the presence of multiple components that can perform the same function (Biggs, et al., 2012). It is noted that response diversity is equally important when considering resilience. It is defined as “differences in the size or scale of the components performing a particular function give them different strengths and weaknesses, so that a particular disturbance is unlikely to present the same risk to all components at once.” It is important that systems have overlapping functions with redundancy. Connectivity on the other can play both the ways either to enhance or reduce resilience. Higher connectivity can help in improving resilience by either rerouting flows or preventing a disturbance from spreading. Higher connectivity can also have negative consequences if its leads to spread of a disturbance. In this situation it will be advisable to limit the connectivity. It is emphasized that the resilience of a system should foster complex adaptive system thinking. The report stresses that such thinking does not directly enhance resilience; however this is the first step in accepting the complex interaction and interdependencies of the system we live in. The report continues that the importance of feedback, both positive and negative, is crucial in enhancing resilience of the system. This is considered essential to maintain certain ecosystem services.

3.2 Relationship between Interconnectivity and Resilience

A recent approach in the resilience literature has been introduction of the ecological information approach, which mixes the ideas from the field of information theory and ecology. This paper put forth the idea of a trade-off between efficiency and resilience (Ulanowicz 1986). Ulanowicz contend there is an optimal robustness range which is observed in all the natural systems such that these systems select a mix between low interconnectedness (efficient) and high interconnectedness (resilient) in ratio of one part is to two. There are two inherent assumptions in this idea (Ulanowicz, 1986). When the diversity is smaller, the efficiency of the system is higher and if the diversity is high, the system is inefficient. However in a complex world we live in, this assumption can be challenged. Hidalgo and Haussman challenge the view that diversity is inversely related to efficiency or productivity.

> "One possible answer is that some of the individual activities that arise from the division of labor described above cannot be imported, such as property rights, regulation, infrastructure, specific labor skills, etc., and so countries need to have them locally available to produce. Hence, the productivity of a country resides in the diversity of its available nontradable "capabilities," and therefore, cross-country differences in income can be explained by differences in economic complexity, as measured by the diversity of capabilities present in a country and their interactions." (Hidalgo & Hausmann, 2009)

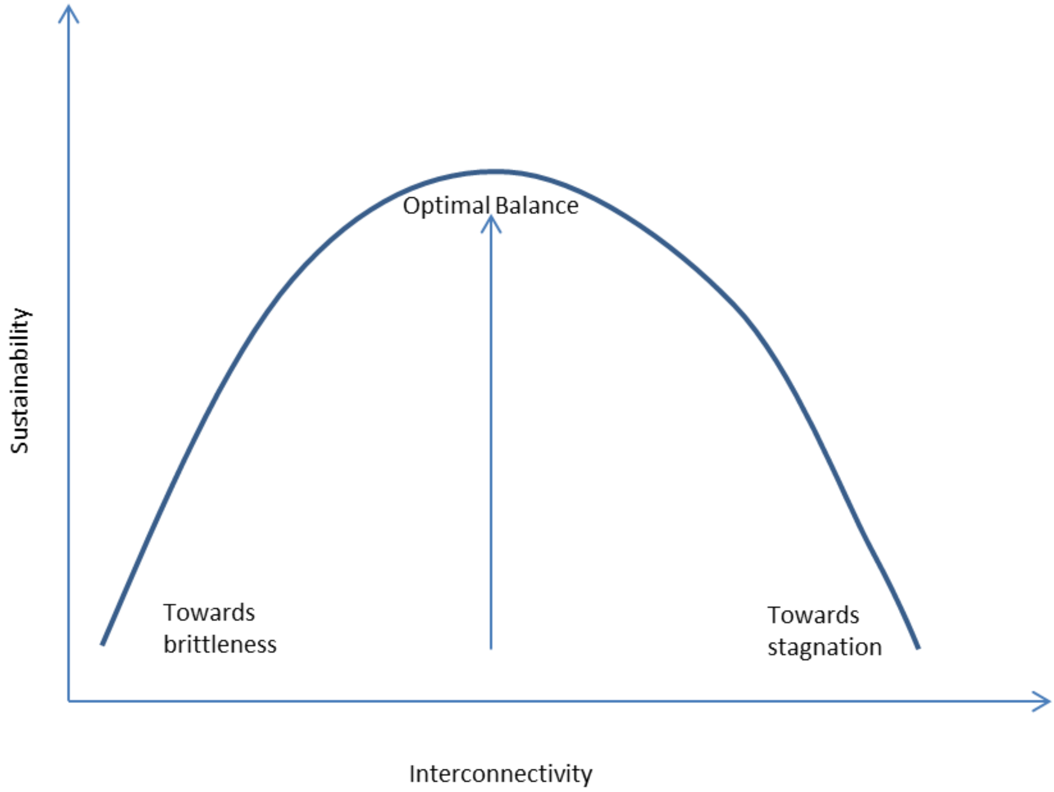


Figure 7- Sustainability Curve (Lietaer, Ulanowicz, Goerner, & McLaren, 2010)

As the above case points out, diversity becomes a prerequisite for efficient outcomes and for innovation, which leads to long term efficiency. However, there seems to be an assumption in the theory that there is a trade-off between efficiency and resilience (Ulanowicz, 1986). Similarly, the theories in the field of manufacturing explicitly mention a trade-off between flexibility and productivity (Gustavsson, 1984) (Son & S, 1987). The adaptive cycle theory incorporates a third dimension of resilience to the existing interconnectedness and potential (growth). However, with the adaptive cycle theory, growth and interconnectedness go hand in hand unlike the information ecology approach. In comparison, the information ecology approach considers the interconnectedness to be directly proportional to resilience. The information ecology describes a system effectively as a locked in system which has to be maintained within that stability range (Ulanowicz, 1986). Also, this kind of approach lacks to incorporate dynamic character of a continuous system that adaptive cycle brings in.

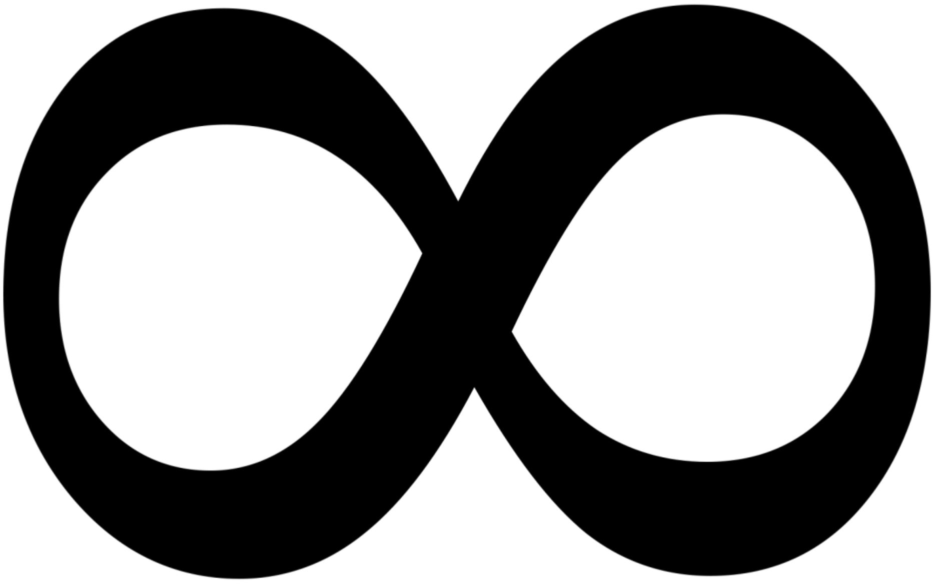


Figure 8- Adaptive Cycle (Gunderson and Holling 2002)

On the other hand, the adaptive cycle has a very dynamic approach, where the relationship between interconnectedness and resilience is not a straight forward linear relationship. However, the relationship between resilience and interconnectedness is more complicated in the adaptive cycle. In the fore loop, as the interconnectedness increases, the systems diversity decreases. In the back loop, the inverse seems to be true, as the interconnectedness decreases, the resilience of the system increases. Significantly, the relationship between the resilience and interconnectedness is inversely related accordingly to the adaptive cycle. This is unlike the information ecology approach, which considers the linear relationship between them. In this case as suggested by the researches in the ecological approach, it makes sense to strike a balance between interconnectedness and sustainability/potential of the system. There seems to be a commonality between the term “resilience of the system” in the adaptive resilience cycle and “sustainability of the system” used in the information ecology approach. The author suspects that they meant the same condition as both studies are from the field of ecology and from the study of biological world. From evolutionary perspectives, this holds an important lesson for the social world and economic world.

3.3 Resilience and Potential

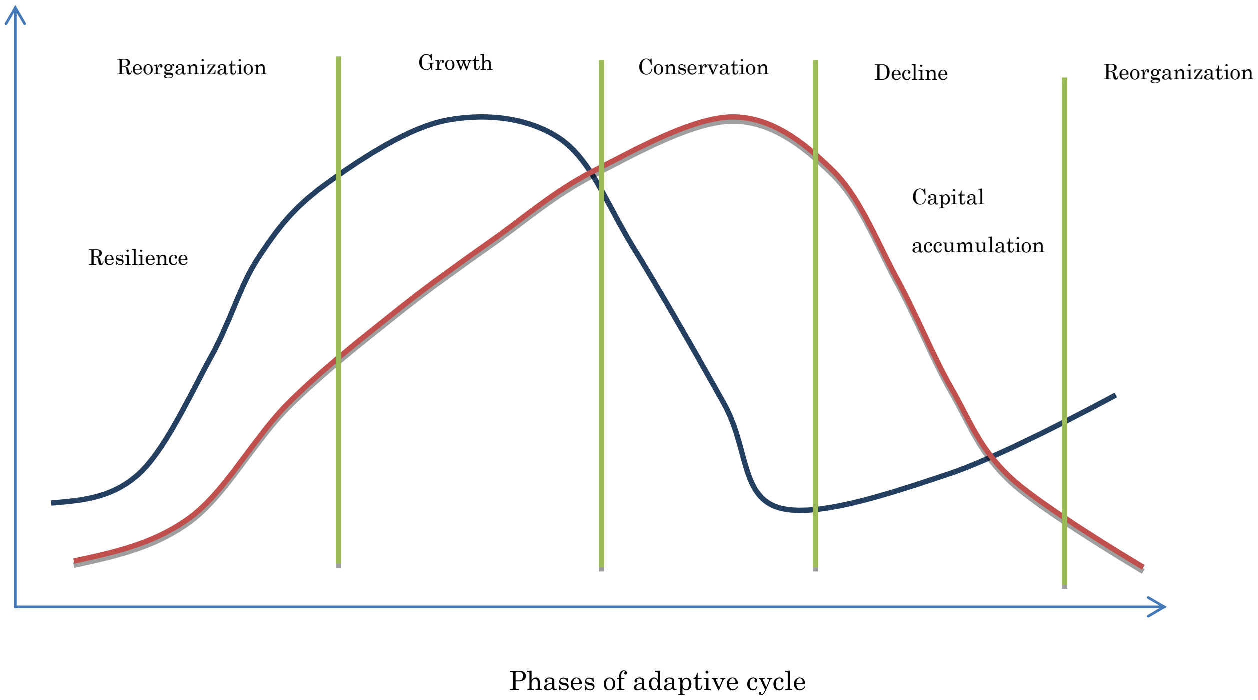


Figure 9- Phases of Adaptive Cycle (Pendalla, Foster, & Cowella, 2010)

The information ecology approach does not explain any relationship between potential of the system and resilience. The adaptive cycle has a more nuanced relationship between resilience and potential (here, capital accumulation). (Simmie & Martin, 2010). In the reorganization and earlier phase of exploitation stage, resilience leads to capital accumulation. In the late phase of exploitation, conservation and early phase of the decline stage resilience lags growth. It is clear that the resilience becomes a prerequisite to see the growth in potential. Without increase in resilience a system might lose out and may not be able to repeat the cycle.

Different phases of adaptive cycle and the resilience at each state are plotted in the graph. The most crucial phase seems to be the conservation stage. In the conservation stage, the potential of the system peaks and simultaneously the resilience of the system decreases at a rapid pace. The most crucial phase for any system's survival seems to be the conservation system. A system while attaining its peak is also losing all its resilience which sets its downfall. The most important factor is interconnectedness. Here the less resilient system is due to increased interconnectedness. As discussed earlier, interconnectedness is indeed a double edged-sword as high interconnectedness makes a system more prone to failure. A highly interconnected system is more prone to an attack or a shock as it transfers that risk across the system which leads to eventual downfall of the system. As suggested in the information ecology approach, there seems to be a merit in balancing the interconnectedness of a resilient and sustainable system.

3.4 Resilience across Scales

Do stable states exist in a dynamic environment? This is a fundamental question which has to be answered. From an evolutionary approach, it is difficult to imagine an equilibrium state given the situation where they are a large number of parameter which constantly changes. A resilient system should be a system which should be able to absorb the perturbation given the uncertainty and unpredictability of a system. There is an important need to understand resilience as a concept which undergoes continuous change rather than as a static condition as in the case of an equilibrium. Adaptive cycle incorporates this dynamic condition and gives us reasons for continued adaptation as one of the best ways of facing these uncertainties.

Resilience across temporal and spatial scale has also to be closely studied. The adaptive cycle gives us one way to understand the temporal scale of a system. However, there is a need to understand and map resilience in a spatial scale. Here it is important to first locate whose resilience we are discussing. We discuss about the resilience of a system but where do we locate the people who are part of these systems. For example, when discussing about the robustness of the system, it is also important for us to locate what kind of perturbation and shocks do individual elements within the system which affect various sections of the society.

Table 2-Types of Perturbation

	External	Internal
Slow	Climate Change	Inequality (Controversial), Terrorism
Shock	Natural Disasters	Economic Depression, War

One of the classic arguments from the social sciences discipline is that the resilience framework does not consider the instability created within system (Brown, 2013). In this whole discussion on resilience, it is more important to note on how people respond to this turmoil. While the discourse has been on the system, it is important to include individual elements when broadly talking about a system. Does a healthy and resilient system mean individual element's (people's) wellbeing is not taken care of? It is crucial when we consider social-economic systems where human decisions can be detrimentally impacted. There is a need to differentiate between the internal shocks and external shocks when discussing the issue of resilience.

3.5 Flexibility as strategy

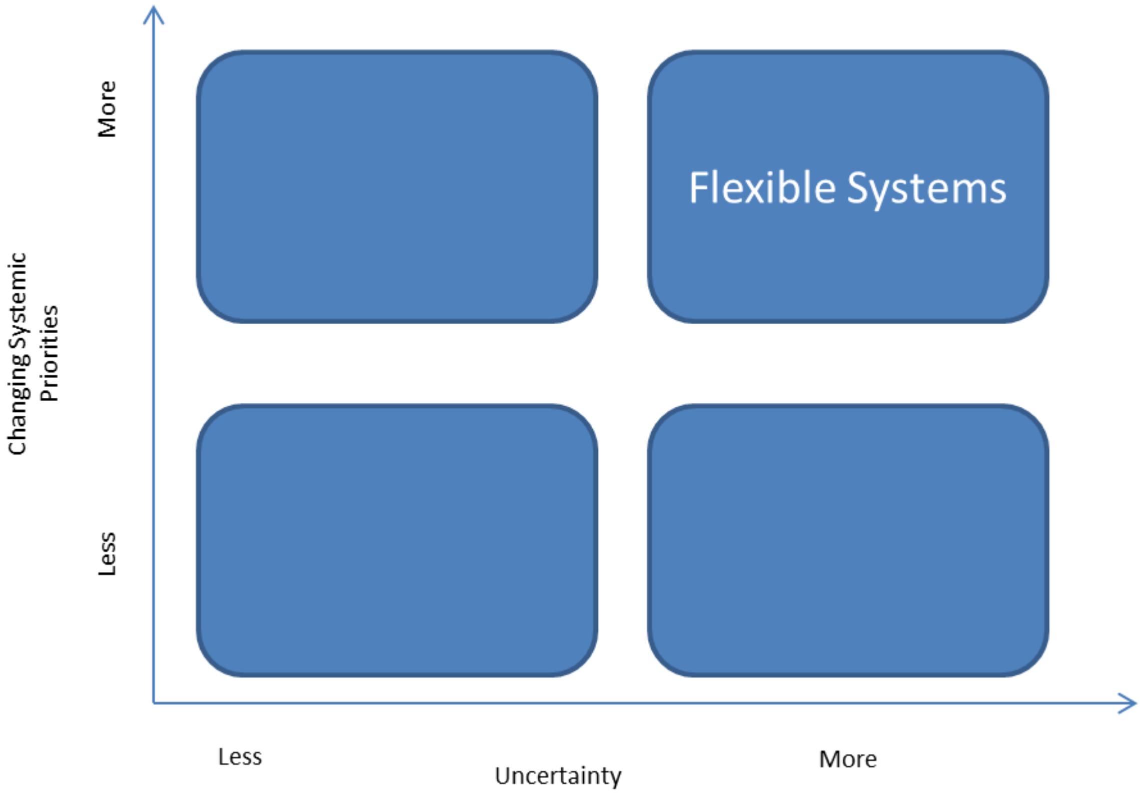


Figure 10 – Flexibility systems are needed with changing environment condition and changing systemic priorities

Most of the shocks and slow perturbation which are external are caused by the nature. The human interventions cannot help much in stopping these external perturbations. The only way is to adapt to these changing environments (External changes). However there are many internal shocks and slow perturbation that are mostly part of the social and economic systems. In addition there are also possibilities that systemic priorities (Internal changes) might change over a period time. Given the human hand in these aspects, humans can reduce or even eliminate the shock or changes. The geopolitical situation at present does not look to be approaching towards that goal. Given these risks and uncertainties, it is important that we create systems which are flexible. These flexible systems should have an inherent capacity to absorb the shock and perturbations such that the system is able to maintain its essential functions.

4 FLEXIBILITY

In the previous chapter we delimit flexibility as a strategy given the uncertainties and risks faced by system. This chapter looks to answers two questions: why is flexibility needed and what flexibility actually is. The second part of the question is answered based on a review of literature of flexible manufacturing systems, degeneracy, economic flexibility etc. Then flexibility is presented with the framework of resilience thinking. The example of a modular system is cited to show the possibility on how the concept can be applied in a network and systems framework.

4.1 Flexibility an imperative for Resilient Complex System

Flexibility is also considered as the property of a system that promotes change in the system (Ferguson, Siddiqi, Lewis, & Weck, 2007). Systems found in the biological arena and social sphere are complex (Peter & Swilling, 2014) (Levin, 2006). These systems are also uncertain and not deterministic in nature. The types of perturbation in these systems can be a sudden shock or a slow change. In addition these shocks can be external or internal in nature. All these perturbation have adverse effect in a system. In a system with multiple components with multiple interactions, it is important that a system has ability to change given the perturbations.

Flexibility as a strategy is used by all at varying levels. Carlsson contents that that there is a vein of theoretical literature, but it is highly formal and abstract (Carlsson, 1989). Bateson defined flexibility as "uncommitted potentiality for change" (Bateson, 1972). He borrowing the idea from ecology adds, 'flexibility' as upper and lower thresholds of variables which together make up a system. When a variable takes on a value close to its upper or lower limit or tolerance, flexibility is lost.

Given these condition, I would like to introduce the concept of flexibility as a measure of resilience. Flexibility as a concept has been used in the economic, engineering and biological world. First, we review the literature broadly from these three fields before demarcating the characteristics of a flexible system which can be implemented in sustainability sciences.

4.1.1 Flexibility from Supply Chain Management

The field of supply chain management has also contributed to the resilience literate. In a book, Goranson differentiated between flexibility from agility as “scheduled or planned adaptation to unforeseen yet expected external circumstance” (Goranson, 1999). Rice and Caniato defined redundancy as additional capacity which could be used during capacity loss. Flexibility on the other hand referred to rerouting the committed capacity elsewhere during the disruption (Rice & Caniato, 2003). Sheffi and Rice define redundancy as “resources in reserve to be used during disruption” (Shefi & Rice, 2005). The same authors define flexibility as organic capabilities that can sense threats and respond to them quickly. Tomlin defines flexibility as contingency action that is carried out in case of disruption. Redundancy is a mitigation action which is taken in advance (Tomlin, 2006). It is clear that redundancy focuses on creating additional stock and buffers. On the other hand flexibility emphasizes the use of available to stock in case of stress or shock by rerouting flows or functions. A flexible system will help to weather a crisis with better use of resources. This does not mean redundancy is not important, rather the author emphasize with increased flexibility, resources can be used more optimally.

4.1.2 Flexibility from the field of Economics

In the economic world, Stifler was the first to define “flexibility” (Stigler, 1939). Carlsson adds that he defined flexibility as those attributes of a production technology which accommodate greater output variation. Thus, he discussed flexibility in terms of firms cost curves: flexibility varies inversely with the curvature of total costs. If the average total cost curve is U-shaped, the more flat it is and the more slowly marginal cost rises, the greater the firm’s flexibility is (Carlsson, 1989). Stigler views flexibility from the economic angle where he finds a system/firm with a flat marginal cost curve as flexibility. Later Scholar like Hart and Mills looked at flexibility from the view of demand fluctuations (Mills D. , 1984) (Hart, 1950). At a systems level Mills and Schumann contented that, “Small firms are able to compete successfully with large, more static efficient producers by absorbing a disproportionate share of industrywide output fluctuations. This is possible because small firms use production technologies that are more flexible than those chosen by large firms. Large firms . . . (have) lower minimum average costs, due largely to scale economies, while small competitors have an offsetting advantage in their superior responsiveness to cyclical or random swings in demand.” (Mills & Schumann, 1985).This definition holds wide ramification when thinking about flexibility on a system levels. Here large firms are considered to be static producers and SME are considered dynamic producer. It is the SME which add the flexibility which is desirable to the system. When conceptualizing a flexible approach, this dialectic nature of large and small firms has to be incorporated. Though the literature from the field of economics deals with demand fluctuation, it was Marschak and Nelson (1962) who extended the boundaries with the following idea (Marschak & Nelson, 1962),

(1) The size of the choice set: a more flexible initial action preserves more choices for actions in the following periods.
(2)Marginal cost: a more flexible plant requires less additional cost to move toward the next position (essentially the Stigler view).
(3) Marginal expected profit: a more flexible plant generates more profits or smaller losses in moving to a new position. (Carlsson, 1989)

It is clear that the economic view of flexibility has been dominated by the cost and primarily focusing demand fluctuation. The ideas proposed by Marschak and Nelson seem to more broader especially the size of choice sets.

4.1.3 Degeneracy

Edelman defines degeneracy as, “the ability of elements that are structurally different to perform the same function or yield the same output, is a well-known characteristic of the genetic code and immune systems. Here, we point out that degeneracy is a ubiquitous biological property and argue that it is a feature of complexity at genetic, cellular, system, and population levels. Furthermore, it is both necessary for, and an inevitable outcome of, natural selection (Edelman & Gally, 2001)”. Edelman and Gally contends that it is this characteristic of a biological system which has been crucial in evolution, as these characteristics allow adaptation, which is crucial for survival given the uncertainty in the biological world. Conventional designs developed by engineers involve modular approach. Edelman and Gally hold that it is conceivable complex degenerate systems can be used by the engineers to build system given the developments in nanotechnology and the reduced cost of electronic chips and memories. However, the understanding of degenerate systems is inadequate at this point of time. It is not known how degenerate systems are linked and synchronized at different levels. This holds important significance in the field of sustainability.

Whitacre demarcates that this degeneracy can be separated into functional redundancy and functional plasticity (Whitacre, Rohlfshagen, Bender, & Yao, 2010). Whitacre adds that in engineering, elements are designed for a specific purpose. He adds that such one to one mapping does not exist in the field of the biological world. Functional redundancy is defined as the characteristics of many-to-one mapping between components and functions. On the other hand, functional plasticity is defined as the characteristics one-to-many mapping between components and functions. Whitacre adds that in these systems the trade-off between efficiency and robustness (sustainability) does not arise due the functional plasticity (one to many mapping). Elements which are excluded from participation with one function can move to another. He points that this happens as excess energy is shared between different processes.

For Whitacre degeneracy leads to a complex hierarchical complex system with robustness and evolvability. Flexibility and robustness are both needed in a biological population, where organisms have to be robust in different environments and at the same time be flexible to adapt to a new environment. Then flexibility and robustness are to be complementary and not stand alone. Degeneracy holds a great potential to operationalize the concept of flexibility in resilience and sustainability. Social and economic systems are needed, which can be innovative and resilient. Degeneracy has been studied with reference to the genotypes and phenotypes; hence care should be taken when applying these concepts at complex social systems.

4.1.4 Flexibility from FMS

Flexible Manufacturing Systems (FMS) have revolutionized the way we used to produce our manufactured goods. Concerns about flexibility have existed for a long time but in a very different form. Marschak and Nelson commented that flexibility is good for uncertainty. However there has been a theoretical belief that flexibility and efficiency/productivity are trade-offs (Abernathy, 1978) (Wheelwright, 1981). However this was because it was not until the 1960's the FMS system were adopted in the firms and plants. Sethi adds that, The efficiency of the mid-volume, mid-variety production is largely accomplished by a drastic reduction or elimination of setup costs and times required for switching from the production of one product to another" (Sethi & Sethi, 1990). Manufacturing flexibility took into account both the external and internal shocks. According to researchers, flexibility arises as it is considered one of the competitive strategies along with price, dependability and product (Hayes & Schmermer, 1978). According to them this flexible strategy should ,"consists of a sequence of decisions that, over time, enables a business to achieve a desired manufacturing structure (i.e., capacity, facilities, technology, and vertical integration), infrastructure (i.e., workforce, quality, production planning/material control, and organization), and a set of specific capabilities (that enables it to pursue its chosen competitive strategy over the long term)."

Table 3– Types of manufacturing flexibility (Sethi & Sethi, 1990),

Types of Flexibility	Meaning	Properties of components in a system/components
Machine Flexibility	"Machine flexibility (of a machine) refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another."	Similarity to one to many mapping
Material handling Flexibility	Flexibility of a material handling system is its ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves.	Ability to move efficiently
Operation Flexibility	Operation flexibility of a part refers to its ability to be produced in different ways.	Similarity to many to one mapping
Process Flexibility	Process flexibility of a manufacturing system relates to the set of part types that the system can produce	A set of outcomes which can be produced
Routing Flexibility	Routing flexibility of a manufacturing system is its ability to produce a part by alternate routes through the system. Alternate	Ability to reach outcomes through alternate routes
Volume Flexibility	Volume flexibility of a manufacturing system is its	Ability to run the system at different output levels

	ability to be operated profitably at different Overall output levels.	
Expansion Flexibility	Expansion flexibility of a manufacturing system is the ease with which its capacity and Capability can be increased when needed.	Ability to expand capacity and capability when needed
Program Flexibility	Program flexibility is the ability of the system to run virtually untended for a long enough period.	Ability of the system to run virtually untended for a long enough period.
Production Flexibility	Production flexibility is the universe of part types that the manufacturing system can produce without adding major capital equipment.	A set of outcomes which can be produced

Review of literature carried out by Sethi and Sethi broadly classified flexibility into ten categories with some category meaning the same. The following characteristics of essential in a flexible system,

- Ability to have overlapping functions (one to many mapping??)
- Reach outcomes through different/alternate ways (many to one mapping??)
- A set of outcomes/results which can be attained without any addition to the system
- Ability to run the system at different output levels
- Ability to expand capacity and capability when needed
- Ability of the system to run virtually untended for a long enough period.

These characteristics can be broadly applied to test systems to test their flexibility, and allow systems to better face uncertainties and eventualities.

4.1.5 Flexible modular Structures

Modular structures are known to be more stable in comparison to other networks such as star networks, random networks or chain networks. A study based on theoretical programming found that stable modular structures are found with multiple hubs and heterogeneous connections (Pan & Sinha, 2008). Modular structures and networks are found in social networks, metabolic and regulatory networks, and computer networks. (Newman, 2006) Modularity systems are considered to be (Schilling M. , 2003).

- Domain specific,
- Expandable,
- Substitutability and combinability
- Near decomposability (as termed by (Simon, 1962))
- Greater internal than external integration

These features stay in close consistency with the values of a system with flexibility. It can be argued that it is flexibility of the structure and the component's which give raise to the above characteristics. Modular structures are domains specific such that individual modules are specialized; however they are also connected to the larger system and are interacting within the system. These systems are also hierarchal nested such that they are modules integrated at different levels. This theme is similar to the concept of panarchy in resilience. Similarly, modular structures are strongly connected within the internally and loosely connected externally. At the same time they maintain strong connection externally. Decomposability of the network is also considered a part of a modular structure. That is, a modular structure is able to neatly delineate from the rest. Modules play a major role of substitutability, which is substituting a function or a component in the system at the time of the need. Garud and Kumaraswamy (1995) emphasize aspect when operationalizing the concept of "economy of substitution" (Garud & Kumaraswamy, 1995). The concept of substitutability is close to the concept of degeneracy used in biological organisms. These systems are also expandable, which allows addition of new components and functions in a system. These ideas on modular system have been developed based on the work of Wagner and Altenberg in field of biology (Wagner & Altenberg, 1996). The work is also based on loosely coupled system and modular organization in the field of economics and technology organization management (Schilling & Steensma, 2001) (Orton & Weick, 1990).

These modular structures are highly capable of change which is represented by the characteristics of Substitutability and combinability, and Expandability. Substitutability and combinability allow for flexibility. Thus flexibility becomes an integral part of a modular structure

4.2 Conclusion

4.2.1 Flexibility and Resilience

The degeneracy concept gives import insights into the behavior of biological system (Whitacre, 2010). Whitacre reinforces that degeneracy positively correlates with robustness and evolvability. It is remarkable to see how our understanding of flexibility has moved from demand fluctuation to the broadly covering various issues. There are some overlaps between our understanding of flexibility in the economic and engineering field with that of degeneracy in the field of biology

Table 4– Flexibility in Different disciplines

1) Economic Flexibility	2) Degeneracy	3) Engineering Flexibility
a) The size of the choice set b) Marginal cost c) Marginal expected profit	a) Many to one mapping b) One to many Mapping	a) Ability to have overlapping functions (one to many mapping) b) Reach outcomes through different/alternate ways (many to one mapping) c) A set of outcomes/results which can be attained without any addition to the system d) Ability to run the system at different output levels e) Ability to expand capacity and capability when needed f) Ability of the system to run virtually untended for a long enough period.

There are clearly some overlaps between degeneracy and flexible manufacturing system. FMS have operationalized one to many mapping 2a and many to one 2b mapping in some aspect. The other interesting feature of the FMS gives us interesting dimensions of flexibility. As suggested by Whitacre with the functional plasticity (2b), it is important to create systems with overlapping function where elements can engage in other functions without wasting resources. Functional plasticity refers to the ability of the system to multi functionality of components. These systems with functional plasticity should make economic sense as they have low marginal cost (1b) and minimum marginal expected profit (1c) . Degeneracy should be considered the essential feature of a flexible system, thus allowing systems to better prepare and face uncertainties. The other broad characteristics listed above table can be considered broad characteristics of a flexible system.

Table 5- Flexibility in Resilience thinking framework

Robustness (persistence)	Innovation (transformation and adaptation)	Both
Ability to run the system at different output levels	Marginal cost	The size of the choice set Many to one mapping
Ability of the system to run virtually untended for a long enough period.	Marginal expected profit	One to many Mapping A set of outcomes/results which can be attained without any addition to the system
	Ability to expand the capacity and capability when needed.	

4.2.2 Flexibility, Interconnectedness and Diversity

The flexibility of a system is the key in an uncertain world. The flexibility of a system as mentioned earlier allows system to adapt to new environments. In an interconnected system, flexibility will allow to easily deploy resources where they are needed. Flexible systems can lead to less damage and quick recovery. However, the role between diversity and interconnectedness is still not clear. Adaptive cycle and information ecology approach point out that interconnectedness and robustness are correlated at the early however after a level this interconnectedness is found to destabilize the system or stagnate the system. Some scholars consider diversity and interconnectedness. However diversity and interconnectedness are not one and the same. While diversity represents the cumulative individual components system, interconnectedness on the other hands reflects how these individual components are connected in the system. It will worthwhile to explore what kind of role can be played by flexibility between diversity and interconnectedness? How flexibility can deal with internal and external shocks. How flexible systems can be perceived by people?

4.2.3 Balancing the extremes

Modular structure allows the balance between tightly connected internal structure and loosely connected external structure. Similar arguments and design are now emphasized by in the field of social networks and information ecology.

Modular structures have domain specificity. This permits to maintain an innate character of modules in a system. This innate characteristic should not be lost due to high interconnectedness. This will lead to reduction in diversity in the system. In the field of sociology, using social network analysis Blau and Schwartz's in 1984 stressed that the societies without any group affiliation would have the highest social integration (Blau & Schwartz, 1984). It also implied that for a complex idea to spread, it was better to reduce social boundaries. This could entail that in a highly diverse population with no social boundary there would be people with no common interest. This leads to erosion of the social network. Damon Centola argues that social integration with no group boundaries is important to a point (Centola, 2015). However, after a certain threshold, it is important that group boundaries are maintained. This permits a population which has some similarities to allow for creation and diffusion of the complex idea within the population. Diffusion of the idea to groups outside the group boundaries would be possible by interaction of members in overlapping groups. The idea here is similar to the structure of a modular networks with identified domain specificity and creation of new novelties in the system

Ulanowicz similarly argues that there is sweet spot, an optimal range between higher interconnectedness and lower connectedness. This he contends is observed in all the natural systems. There is an optimal range between low interconnectedness and high interconnectedness in ratio of one part is to two ratios. (Ulanowicz, 1986). This idea is similar to the structure of modular structure which is a balance between dense internal connection and sparse external connection. It is crucial to seek the balance between these extremes instead of vigorously following one of the extremes.

The debate between generalist vs specialist species follows the same path. The generalist species thrive in various ecosystems. The specialist species thrive in niche ecosystem. However, it is specialist species which are prone to extinction. Some studies have pointed out that specialist species have become generalist species overtime due to changing environments, which has confirmed their long term survivability (Colles, Liow, & Prinzing, 2009). Countries with a more generalist focus on economy rather than a specialist focus tend to be successful over a longer term. Countries like Germany and Switzerland have higher economic complexity, which reflects their focus on a large set of industries. This translates in these countries creating large number of diverse set of goods. Similarly, this is also partly explained in the concept of economic complexity, where countries producing a wide range of goods are able to be more innovative and increase the chances that their technological dominance in immediate future will not go challenged.

An organism has to balance between robustness and transformation in response to the changing condition in the environment. The example of the caterpillar is often cited. Caterpillar need to maintain robustness in terms of functioning and at the same time needs to accommodate the changes in genes required to transform into a butterfly (Ehrlich & Hanski, 2004). Similarly the same ideas are applied to cultural and social sphere, where competing concerns to stabilize the system and transform them at the same time requires that a balance between these needs are struck (Ehrlich & Levin, 2005). These examples point out the importance of balancing the competing extremes. Between low interconnectedness and low interconnectedness, and high specialization and low specialization. The flexibility characteristics of the modular structure allows for this balance.

5 CONCEPTUAL FRAMEWORK

The link between flexibility and resilient system was established in the previous chapter. In this chapter we introduce the conceptual framework for the present study. The mechanism of the model is explained. In the second half of this chapter the author provides the explanation for its applicability in social systems. A case is made for the application of the model for a particular case study of knowledge creation in the economy.

5.1 Conceptual Framework

As noted earlier, robustness and innovation are both important for a system. Robustness is important in the context of present however innovation becomes important in the context of future. Edelman and Gally note that in systems which are planned, robustness is introduced by incorporating redundancy of known externalities (Edelman & Gally, 2001). However in an event of an unknown externality, the author contends that the flexibility of a system is crucial in maintaining the robustness of the system. Also the same flexibility is crucial in realizing innovation within that system. The paper introduces the concept of flexibility from fields like biology, engineering and economics before organizing them within the resilience thinking framework. In this framework, as depicted in the figure 1, this thesis will capture the relationship of complexity with robustness and evolution. In this paper we also explore the factors which influence creation of complexity in economic system.

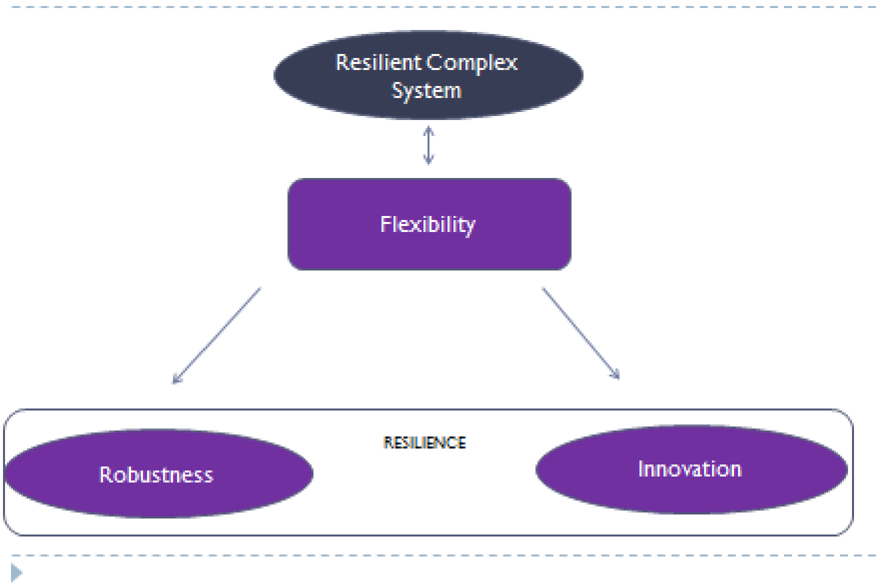


Figure 11 - Illustration of the relationships between flexibility and complex system

Whitacare has put forth the model to explain the complex, robust and evolvable nature of biological system. This model was developed to explain the complex regulatory gene networks in the biological systems. However, the framework is based on studies in the field of biology and in the process of development. It is crucial for us to understand the functioning of biological system. This knowledge can be used in our efforts to create systems especially socio economics systems which are both resilient and sustainable. Also, the model is developed from the concepts used in the field of product design. Similar ideas have been used to conceive products which are both flexible and reconfigurable (Ferguson, Siddiqi, Lewis, & Weck, 2007).

5.1.1 Flexibility

Flexibility is at the core of the system to create complexity. This complexity creates a system which is both innovative and robust. These are important conditions of the system which has to be kept in mind while creating system. The following sections describe various characteristics of a flexible system. These characteristics have to be considered in a case by case to see their relevance in different fields. However these characteristics will serve as basic guidelines when thinking about flexibility.

5.1.2 Flexibility, Innovation and Robustness

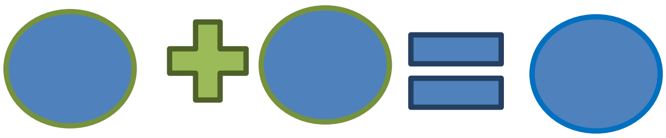


Figure 12- Combination in Flexible Systems

A flexible system allows transfer of flows in a system. Flow in a system can be flow of goods, knowledge, financial capital etc. Flow of goods, capital, and knowledge will allow innovation which will result in new products or way of doing things. Innovation is severely hindered in a "locked in system". A locked in system does not allow flow of goods, capital and knowledge. Such a system will severely hinder innovation and the system would become vulnerable to changes in the long run. Combination of existing parts in the system is considered a critical process in innovation. Combination creates novelties and leads to innovation. Numerous examples, in the field of biology prove the presence of combination in novelties. For example, Andreas Wagner cites the example of combination of chemical reaction in creation of life (Wagner & Rosen, 2014). Solee et al reviewed the biological and technological evolution. They emphasize that technological evolution and biological evolution are driven by reuse and combination of existing resources. They stress that unlike biological evolution, technological innovation can be planned. This is an important perspective which can be applied to the human controlled domain. Systems created by humans with the above perspective can be aimed for higher performance in form of resilience and flexibility. (Solée, et al., 2013) An innovative system has a higher potential not to become vulnerable and fragile to stress and strain.

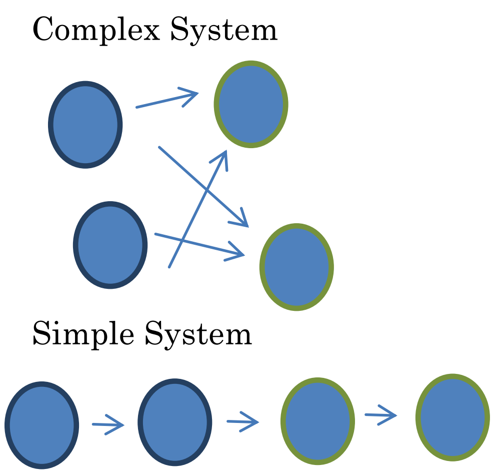


Figure 13– Multiple pathways and parts in complex system vis a vis simple system

Assume a simple system with four parts (circle) is arranged in a linear fashion. The circles enclosed with green perimeter are under stress. It would take a larger time and resources for the simple system to take the resources to the parts under stress. Also, if these linear pathways are broken, there is a higher chance that the flows cannot reach the parts under stress. On the other the complex system in the above figure with two pathways is more oriented towards providing resources at time of stress. Also, if there is random breakdown of a pathway, there are higher chances that the resources reach the part under stress in comparison to the simple system. Similar arguments have been made by Carlson & Doyle (2002), who emphasizes the cliché that complex systems are not robust, is not true. They present the analogy of a simple bacterium. They have several hundred genes in comparison to Escherichia coli, which have ten times the genes present in simple bacteria. Thus, the simple bacteria can only survive in highly regulated environments. E. coli on the other hand can survive in a wide range of environments. Similarly, they also present the example of older automobile which have simple systems, the newer vehicles have complex systems with airbags, antilock -breaking system, anti-skid systems etc. The newer automobiles are safer and robust in comparison to the earlier older automobiles. They point that internal complexity drives robustness in the system (Carlson & Doyle, 2002).

A flexible system is able to transfer the needed resources from the point of surplus to deficit in times of stress or strain. The system stays stable without drastically affecting the system. This permits robustness of a system through flexibility. In short, flexibility has ability to create both robustness and innovation which is responsible for creating systems which are resilient. Robustness and innovation reflect short term resilience and long term resilience of a system

5.1.3 Flexibility and Resilience Complex System

Robustness and innovation are important features for successful systems, as explained in the previous sections. A complex system is better able to provide robustness and innovation. Robustness and Innovation in the system is only possible if the system is able to change. A system which is inflexible or locked in has a major possibility of damage. It is in this context the flexibility of a system is crucial. Flexibility refers to the property of the system to change (Ferguson, Siddiqi, Lewis, & Weck, 2007). Hence a system which can be actively change can be robust under stress and strain. Also, a system which can change has more chances of transformation. Flexibility in that case is an essential property for a resilient system which is complex.

Table 6-Relationship between Flexibility and Variables

	Flexibility	Relationship	Citation
Robustness	More parts and pathways	Flexibility allows higher chance of survival	(Carlson and Doyle 2002)
Transformation	More interactions	Flexibility facilitates the interaction	(Wagner and Rosen 2014) (Solee et al. 2013)
Complex System	Robustness and Transformation	Allows changes	(Fergusson et al. 2007)

5.2 The Conceptual Framework in Socio Economic Context- Empirical Illustration

5.2.1 Existing Study on Resilience and Economy

Studies have linked the concept of the economy with resilience. Certain have tried to map resilience by capturing macro indicators related to economic resilience. Briguglio et al notes that for resilience certain macro-economic factors like fiscal deficit-to-GDP ratio, the sum of the unemployment and inflation rates; and the external debt-to-GDP ratio are crucial (Briguglio, Cordina, Farrugia, & Vella, 2008). Briguglio et al recognizes the importance of social factors captured in human developed index like condition of the population in terms of education and health. HDI is also considered a crucial component in estimating the resilience. The environmental dimensions of the country are also considered crucial. This is captured by incorporating the per capita ecological footprint. The variable also captures the amount of resources entering an economy from outside the political boundaries of the country. Paton and Johnston (2001) stressed that countries with higher per capita GDP are more resilient (Paton & Johnston, 2001). Other parameters which describe the social condition of the population like employment in various sectors and income equality are sometimes included to include the social dimension (Morrow, 2008). An OECD study noted that stable macroeconomic condition and low interest rates stimulate innovation. It also notes that lower barrier to FDI results in innovation (OECD, 2007).

Similarly scholars have focused on connectivity with the global economy to ascertain resilience. The migration and global flows reflect the interconnectivity of countries economy with the global economy. Duval, Elmeskov, and Vogel found that nations which restrict ability to lay off employees face less shock but they last longer (Duval, Elmeskov, & Vogel, 2007). Briguglio developed a hypothesis that concentration of export industries inhibits resilience.

5.2.2 Evolutionary in nature

Thorstein Veblen (1898) introduced the term evolutionary economics to emphasize the dynamic nature of the economy (Veblen, 1898). It is the work of Richard Nelson and Sidney Winter "An Evolutionary Theory of Economic Change" which was published in 1982 which brought renewed interest in the field (Nelson & Winter, 1982). The work focused on the dynamic aspects at the firm which resulted in knowledge creation, economic growth, and technological progress. Earlier scholars like Schumpeter, Marshall and Hayek had also made similar points. Schumpeter (1942) hinted at the same argument and highlighted (Schumpeter, 1942),

> "Capitalism ….. is by nature a form or method of economic change and not only never is but never can be stationary."

Schumpeter contended that economic changes are both static and dynamic properties in a capitalist economy. However he found most of the emphasis in the academia on the static property of the economy. The academic field had not concentrated much on the dynamic property of the economy and society. Knowledge creation fell into the dynamic nature of the economy. Alfred Marshall noted that the economy changed endogenously due to an organic process of incremental change (Marshall, 1898). Marshall added that the functioning of economy was closer to modern biology however he was critical about the methodology to study the aspect. The modern economic development was made possible by the complex nature of the knowledge creation in the economy. Hayek did not believe in the deterministic nature of development of the society and the economy. He looked towards an open view on development of the society and the economy (Hayek, 1945).

At another level, Kurt Dopfer argued that the level of analysis differ in mainstream economic approach and evolutionary approach (Dopfer, 2015). In his words,

> “One is the level of knowledge for economic operations, the other that of operations under the assumption of given knowledge. Evolutionary economics deals with the former, neoclassical mainstream economics with the latter.”

He emphasizes that the study of structure and evolution of knowledge creation required approaches from the evolutionary perspective. He also adds that such analysis will leads towards “integration of Smith (structure) and Darwin (process).”

In the thesis, the study focusses on the study of the structure and evolution of knowledge. We focus on the role of knowledge creation through diffusion in the knowledge intensive sectors. The conceptual framework from the biological field is applied to socio economic context where social institutions, economic markets and can be represented as a network. This is the extension to the rich tradition of evolutionary concepts being applied in the field of economics to study societal and economic factors. Markets and institutions allow the flow of products, knowledge etc. to reach places which were not directly related in creation of either knowledge or product.

5.2.3 Concepts

5.2.3.1 Economic complexity

Economic Complexity – The Atlas of Economic complexity prepared by Hidalgo et al measures the productive capacity possessed by countries (Hausmann, Coscia, Simoes, & Yildirim, 2014). This productive capacity is developed over a period of time through trial and error method. This productive capacity predicts the technological prowess of countries. This technological prowess is also reflected in the relative wellbeing of the population and gross domestic product of countries. Countries without the “geological luck” of being endowed with minerals and other natural resources are left with no choice but to to raise the wellbeing of population through accumulation of productive knowledge. For producing a product, diverse sets of skills, knowledge and capital is needed. The skills and knowledge can include different skills like design, marketing, technology, law, operation etc. The combination of all these knowledge and skills reflects the productive capacity to produce the products in that country. Thus countries are capable of making certain products provided they have knowledge and skills with their country or are able to sources it to their countries from others. In short economic is complexity is reflects as,

> “Economic complexity, therefore, is expressed in the composition of a country’s productive output and reflects the structures that emerge to hold and combine knowledge.”

5.2.3.2 Business Services

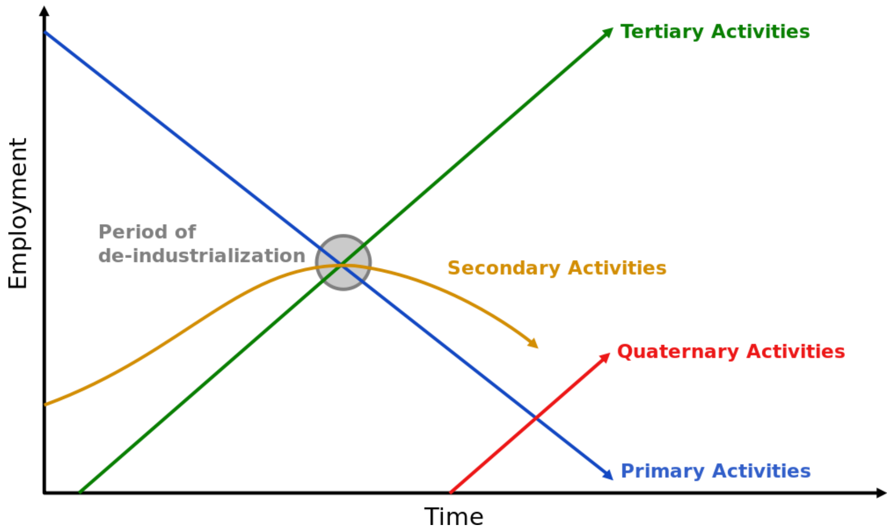


Figure 14 – Colin Clark’s three sector model and growth of quaternary sector (wiki - commons)

The Service Sector has slowly replaced agriculture and manufacturing sectors as the dominant sector in OECD countries. This shift is considered part of the natural evolution of a country’s economy structure (Clark C. , 1940). The Service Sector, especially the knowledge intensive service sector, includes information generation and sharing, information technology, consultation, education, research and development, financial planning, and other knowledge-based services. These services play an important role as they create avenues for new knowledge. The illustration shows natural evolution of industries based on Clark (1940) three sector model. Recently, quaternary sector which reflect the knowledge-intensive service sector are considered to be knowledge driven new age industries. These industries are also called business services under Eurostat system of classification.

Business functions can be of two types. They are core function and support functions. The core functions comprise the primary activities of an enterprise. The activities will be primarily intended towards the customer. The support business services involve the critical activities, which include other crucial role in facilitating the functions of primary core business. These include functions like logistics, marketing, Information Technology, administrative function, engineering services and R &D.

The business services according to Eurostat data are set of business activities performed for another enterprise which are as follows, (eurostat , 2013)

- technical services such as engineering, architecture and technical studies;
- computer services such as software design and database management;
- other professional services such as legal, accounting, consultancy and management services.

These business services provide specialized niche specialized services which are different from the core activities of the enterprise that use these services. This specialized niche services play a major role in the competitiveness of an economy.

5.2.4 (Business Services leads to Flexibility) - Operational Mechanism

In recent times the increasing importance of the knowledge economy has been stressed (OECD, 1996).Von also identifies business services with knowledge intensity, low capital intensity, and a professionalized workforce as identifiable characteristics (Von Nordenflycht, 2010). The knowledge intensity and professionalized work force shows the importance of the knowledge and the people who possess the knowledge. Strambach identifies the strong link between user and supplier; and consultancy as two main characteristics of knowledge based business services (Strambach, 2008). The strong interaction between the user and the supplier leads to cumulative learning. Consultancy reflects a strong emphasis on the problem solving with knowledge. Further, Innovation in business services is reflected by the following, (European Commission, 2012)

- Knowledge embedded in humans
- Output which is intangible
- Strong links between user and creator
- Production and consumption of knowledge is simultaneous

In addition, the nature of knowledge addition is project based and interactives. Hence, the knowledge accumulation is iterative. The knowledge in short is “"embodied in people and embedded in networks" (Strambach, 2008). The intangible services are also hard to protect (Gallouj & Weinstein, 1997), hence patents do not play a major role in these industries unlike manufacturing (Howells, 2001). However, some sectors within the business services have strong tradition of filling copyrights (Miles, 2001). In these sectors, trust, secrecy and reputation become an important asset (Miles, 2001).

In traditional sector manufacturing sectors knowledge is created through an incremental approach through p combination of earlier knowledge, low levels of R&D, learning by doing and interacting. However in fields like biotechnology and ICT (Information and communication Technology), the knowledge is gained though high R&D The knowledge creation in business services is a complex mix of tacit knowledge and codified knowledge (Nonaka & Takeuchi, 1995) (Johnson, Lorenz, & Lundvall, 2002). Tödtling emphasized the importance of tacit knowledge in innovation process. Face to face communication becomes crucial and leads to spatial clustering (Tödtling, 1994). On the other hand, the “global p pipelines” becomes a crucial indicator in gaining codified knowledge (Bathelt, Malmberg, & Maskell, 2004).

The knowledge intensive service sector industries play an important role in transfer of knowledge especially the tacit knowledge. This tacit knowledge is responsible in creation of economic complexity as this transfer of knowledge leads to creation of new knowledge. This knowledge in turn leads to creation of new services and goods in the nation’s economy which leads to economic complexity in the system. Tacit knowledge can move through two ways. Through movement of people and movement of knowledge

5.2.4.1 Movement of people

Hidalgo stresses the importance of individual who possess the knowledge which they gain through first hand practice at a firm. The movement of an individual also moves the knowledge. Individuals learn to work in groups by doing things together in a group and by bringing their skills together. For example, Hausmann et al (2013) note that the pioneering firms bring knowledge from outside the region. Similarly, Neffke et al (2014) contend that new economic activities are brought by non-local firms and entrepreneurs (Neffke, Boschma, & Henning, 2014). This helps in movement in the tacit knowledge with the people.

Similarly, this interplay is reflected in quaternary sector as it allows in mingling of knowledge from diverse fields. For example, a consultancy firm employs individuals with different skills and such that there are greater possibilities in novelties. This is mainly due to the higher chances of diverse ideas combining giving rise to novel ideas and suggestions. The movement of people to knowledge intensive service sector through tacit knowledge allows for these possibilities. Since knowledge intensive service sector are critically dependent on knowledge, this movement is very crucial for their survival.

5.2.4.2 Horizontal Transfer – Movement of knowledge

The quaternary sector permits for horizontal transfer of knowledge. In biological organisms, several studies have documented horizontal gene transfer in bacteria and archaea evolution (Boto, 2009). This has resulted in benefits as the organism does not have to wait for the development of the gene endogenously rather it accepts exogenously. Also, scholars have proposed Symbiogenesis as a concept explains that evolution is also established due to associations and inter connections within organisms (Carrapiço, 2010)). Roossnick contented that HGT, by introduction of new novel elements, (genomic) allows for faster adaptation to environmental conditions (Roossinck, 2008). Zook proposes that "symbiosis is the acquisition and maintenance of one or more organisms by another that results in novel structures and metabolism." (Zook, 1998) These insights point that there are inter dependent connection between biological organism and the benefits horizontal movement of gene or organism. Given human insights, horizontal movement of information is highly possible and will be positively enhancing. The quaternary sector allows this flow of information which increases the knowledge creation, both technological and organizational. Knowledge creation leads to the economic complexity. This complexity with diverse economic sector will entail further knowledge creation and it is a cyclical process.

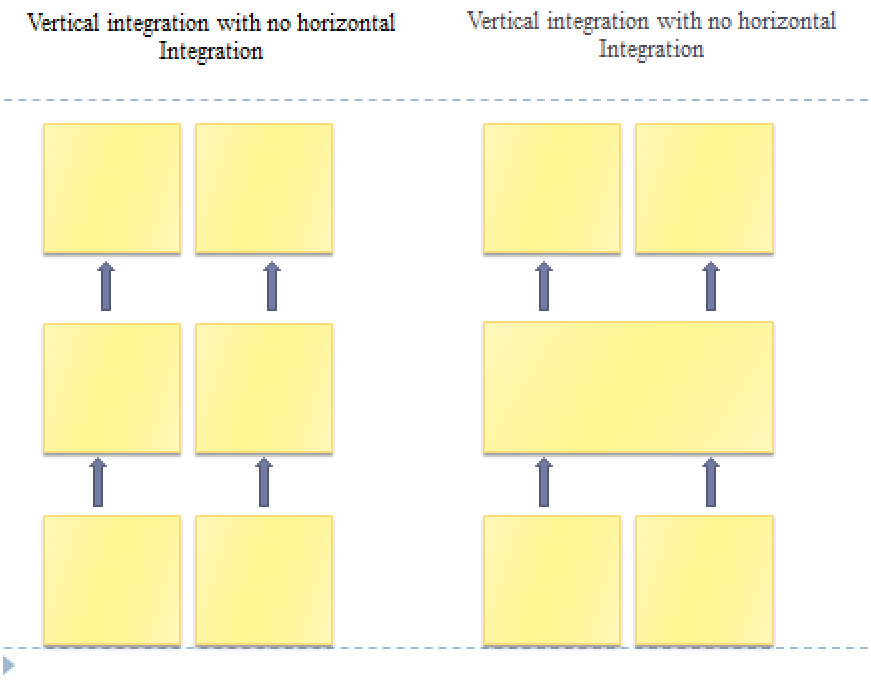


Figure 15 Horizontal and Vertical Integration

The complex challenges faced by human society need a combination of ideas and technologies from diverse set of fields. This combined knowledge creation will help in fighting challenges. The traditional form of knowledge creation was vertically oriented. This was possible with growth of individual disciplines and specific industries (Modern education) which started on focusing their unique research. Ronald Coase (1937) noted that transaction cost allowed for a vertical structure with some producer and infinite customers (Coase, 1937). On the other hand, Rajdou and Prabhu recently assessed that with the growth of technology and quaternary sector, the chance of horizontal movement of information has increased. They add that technology like internet, mobile technology and social network allow do it yourself (DIY) platforms and peer to peer horizontal networks (Radjou & Prabhu, 2015). A study by Matous, and Todo has shown how the interlocked Japanese companies with vertical integration are now breaking to form a more diversified supply chain possibly hinting at the horizontal integration (Matous & Yasuyuki, 2015).

5.3 Knowledge Transfer as flexibility

Todtlinga et al (2006) noted four types of knowledge interactions (Tödtlinga, Lehnera, & Trippl, 2006). They are of two types – knowledge transfer and collective learning. The knowledge transfer involves direct market transfer of knowledge and knowledge spillovers. The market transfer allows for direct transfer of knowledge from one firm to another. The knowledge spillover could involve imitation of knowledge from a university or another firm. The collective learning is in the form of formal and informal modes of interaction. The formal modes of interaction are through cooperation. The informal modes of interaction are through milieu.

Table 7 – Connecting characteristics of flexibility and Knowledge Transfer

Market Relation	Ability to expand the capacity and capability when needed.
Spill over	A set of outcomes/results which can be attained without any addition to the system
Formal cooperation	Many to one mapping One to many Mapping
Informal Milieu	Many to one mapping One to many Mapping A set of outcomes/results which can be attained without any addition to the system

The above table matches the concept of flexibility with the knowledge transfer mechanism. The direct market transfer of technology allows transfer of knowledge into a new form. The process allows for expansion of productive capabilities in the system. At a firm perspective, it brings new opportunities with advent of the new knowledge. A knowledge spillover similarly allows for changes in the system without any necessary addition of effort. A firm can gain new knowledge through imitation. This knowledge can be gained by firms through university or another firm in close proximity. Formal cooperation and informal milieu increase the many to one mapping and one to many mapping. These two strategies allow a firm to extend networks with other firms and collaborate with them in creating new knowledge. The informal milieu in addition to advantages of the network does not incur much cost to the firm. Todtlinga et al (2006) based on their study found that the existence of transfer of codified knowledge at an international level. (Tödtlinga, Lehnera, & Trippl, 2006). In addition, at a regional or national level, transfer of tacit knowledge transfer through spillover or informal milieu was observed in the same study. The movement of tacit knowledge can also be through movement of people with the knowledge (Neffke, Boschma, & Henning, 2014).

5.4 Conceptual Framework application for the illustrative example (part of flexibility used in the study)

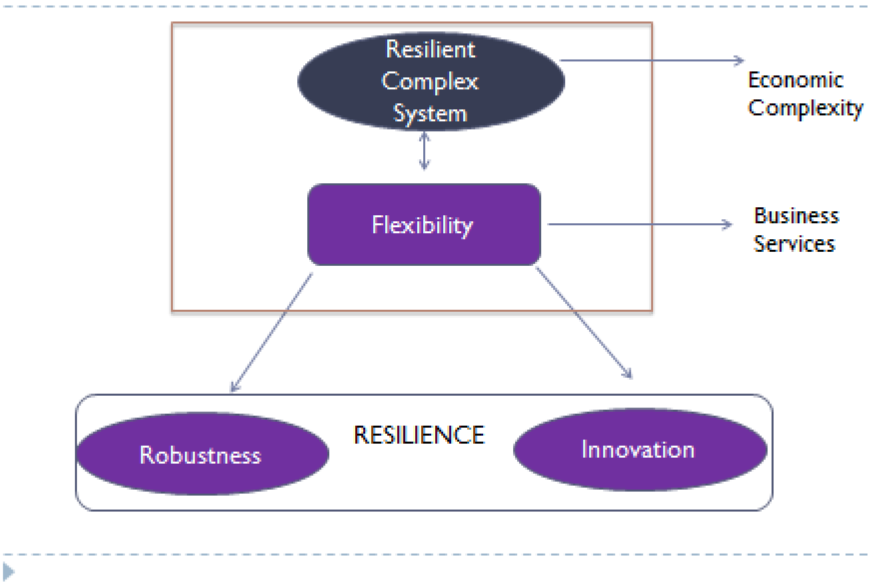


Figure 16 Conceptual framework

A flexible system is able to transfer the needed resources from the point of surplus to deficit in times of stress or strain. Also, it plays a major role in combination of existing resources to raise newer ideas and products (Hausmann, Coscia, Simoes, & Yildirim, 2014). For the illustrative example, we consider the knowledge-intensive service sector to create the flexibility in terms of knowledge flow. Following sections link the concept of knowledge-intensive service sector as creator of flexibility. The section that follows charts the links between,

Economic complexity and Business Services (Link 1)
Economic Complexity and Innovation link through Flexibility (Characteristic 1)
Economic Complexity and Robustness link through Flexibility (Characteristic 2)

5.4.1 Economic Complexity and Innovation link through Flexibility

Hidalgo et al notes that there are two kinds of knowledge – explicit and tacit. The explicit knowledge on one hand can be easily transferred through text or visualization, it is the tacit knowledge which is very difficult to transfer and it is this knowledge which limits growth and development in countries (Hidalgo & Hausmann, 2009). It also important that this tacit knowledge, which is embedded in an economy, is modularized at the level of an individual, organization is grouped to make sure execution of complex process task and process is possible. Hence it is also important that the knowledge which is available modularly should be integrated to execute the complex process which needs knowledge sets from wide fields. An economy with higher amount of modular knowledge sets and interaction among them has a complex economy. Flexibility is a key concept in maintain modular structures and networks.

A country with a higher economic complexity is better positioned to create newer products and process which will directly lead to more innovation in these countries. Also, newer knowledge creates newer products and process which will in turn increase the complexity of the economy.

5.4.2 Economic Complexity and Robustness link through Flexibility

A country with a higher economic complexity will be able make more products and hence has a greater chance of exporting them to other countries which do not have the tacit knowledge to create them. This allows the countries with higher complexity to earn foreign exchange. The countries with higher complexity have higher chance of having positive balance of trade. A positive balance of trade allows a country the opportunity of having trade surplus. This will allow the countries to be more robust with in times of economic slowdown (which can be considered shock or stress in resilience literature).

Robust systems needs clear integration of the society at times of need. This integration between diverse set of industries needs interconnections and interactions among various economic sectors. Such a network with interconnections between different economic sectors can help in transfer of materials, skills during stress or strain which is crucial for a system to survive thus instilling robustness into the system. Under extreme stress and strain, the countries might not be able to pool in scarce resources. A flexible economy allows easily pooling of resources with easily flow of resources.

5.4.3 Economic complexity and Business Services – Hypothesis

The study deliberates into the role of business services with technological prowess of countries. The economic complexity index captures the amount of products a country exports. It is argued that the country which exports most diverse and least ubiquitous product have the capabilities to do so. This also entails that the countries also possess the knowledge to do so.

The business services include functions like functions like computer services, engineering services, consulting services, R &D etc. The author identifies the role of the services in transferring the horizontal information from peer to peer industries in form of horizontal flow of information. The business services are services in nature. These are intangible services which are not goods. The services are in form of knowledge and knowhow which help the manufacturing firms to produce goods which are tangible in nature. The horizontal nature of transfer flow takes the knowledge to the peers who accelerate diffusion and spreads the benefits economy wide. For example, there are studies on horizontal knowledge flow between MNC subsidiaries (Silva, Guevara, Fernandes, & Rodrigues, 2014) (Monteiro, Arvidsson, & Birkinshaw, 2008). These studies for the economy wide have not been yet conducted. The business service firm would be able to learn as they do and extend the same knowledge to other firms. This process results in movement of knowledge from one firm to another. This movement of knowledge flow is horizontal in nature in comparisons to the earlier vertical integration. The horizontal knowledge flow allows for faster adaptation in comparison to conventional means, which includes creation of solution "in-house". In the study the author points at the mutual relationship between business services and economic complexity. These two variables are self-reinforcing. The Greater complexity results newer knowledge which can improve the amount of knowledge flow in the economy. Similarly the movement in peer to peer knowledge flows increases the complexity and innovation.

The general proposition used in the empirical illustration is as follows,

There is mutual relationship between increased activity of business services which leads to increased economic complexity and vice versa.

6 METHODOLOGY

In this chapter in order to illustrate the concepts described earlier, the author checks whether an economic system that has a higher contribution of knowledge intensive service sector to the economy is positively related to economic complexity in that country. To analyse the role of business services, the author maps the countries contribution of the business services per GDP with the economic complexity. This is done to estimate the conditions that are suitable for creating higher economic complexity in the system.

6.1 Focus on Europe

The focus on the European Union is primarily due to three reasons. First, European Union region is the most open to trade globally. European Union has 15 % of the share in world trade in goods in 2013. The share of global trade in goods and service is higher at 16.5 % in 2013 (Directorate General for Trade - European Commission). Second, the countries in the European Union have a high share of trade with other countries within the union. It is the world's largest single market (European Commission , 2014). Third, Eurostat consistently collects data on business services for these countries. The data consistency combined with the nature of open trade makes Europe an ideal choice for analysis.

6.2 Data Source

The data sources for the analysis are primarily sourced from the OECD-WTO Trade in value added database, Eurostat and Atlas of Economic complexity database. The data for the year 2008 was used as it was the latest among all the data sources. The data pertaining to business services for European countries is taken from Eurostat database. The data on economic complexity is sourced of Atlas of economy complexity. Supplementary data to support the discussions were taken from WTO OECD trade in value added database

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6.2.1 Economic Complexity

In the following section, the author explains the calculation of the ECI. The values of ECI are developed from the data on international trade. The trade data of countries is available in the matrix form with the amount of products exported by them. Consider matrix M_{cp} which consists of n rows which represent different countries (c) and n columns representing different products (p). The entries in the M_{cp} matrix are filled based on Ballassa's Relative Comparative Advantage (RCA). RCA is an index which reflects the relative position of country exports in certain categories of goods and services globally. RCA allows estimating if the product is exported more than the fair share. The RCA_{cp} is calculated as follows,

$$RCA_{cp} = \frac{\frac{\mathbf{x_{cp}}}{\sum_{\mathbf{c}} \mathbf{x_{cp}}}}{\frac{\sum_{\mathbf{p}} \mathbf{x_{cp}}}{\sum_{\mathbf{c,p}} \mathbf{x_{cp}}}} \quad (1)$$

Where, the term X_{cp} represents the exports of product "p" from country "c" to other countries. Based on the value of RCA_{cp}, the matrix M_{cp} is filled as follows,

$$M_{cp} = \begin{cases} \mathbf{1\ if\ RCA_{cp}\ \geq 1} \\ \mathbf{0\ otherwise} \end{cases} \quad (2)$$

The matrix is defined as 1 if the country's relative position of countries export is more than fair share and 0 if it is not. The diversity and Ubiquity are defined as follows,

$$\text{Diversity}=kc,0= \sum_{\mathbf{c}} \mathbf{M_{cp}} \quad (3)$$

$$\text{Ubiquity}=kp,0=\sum_{\mathbf{p}} \mathbf{M}_{\mathbf{cp}} \quad (4)$$

Economic complexity is calculated by taking into account two factors. The diversity of the product produced by a country and the presence of the same product's in other countries (ubiquity). To calculate ECI, diversity and ubiquity of the country are used to each other through recursion as following,

$$K_{c,N} = \frac{\mathbf{1}}{\mathbf{Kc,o}} \sum_{\mathbf{p}} \boldsymbol{M_{cp}} \cdot \boldsymbol{K_{p,N-1}} \quad (5)$$

$$K_{p,N} = \frac{\mathbf{1}}{\mathbf{Kp,o}} \sum_{\mathbf{c}} \boldsymbol{M_{cp}} \cdot \boldsymbol{K_{c,N-1}} \quad (6)$$

Applying (6) in (5), we get

$$K_{c,N} = \sum_{\mathbf{c}} \boldsymbol{K_{c',n-2}} \ \tilde{\mathbf{M}}_{\mathbf{c,c'}} \quad (7)$$

Where $$\mathbf{M}^{\sim}_{c,c'} = \sum_p \frac{\mathbf{M}_{cp} * \mathbf{M}_{c'p}}{\mathbf{K}_{c,0} * \boldsymbol{K}_{p,0}} \tag{8}$$

The economic complexity index is reflected by

$$ECI = \frac{\mathbf{K}^{\rightarrow} - <\mathbf{K}^{\rightarrow}>}{\mathbf{stdev}\ (\mathbf{K}^{\rightarrow})} \tag{9}$$

Where, $k^{\rightarrow}$ is an eigenvector of $M^{\sim}_{c,c'}$ the Economic Complexity Index is defined as the second largest eigenvector of the $M^{\sim}_{c,c'}$ matrix.

Table 8- Economic complexity of European countries in 2002

Countries	Economic Complexity in 2002
BE:Belgium	1.18184
BG:Bulgaria	0.47551
CZ:Czech Republic	1.61843
DK:Denmark	1.31846
DE:Germany	2.15217
EE:Estonia	0.856224
IE:Ireland	1.60851
EL:Greece	0.245548
ES:Spain	1.04987
FR:France	1.5488
HR:Croatia	0.962526
IT:Italy	1.44831
LV:Latvia	0.718831
LT:Lithuania	0.490175
HU:Hungary	1.19581
NL:Netherlands	1.08529
AT:Austria	1.78976
PL:Poland	1.03651
PT:Portugal	0.734011
RO:Romania	0.640986
SI:Slovenia	1.47138
SK:Slovakia	1.32079

FI:Finland	1.8937
SE:Sweden	1.98691
UK:United Kingdom	1.79361
NO:Norway	0.519007
CH:Switzerland	2.05461
MK:Former Yugoslav Republic of Macedonia, the	-0.07057
TR:Turkey	0.097425

The data from the atlas of economic complexity is used in the study as it is reflective of the total complexity in the economy. The values of ECI of European countries were taken for the year 2008 as mentioned earlier.

6.2.2 Business Services

The economic services contributing to business services data is taken from Eurostat database. The relative contribution of these services to the total GDP of the country is calculated and represented as follows,

$$\text{Relative Activity of Business Services} = \frac{\textbf{Gross value added in buisiness srvcies}}{\textbf{Total GDP}} \quad (10)$$

This measure gives us the relative contribution of business services in the economy. Similarly the disaggregated business services contribution is calculated and represented as,

$$\text{Relative Activity of Specific Business Services} = \frac{\textbf{Gross value added in specific buisiness srvcies}}{\textbf{Total GDP}} \quad (11)$$

The specific sectors used in the study are as follows,

- Architectural and engineering activities; technical testing and analysis
- Financial and insurance activities
- Scientific research and development
- Legal and accounting activities; activities of head offices; management consultancy activities

Table 9 – Concepts and Variables used in Case Study

Concept	Variable	Data source
Complex System	Economic Complexity I	Atlas of Economic Complexity
Flexibility	Business Services	Eurostat

6.3 Methodology

The author carried out a correlation analysis to show the dependence of business services in the creation of economic complexity. The increased role of business services in an economy reflects the flexibility. This flexibility shapes the movement of knowledge in the economy. The increased chance of movement of knowledge increases the chance of creation of knowledge.

The correlation analysis will help in establishing mutual relationship between these two variables rather than proving causality. There are two reasons for not using regression analysis. The data at this point is not necessarily available to test the relationship to prove causality. Only data for European countries and developed countries are available for shorter duration of time. Data availability over a longer time frame and data availability for all, both developed and developing, countries is necessary to prove causality between variables. Given the complex nature of economic structure and interaction, it is difficult to establish causation between these two variables with limited variables. In addition, the illustrative example is used to here to explain mutual relationship between flexibility and resilient system through role of business services and economic complexity index respectively. The study stops at establishing the mutual relationship rather than proving causation.

In the thesis, three correlation analyses are carried out. The first correlation relationship is between Relative Activity of Business Services and Economic Complexity of European countries for the year 2008.

The second correlation analysis is between Relative Activity of Specific Business Services and Economic complexity. This is more specifically to check the relationship specific between disaggregated business service sector and economic complexity. The specific sectors mentioned are,

- Architectural and engineering activities; technical testing and analysis (mentioned in short as technical services)
- Financial and insurance activities (mentioned in short as financial services)
- Scientific research and development (mentioned in short as research)
- Legal and accounting activities; activities of head offices; management consultancy activities (mentioned in short as professional services)

The last correlation analysis is carried out for technical services, financial services, research and professional services in large economies for Europe. This correlation analysis is specifically carried out to ascertain the relationship between the above mentioned and economic complexity index a. All countries are not same and the size has a major impact on the economic activities. The economy of scale might play a major role in creation of economic complexity vis a vis a small country which does not have the advantage of economic of scale. Countries with bigger economy have certain cost advantage because of their sheer size. This might allow them the possibility of supporting a diverse set of industries and services.

6.3.1 Mapping Global Business Service Flows

The author maps all the global business services flows to identify movements of business services. The data for the flowing analysis is sourced from OECD-WTO value added database. The data is then mapped in the NodeXL and the resultant graphs are used to supplement the results and are discussed in detail in later chapters.

7 RESULTS

In this chapter the author list down the results of the correlation analysis. This is followed by the list of major finding in the study. The findings based on the earlier theoretical concepts are matched with the concepts. The results are compared with the horizontal knowledge flow, the role of financial services and importance of imitation and innovation.

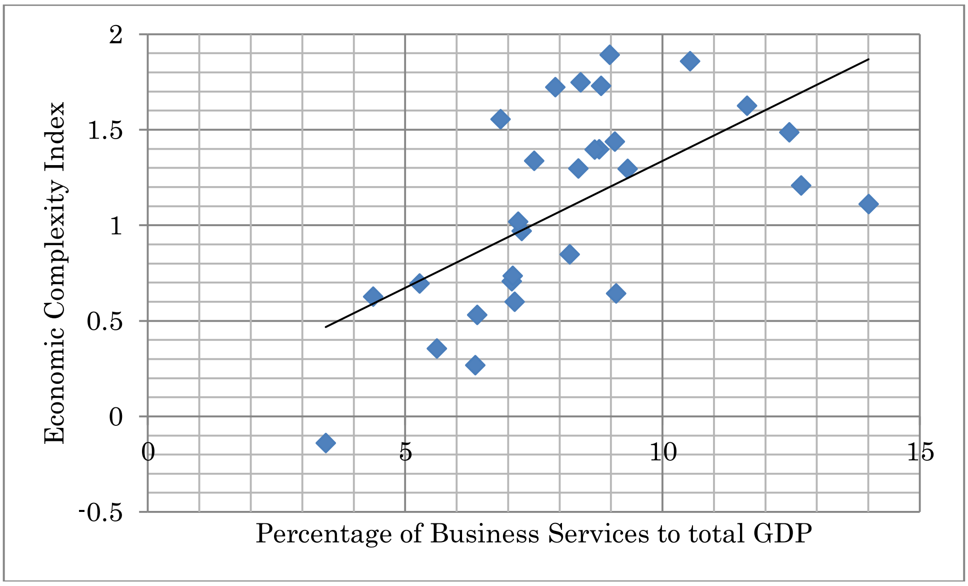


Figure 17 Economic Complexity Index and Percentage of Business Services to total GDP

Table 10 - Correlation Matrix between ECI and Relative Activity of Business Services

	ECI	Relative Activity of Business Services
ECI	1	
Relative Activity of Business Services (in percentage)	0.60	1

The correlation relationship between the economic complexity and Relative Activity of Business Services was obtained from the data available in economic complexity atlas and Eurostat database. The correlation coefficient between these two variables is 0.60, which proves the link between flexibility and complexity in national economic system. The flexibility of business services in the creation and transfer of knowledge is positively associated with the economic complexity of a country. However, this analysis does not further explain the role of disaggregated sectors like technical services; professional services, financial services and research. To ascertain these relationships, the disaggregated data is used to study the relationship between economic complexity and Relative Activity of these particular services.

Table 11 Correlation Matrix between ECI and Specific Sectors

	ECI	Relative Activity of Technical Services	Relative Activity of Financial Services	Relative Activity of Research	Relative Activity of Professional Services
ECI	1				
Relative Activity of Technical Services	0.630	1			
Relative Activity of Financial Services	0.069	0.252	1		
Relative Activity of Research	0.443	0.526	-0.034	1	
Relative Activity of Professional Services	0.201	0.036	0.511	0.09	1

The relationship between the economic complexity and Relative Activity of these particular services is captured in the correlation analysis. The Relative Activity of technical services is positively related with economic complexity with a moderately high correlation coefficient of 0.630. The importance of Relative Activity of technical services might be crucial after a stage. After that point, the contribution of the sector does not really play a bigger role in creating the economic complexity. The figure below shows the stagnation of R.A. of Technical Services between 0.015 and 0.020. However these results are true given the economic structure at present and could change based on changes in global economy in future. Similarly, Research has moderate correlation coefficients of 0.443 with economic complexity. There is a moderate correlation between the Relative Activity of technical services and Relative Activity of research as the correlating coefficient is 0.53. This signifies the scientific nature of technical services, which need strong knowledge creation to provide high quality services in scientific and technical fields. The Relative Activity of professional services and Relative Activity of financial services have no relationship with economic complexity.

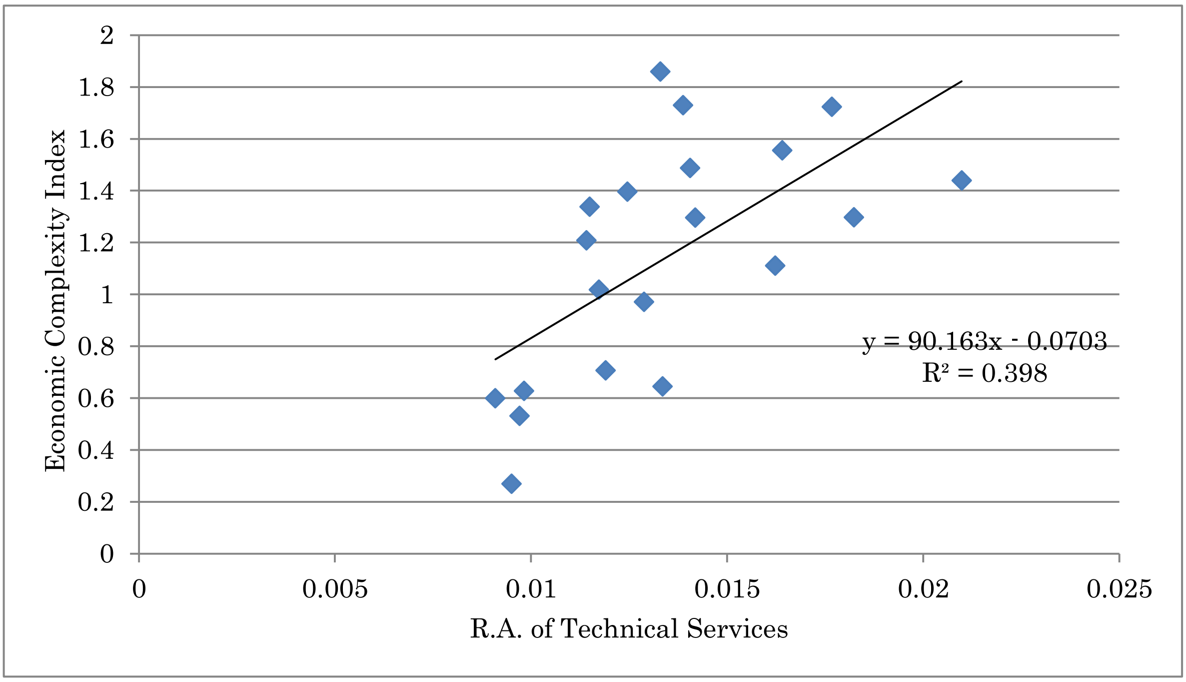


Figure 18 – Relationship Economic Complexity Index between R.A. of Technical Services

However, financial services and professional services play an important role in an economy. Financial services play an important role in providing the finance and ascertaining the financial viability of economic investments. The legal services help with smooth functioning of institutions in a capitalist environment. The legal services provide opinion and legal assistance to firms and individuals to protect their property rights. The management consultancy services play an important role in providing services which help an organization to identify problems, which can lead to an increase in the productivity of the firms.

However, the correlation analysis clearly shows no relationship between economic complexity and the professional and financial sectors. There is a possibility that these sectors are concentrated in countries with big economies. To test this relationship, a correlation analysis between economic complexity and the Relative Activity of disaggregated sectors is carried out.

Table 12 - Correlation Matrix between ECI and Specific Sectors in Bigger European Economies

	ECI	Relative Activity of Technical Services	Relative Activity of Financial Services	Relative Activity of Research	Relative Activity of Professional Services
ECI	1.000				
Relative Activity of Technical Services	0.500	1.000			
Relative Activity of Financial Services	-0.108	0.285	1.000		
Relative Activity of Research	0.467	0.526	-0.608	1.000	
Relative Activity of Professional Services	0.745	0.764	-0.200	0.630	1.000

The relationship between the economic complexity and Relative Activity of these particular services is captured in the above correlation analysis for bigger economies in Europe. Technical services positively correlates with economic complexity and have moderate correlation coefficients of 0.50. Similarly, Research has a moderate correlation coefficient of 0.47 with economic complexity. There is a moderate correlation between the Relative Activity of Technical Services and Relative Activity of Research with a correlation coefficient of 0.53. This signifies the scientific nature of technical services which needs strong knowledge creation to provide high quality services in scientific and technical fields. Similarly there is a strong relationship between Relative Activity of Technical Services and Relative Activity of professional services, with a correlation coefficient of 0.76. Relative Activity of professional services and economic complexity have correlation coefficient of 0.75.

The analysis indicates a closer relationship between these two business services in bigger economies, namely technical services and professional services. The result also tends to point out the dominance of professional services in bigger developed European countries in creation of economic complexity. These services are concentrated in few European countries, which form the hub in coordinating the activities in different parts of the world. Financial services do not play any major role even in bigger countries. This points out that the view that the financial sectors might not be playing a major role in economic complexity.

Surprisingly, Relative Activity of Technical Services and Relative Activity of Research play a moderate role in bigger economies of Europe. The sample size for the analysis is very small; hence further studies are needed to validate these observations.

7.1 Major findings from Analysis

7.1.1 Service sector and horizontal transfer of knowledge

Business Services includes information generation and sharing, information technology, consultation, education, research and development, financial planning, and other knowledge-based services. These industries play an important role in transfer of knowledge, especially tacit knowledge. This tacit knowledge is responsible in the creation of economic complexity, as this transfer of knowledge leads to the creation of new knowledge. This knowledge in turn leads to creation of new services and goods in the nation's economy, which leads to economic complexity in the system. Our analysis confirms the role played by technical services in this horizontal transfer of knowledge. It also captures the role of professional services especially in the bigger European countries

7.1.2 Role of technical services and R &D

Our analysis suggests a mutual relationship between service sectors and knowledge creation, which leads to economic complexity in the system. The correlation coefficient of the simple model showing the relationship between business services and economic complexity is 0.60. The disaggregated data for the business sector shows those technical services and Research is positively correlated with economic complexity with high correlation coefficients of 0.630 and moderate correlation coefficients of 0.443 respectively.

7.1.3 Role of Other consultancy – Crucial in Bigger economies

On the other hand the role of financial services and professional services did not play a significant role in creation of economic complexity. The correlation coefficient was also compared for the disaggregated data of the bigger economies. The role of the Role of technical services and research were moderately correlated with coefficients 0.50 and 0.47. However, the role of professional services was significant in bigger economies. This could point towards the influence of the bigger economies on the smaller economies in terms of strategic decision making. This might point towards flow of tacit knowledge from bigger economies to smaller economies in the form of strategy and decision making. This explains their relative importance of professional services in creation of higher economic complexity in other countries with a relatively bigger economy. It can also explain the relative inability of smaller countries in gaining crucial knowledge for which they depend on the bigger economies, especially Germany and United Kingdom in this case.

7.1.3.1 Critic of consultancy and legal services –

The consultancy sector and the legal sector are dominated by two factors – agility and opacity (Christensen, Wang, & Bever, 2013). The decisions in professional services, -like consultancy sector and legal services,- are very opaque in nature. This happens since the decisions are taken in a black box and the customer has less information about these services. In addition, the knowledge of the expert is unknown to the non-expert. Hence, mechanism like bonding, reputation, appearance, and ethical codes become crucial (Von Nordenflycht, 2010). This is unlike the traditional manufacturing sector or other services sectors like retail, logistics etc. He also identifies professional services with knowledge intensity, low capital intensity, and a professionalized workforce as identifiable characteristics (Von Nordenflycht, 2010). This allows these sectors to be highly agile with idea creation. These characteristics make it difficult to estimate their role in economy.

7.1.4 Finance Sector and Economic complexity

Financial services are not classified as business service under the statistical classification of economic activities in the Eurostat. The author added financial services to the study. This was done to compare and contrast the role played by financial services in creating the economic complexity vis a vis business services. There was no correlation between Relative Activity of Financial services and economic complexity. This relationship is also captured by some other studies. Interestingly in bigger economies, there was a negative correlation between financial services and research. A study has mentioned that disproportionate rise in finance sector hampers the total factor productivity (Cecchetti & Kharroubi, 2015). They emphasized that the labor working in finance sector grows faster at the expense R&D-intensive industries. This steals the skills from technical services to the financial services. Our analysis also hints at a similar role between financial services and research.

When labor and skills move to finance sector, sectors which improve the economic complexity are hit.

7.1.5 Imitation in contrast to Innovation

The model proves that movement of knowledge from different sectors within the business sector to other sectors. Also, the model proves the role of imitation of knowledge which is reflected in movement of already existing knowledge in comparison to creation of new knowledge. The correlation coefficient of economic complexity and scientific research and development was 0.44, which is still significant yet not that important in comparison to role of Technical services. The technical services which include architectural and engineering activities; technical testing and analysis, allow transfer of existing knowledge to other sectors. Similar arguments have been made by Shenkar (2010) and Perla and Tonetti (2014) at the firm level. (Shenkar, 2010). Similar arguments have been made for a country. (Benhabib, Perla, & Tonetti, 2014)

8 DISCUSSION

This chapter discusses the strategy for the countries with lower economic complexity to gain higher economic complexity. A quadrant approach is conceptualized to identify the countries and the stages of their respective development. The data for global business services trade is used to explain the dependence of countries with a lower economic complexity to gain higher economic complexity through a hub and spoke model.

8.1.1 Quadrant Approach

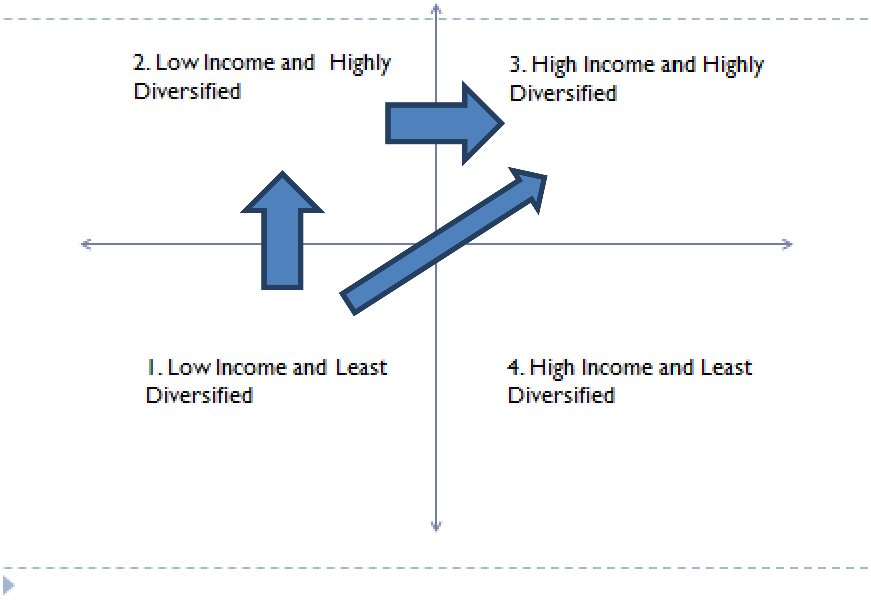


Figure 19 Quadrant Approach

The connection between economic development and economic complexity is explained through quadrant approach. The four quadrant approach divides the countries into four categories. They are,

- Low Income and Least Diversified exports
- Low income and Highly diversified exports

- High Income and Highly Diversified exports
- High Income and Least Diversified export's

This section explains the quadrant approach as an abstract concept for a nation's economy. Ideally when a country has low income and is least diversified it does not possess enough capabilities to produce diverse goods and services. Preferably, over a period of time, the country would diversify its capabilities to produce diverse goods and services. A country with higher capabilities is typically able to produce a wider range of products, which will bring in revenue and prosperity. Ideally a country is supposed to move from low income and least diversified state to low income and highly diversified state. With increased prosperity, a country can then move to High Income and Highly Diversified. Alternatively this movement can also be diagonally from low income and least diversified to high Income and highly diversified state. Conversely it is possible for a country to move to high Income and least Diversified export's without diversifying its exports base. These countries are more prone to shocks. These countries are prone to shocks and stress as the countries do not possess the capabilities to produce diverse goods and services. Such countries are more dependent on other countries for productive knowledge in times of need. There are many reasons which affect a state of nation's economy. Taking these other factors as constant, the author discusses the importance of knowledge in creating productive capacity.

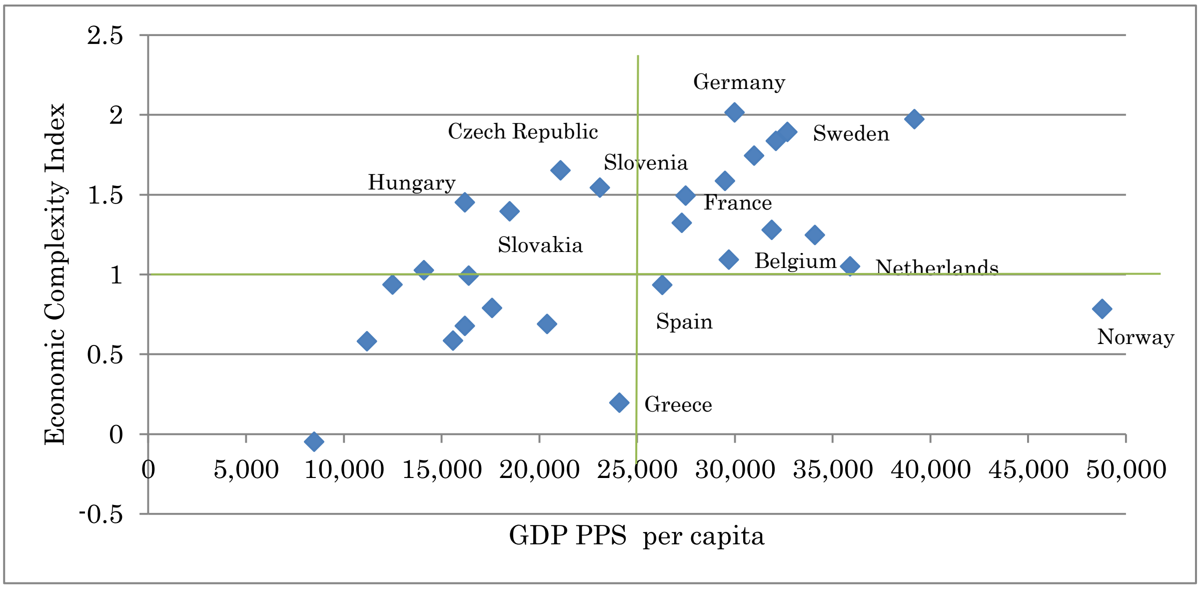


Figure 20 Quadrant Approach applied for European Union

In the table above, the two cutoffs are used. The cutoff for economic complexity was established at 1. The cutoff for the income criteria per capita was set at PPS 25,000. The slab used by World Bank to denote high income countries is GNI $12,736 or more (World Bank). The median income of high income OECD countries is GNI $ 44,290 according to World Bank data (World Bank). As there is a huge difference, the author takes PPS 25,000as a slab for high income countries in Europe. As there is no slab already set for ECI, the author sets ECI index of 1 as a ballpark figure to set the slab. These cutoffs have been assigned conveniently to explain the concept. The above table shows the quadrant approach mapped for countries in the European Union. Most of the countries are in first, second and third quadrant. Spain and Norway are the only European countries in the fourth quadrant. The countries in first and fourth quadrant are more prone to shock and stress. These countries are more prone to shocks and stress as these countries do not have the productive capacity, when other considerations are taken as constants, to contain them. Norway might be better able to better able to handle any stress or strain given their higher share of per capita income. However, the money can only act as a temporary buffer given the fact that export diversification is limited in Norway. Countries like Czech Republic, Hungary, Slovenia and Slovakia are in the second quadrant and have a relatively diversified economy. This shows the potential of these countries to move to the desired third quadrant with high income with diversified exports. The third quadrant is dominated by the economies in the Northern and Western part of Europe including Germany, France, and Scandinavian countries. Belgium and Netherlands are closer to the fourth quadrant in comparison to the other countries in the third quadrant. Greece on the other hand is in the first quadrant, thought with a relatively higher per capita income. The recent crisis in Greece shows the potential problems faced by its economy and the kind of an impact any crisis can cause. In the study, the author focuses on the countries in the second and third quadrant.

8.2 Hub and Spoke Model

The movement of business services with in European Union can be represented as a hub and spoke model. Hub and spoke model is used in supply chain networks and transportation networks (Cook & Goodwin, 2008). The knowledge movements in form of business services are represented by the core hubs and the peripheral spokes. Hubs are countries which are located mostly in the third quadrant. The peripheral spokes are in the other quadrants. The hubs have the following advantages for knowledge creation:

- The hub allows for flexibility in terms of connections within the network.
- The complex operation can take place in the hubs.
- The hubs allows for a higher chance of combination of creation of new knowledge.
- The hubs allow for accumulation of human resources and skills.

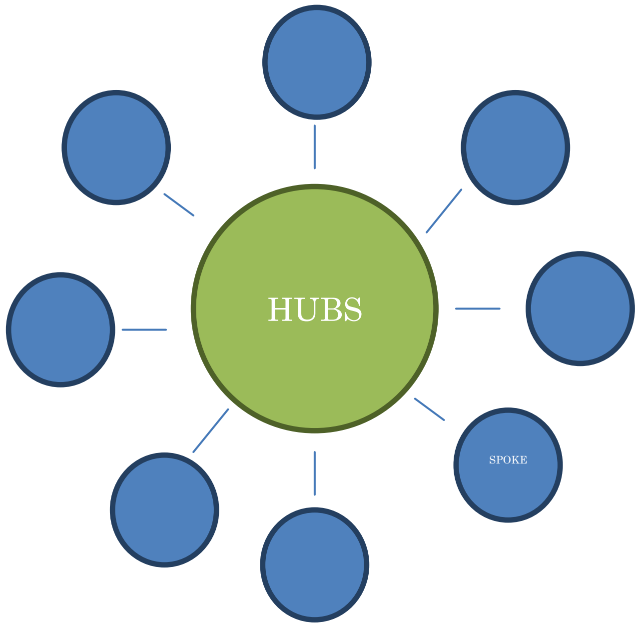


Figure 21 – A central Hub with spokes around

However the hubs and spoke model also comes up with its own problems. The presence of small number of hubs allows for too much centralization of knowledge in hubs. A single obstacle in the hub can cause problems within the network. There are also higher chances of overcrowding in the hub. However these problems can be solved or reasonably managed with multiple hubs and spokes. **Multiples Hubs and spokes** can comfortably avoid problems with single barrier. Also it would allow for more spaces within the system there by avoiding chances of overcrowding in one hub.

The figures in the section represent business services flows globally from one country to the other. This data from WTO-OECD value added trade database is used to map these business service flows in the NodeXL. In these figures, the author only shows the strong connection between countries. Only the strong connections are considered as important connections. This is done to show the link between links and hubs. The strong connection represented in the thesis is if trade between countries is more than 10% of their total share of imports. Similarly the shares of exports more than 10% between countries are represented. Imports and Exports shown are shown as two different figures (figure 22 and 23).

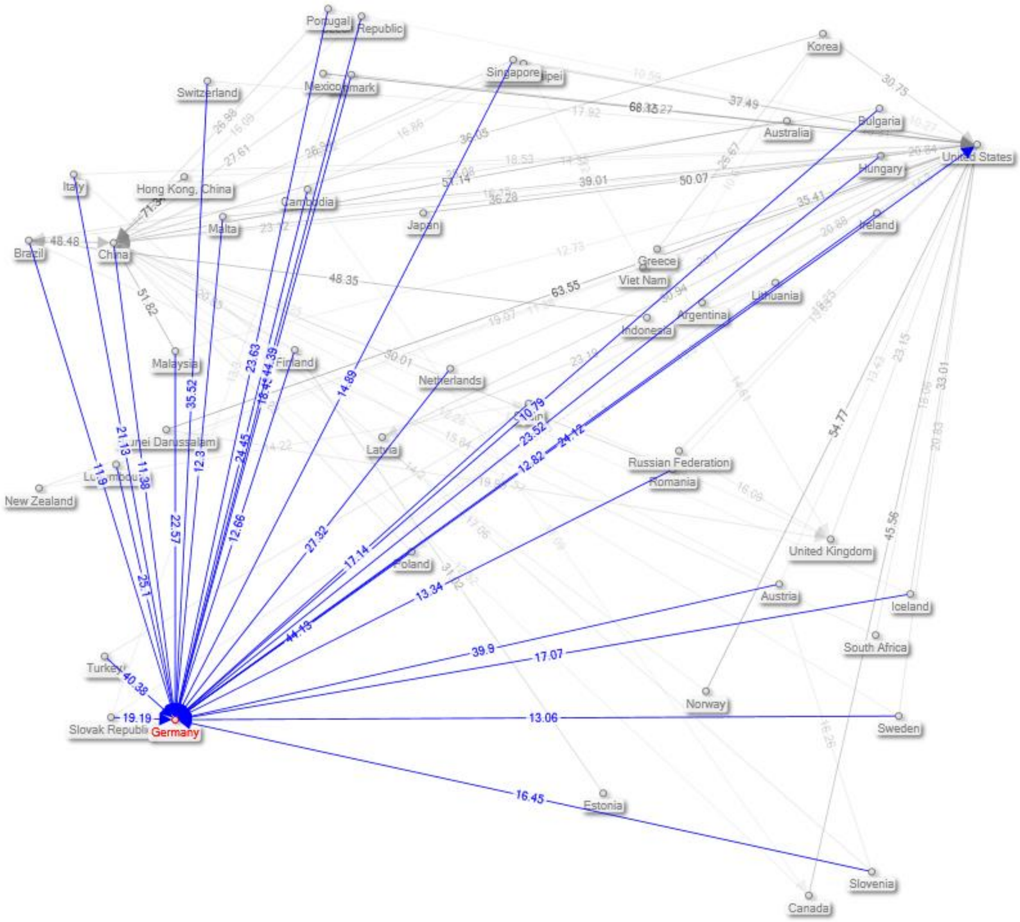
8.2.1 Germany and United Kingdom - The knowledge Hubs

Based on the mapping the global business Services trade, the four major hubs are identified as Germany, United States, United Kingdom and China (refer figure 22 and 23). Germany and United States are hubs for both exports and imports (refer figure 22 and 23). However, China on one hand is hub for imported business service products (refer figure 22). United Kingdom on the other hand is the hub for exported business services products (figure 23). Germany and United Kingdom play an important role in movement of business service knowledge flow within Europe and rest of the world respectively.

Table 13 – Spokes to Hub Connection

Spokes	Connection to Hubs
Slovenia	Germany, Italy, France and United States
Czech Republic	Germany, United Kingdom and United States
Switzerland	Germany, United Kingdom
Austria	Germany

Germany is both exporter and importer of business services. Germany serves as a hub for both exports and imports. Germany's business services flows are more concentrated within European network. Germany dominates the business services exports and many countries are dependent on Germany for knowledge. Several countries are significantly dependent on United States and Germany as import partners of business services knowledge. The United States and Germany share a two way mutual relationship with other countries. However, Germany is highly integrated within the European network contributing significantly to increase of economic complexity of countries like Austria, Hungary, Slovenia and Austria. These countries form a strong German hub and with the rest forming spokes.



Created with NodeXL (http://nodexl.codeplex.com)

Figure 22– Knowledge flows to Germany marked in blue. Germany, China and United States form Import Hubs. The figure shows the import hubs

On the other hand, United Kingdom is majorly an exporter of business services. The distribution of knowledge flows is also contrasting with Germany. United Kingdom has a global footprint with business services exports to many countries out of European network. Germany with Slovenia, Czech Republic, Switzerland and Austria form a strong knowledge hub and spoke model. Slovenia, Czech Republic, Switzerland and Austria have the highest economic complexity in the world

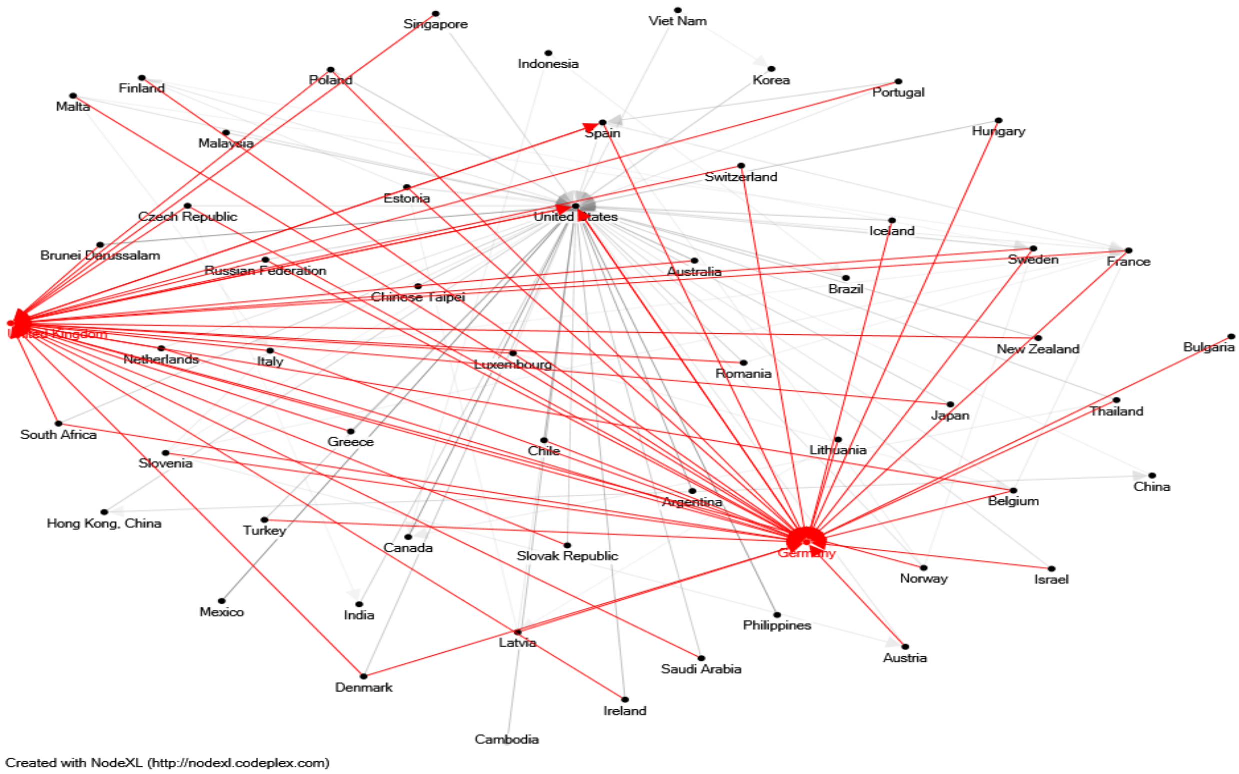


Figure 23– Knowledge flows from UK and Germany marked in red. Germany, UK and United States form export hubs. The figure shows the export dependence of other countries on hubs

8.2.2 The spokes – Slovenia, Czech Republic, Switzerland and Austria

These countries are dependent on Germany for business services knowledge. Switzerland and Czech Republic are also dependent on United Kingdom for business service knowledge. Slovenia in addition to Germany and UK is also highly integrated with other big economies of Italy and France. The global hub of knowledge services, United States, is also connected with Slovenia and Czech Republic

The integration of countries with hubs like Germany, United States, and United Kingdom becomes necessarily important in creation of higher economic complexity. With increased dispersion of production process across countries and continents, the global value chain has tremendously expanded in the past. This creates opportunities for countries with lower complexity to increase their economic complexity. The movement by knowledge flow through expansion of production process and movement of business services is crucial in creation of higher complexity.

Table 14 - Gross value added by management consultancy, technical services and technical testing services in European Countries

Countries	Economic Complexity Index	Technical Services - Within Country	Technical Services - Exports	Management Consultancy -Within Country	Management Consultancy Exports	Technical Testing - Within Country	Technical Testing - Exports
Belgium	1.2	1109.3	1055.1	1892.6	1231.3	602.4	160.0
Bulgaria	0.4	222.0	5.8			21.1	6.4
Czech Republic	1.6						
Denmark	1.3			802.8	61.3		
Germany	1.9	14820.1	5433.7	9157.6	1186.6	5539.8	605.8
Estonia	0.6						
Ireland	1.4					97.6	12.5
Greece	0.3	855.8		610.1	154.5	65.4	26.6
Spain	1.0	9489.9	3832.2	1801.0	337.6	2037.2	202.5
France	1.5						
Italy	1.3	4985.9	3204.2	6755.5	729.5	1242.5	193.0
Latvia	0.7			18.6	2.1	30.0	12.3
Lithuania	0.5	78.5	4.8	64.6	18.6	31.7	0.8
Hungary	1.4	528.0	104.9	140.9	113.8	130.0	
Austria	1.7	2631.3	652.6	544.4	268.3	260.2	33.1
Poland	1.0	1032.8	183.4		245.6	290.3	41.8
Portugal	0.6	1047.7	143.2		172.2	150.0	17.6
Romania	0.6	620.9	237.6	559.4	61.8	101.3	12.1
Slovenia	1.4	400.8	108.2	59.2	7.8	100.7	7.0
Slovakia	1.3	386.3	0.0	87.1	88.4		0.0
Finland	1.7	1409.5	512.8	407.2	334.6	275.2	26.5
Sweden	1.7	3077.3	1274.5	1481.0		507.5	73.1
United Kingdom	1.6	23472.4	5935.4	21358.9	8183.1	3244.9	1008.3

The table 14 above shows the gross value added by management consultancy, technical services and technical testing services. Countries like United Kingdom, Germany, Italy and others have a significant exports of these services to other countries (The data for France, Switzerland, Netherlands is not available). This shows transfer of capabilities and knowledge to other countries. The United Kingdom and Germany play a major role as hubs and countries in periphery are highly dependent on them.

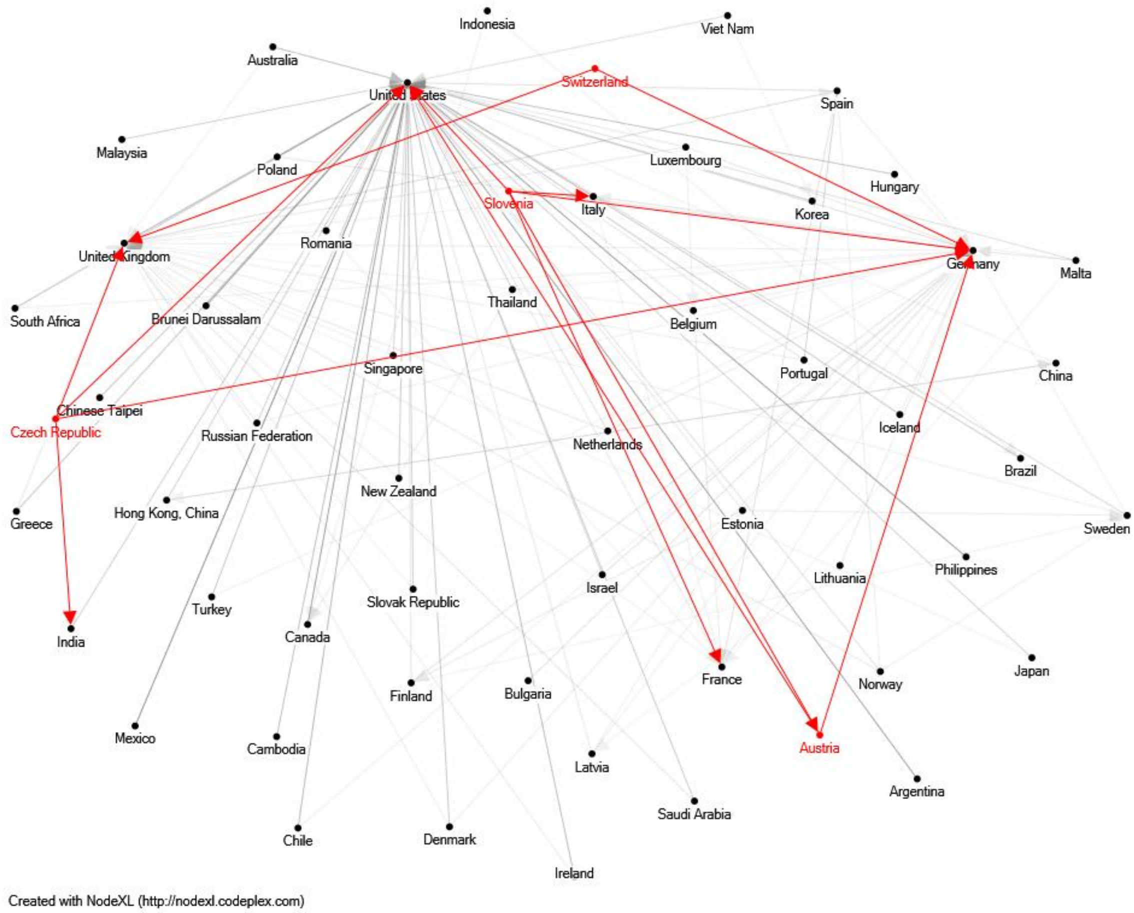


Figure 24– Spokes like Slovenia, Czech Republic, Switzerland and Austria connected to Hubs like UK, USA and Germany

8.2.3 Single Hub and Multiple Spoke to Multiple Hub and Multiple Spoke – At Country level

A single hub and multiple spoke model allows for centralization of knowledge in certain countries the present model is more attuned to restrict the knowledge in certain countries. This model can create a higher economic complexity in few hubs without dispersion of knowledge to other countries (spokes). Increasingly many countries increase the economic complexity through trade and economic contacts with countries, especially through connecting to hubs. The study here shows the movement of knowledge flow through business services as a way to boost the tacit knowledge and codified knowledge in the country. This knowledge can be used later to increase the economic complexity within the country. This will allow the movement of a country from low income and least diversified state to high income and highly diversified state

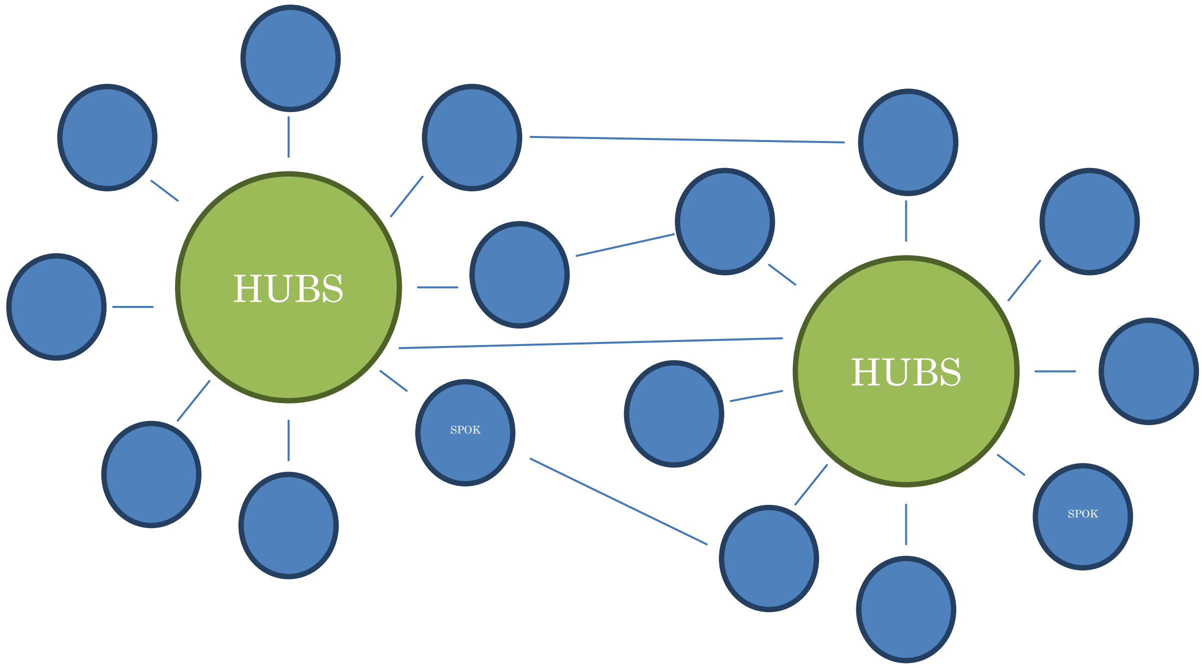


Figure 25 - Multiple Hub and Multiple Spoke

With increasingly countries having higher complexity, there is a possibility for the new countries to turn into hubs. When more and more countries start having higher complexity, the importance of the hubs will slightly reduce though they might be very important. Knowledge flows will start flowing across many countries rather than being dominated by a small number of hubs. This will also lead to dispersion of knowledge, including tacit knowledge, to different countries.

8.2.4 Single Hub and Multiple Spoke to Multiple Hub and Multiple Spoke (Modular) – At Firm level

The shift to multiple hub and spoke mode is reflected by the following developments. The growth of global value chains and horizontal structure of business have brought about these changes. Traditional organization structure representing vertical hierarchical organizational structure where core and non-core activity was performed within the industry is being replaced. For instance, growth of knowledge sector business services performing non-core activities is facilitating horizontal flow of knowledge. This structure results in firms developing ideas and solutions more independently which are then dispersed to the core firms. These firms also provide services to a wider customer base there by diversifying the destination audience for the finished products. Also the companies performing core functions can dependent on multiple firms performing non-core functions. This creates a modular network in comparison to the earlier structure.

These changes also give more flexibility to both, core firm and non-core firm. It is essentially that the core functions of a firm are not compromised as innate character of a system or a firm should be maintained. As discussed earlier, flexibility can be conceptualized for both, short term and long term. The long term flexibility of the system has to be given higher priority than the shorter term flexibility. There are chances that the emphasis given to shorter term flexibility loosens the long term capabilities and flexibilities from the system. This has been also reflected by specialization myth and economic complexity idea put forth by Hausmann et al. The trend between generalist and specialist species is seen in the biological world represents an similar idea.

8.3 Perquisite for Economic Complexity

The hub and spoke model of knowledge capabilities with domination of hubs like United States, Germany and United Kingdoms are confirmed in the study. The study shows that the countries which are improving their economic complexity are the ones which are highly connected with the hubs. The countries have both a higher business service exports and business service imports o with the hubs. The countries which are in periphery and are more connected to multiple hubs are capable of increasing economic complexity.

Hidalgo et al use the analogy of scramble to explain economic complexity where letters reflects the possible words which can be made with the help of letters. Letters describe the capabilities a country possesses. The words which a country can make are reflected by the number of letter a country possesses. Similarly, knowledge Hubs possesses the letters and it is necessary for the countries in the periphery to have these letters to produce certain products or new products. Countries which are closer to knowledge Hubs or who extend connection to the hubs have easier chances to access the letters i.e. capabilities. In a modular structural arrangement, we will have denser connections among countries within a region and sparse connections countries beyond their region. The advantaged of modular structure with multiple hubs and heterogeneous connection is considered advantageous given the uncertainty.

9 CONCLUSION

As declared in the problem statement, the present thesis focused on understanding terms like resilience, sustainability, interconnectivity, diversity etc. This was crucial as our understanding of these terms is not complete. The answers for the following question are only possible with a better understanding of these terms, “Do we develop systems which are resilient or those which are efficient or do we optimize between efficiency and resilience?” In order to answer this question the author employed a conceptual model to an illustrative example.

9.1 Conceptual Framework

The focus was on developing a conceptual framework to create resilient systems. In the thesis an approach is put forward to look at the robustness and transformation of the system. Essentially a balance between robustness and transformation are identified as the components of a resilient system. Flexibility as a concept was identified to attain these two important characteristics – robustness and transformation. Flexibility is the property of a system that promotes change in the system.

These ideas were identified from biological science and social science to understand the concepts like resilience, interconnectivity, robustness and innovation. The first part of the study is exploratory in nature. Based on the literature review, robustness and transformation are identified as components of resilience. A **conceptual framework** is introduced to link resilience with a system through flexibility.

9.2 Empirical illustration

Finally, an **empirical illustration** involving economic complexity and business services is conducted. In the illustration, business services are considered to allow flexibility in a system. This is represented in the ability of the system to transfer knowledge within the economy. Business sector allows horizontal knowledge flow, which leads to a faster adaptation of ideas. This represents the relative flexibility in an economic system. The economic complexity index on the other hand reflects the measure of a system, in the illustrated case an economy. As pointed earlier the ECI reflects, “country’s productive output and reflects the structures that emerge to hold and combine knowledge" (Hausmann, Coscia, Simoes, & Yildirim, 2014) A higher economic complexity refers to the higher productive output and vice versa.

The results of the correlation analysis show a mutual relationship between business services and higher economic complexity index value. The disaggregated analysis showed that the technical services had a bigger impact on creation on economic complexity in European countries. However for the countries in Europe with bigger economies, the professional services played an equally important part with technical services. The illustration shows that business services play an important in transfer of knowledge economy wide. Conceptually, the author shows an empirical illustration in the study between flexibility and a system which is resilient.

9.3 Significance of the study

It is important to understand where to use the concept of resilience. The concept of resilience emerges from the field of ecology. In the thesis, the facts are identified from both biological sciences and social sciences to show certain similarities in both the systems. The major contribution in the study is in identifying the importance of flexibility. The author contends that flexibility can play a role as a characteristic. In addition it can also help a system balance between competing priorities of robustness and transformation.

9.3.1 Flexibility as a lens and a characteristics

The thesis looked into a dynamic theoretical approach needed to appreciate the importance of flexibility in creating resilient systems. This is important while thinking about systems. It is important for a system to be both robust and transformative. Flexibility has a key role to play in such a system. Flexibility can be used as a lens to study the systems. This perspective will allow developing systems which are both robust and transformative in nature. It is crucial to have such systems given the need of transition into a sustainable future.

9.3.2 Flexibility as a way to balance

An organism has to balance between robustness and transformation in response to the changing condition in the environment (Ehrlich & Hanski, 2004). Similarly a system has to balance between extremes of robustness and transformation. The flexibility characteristics if embedded in a system can allow for such a balance between extremes.

9.4 Limitation

In the thesis, the focus on flexibility as a characteristic in bringing about a resilient is stressed system. However, the study has some limitations. The conceptual model has been applied only to one empirical case. More empirical cases are important to validate the concept and to appreciate the concept of flexibility. In the empirical illustrative case study, the focus is on Europe. Eurostat is consistent in collecting data for business services in European countries. However while doing so; the focus has not been on all the countries. Also, due to data consistency, the study was not able to be expanded to other countries outside Europe. The concept of Economic complexity Index favors countries with a higher share of exports to the Gross Domestic Product. There is a chance that countries might have a higher productive capacity but that they do not export technology. However, ECI still gives the best estimation of productive capacity.

9.5 Future Studies

Further studies are needed to apply the concept of flexibility to other cases. The concepts can be well applied to the topics in urban planning, socio technical systems etc. In addition, there is also a need to quantify the concept of flexibility. The features of flexibility should be applied on a case by case basis. Certain features of flexibility mentioned in the studying might not be applicable to certain fields.

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11 APPENDIX

Table 1 – ECI and Business Services

	Relative Activity of Business Services	ECI (no unit)
BE:Belgium	0.127	1.207
BG:Bulgaria	0.056	0.354
CZ:Czech Republic	0.069	1.554
DK:Denmark	0.084	1.296
DE:Germany	0.105	1.858
EE:Estonia	0.091	0.643
IE:Ireland	0.088	1.397
EL:Greece	0.064	0.268
ES:Spain	0.073	0.970
FR:France	0.125	1.486
HR:Croatia	0.082	0.846
IT:Italy	0.093	1.294
LV:Latvia	0.071	0.706
LT:Lithuania	0.064	0.530
HU:Hungary	0.087	1.395
NL:Netherlands	0.140	1.110
AT:Austria	0.088	1.729
PL:Poland	0.072	1.017
PT:Portugal	0.071	0.599
RO:Romania	0.044	0.626
SI:Slovenia	0.091	1.438
SK:Slovakia	0.075	1.337
FI:Finland	0.079	1.722
SE:Sweden	0.084	1.748
UK:United Kingdom	0.116	1.625
NO:Norway	0.071	0.736
CH:Switzerland	0.090	1.891

MK:Former Yugoslav Republic of Macedonia, the	3.458	-0.140
Serbia	5.283	0.694

Table 2 Disaggregated Business Activities with National Account Aggregates

	ECI	Relative Activity of Technical Services	Relative Activity of Financial activities	Relative Activity of Research	Relative Activity of Professional Services
BE:Belgium	1.207	0.011	0.056	0.004	0.065
CZ:Czech Republic	1.554	0.016	0.045	0.005	0.018
DK:Denmark	1.296	0.018	0.063	0.009	0.021
DE:Germany	1.858	0.013	0.047	0.007	0.031
EE:Estonia	0.643	0.013	0.044	0.009	0.023
EL:Greece	0.268	0.010	0.046	0.002	0.021
ES:Spain	0.970	0.013	0.053	0.003	0.017
FR:France	1.486	0.014	0.040	0.017	0.033
IT:Italy	1.294	0.014	0.051	0.006	0.033
LV:Latvia	0.706	0.012	0.036	0.004	0.017
LT:Lithuania	0.530	0.010	0.026	0.003	0.019
HU:Hungary	1.395	0.012	0.047	0.007	0.023
NL:Netherlands	1.110	0.016	0.076	0.005	0.052
AT:Austria	1.729	0.014	0.047	0.002	0.025
PL:Poland	1.017	0.012	0.039	0.005	0.022
PT:Portugal	0.599	0.009	0.071	0.003	0.020
RO:Romania	0.626	0.010	0.024	0.003	0.009
SI:Slovenia	1.438	0.021	0.053	0.009	0.021
SK:Slovakia	1.337	0.011	0.039	0.002	0.025
FI:Finland	1.722	0.018	0.029	0.009	0.014

Table 3 Disaggregated Business Activities with National Account Aggregates – Bigger Economies

	ECI	Relative Activity of Technical Services	Relative Activity of Financial Services	Relative Activity of Research	Relative Activity of Professional Services
DE:Germany	1.858	0.013	0.047	0.007	0.031
FR:France	1.486	0.014	0.040	0.017	0.033
PL:Poland	1.017	0.012	0.039	0.005	0.022
ES:Spain	0.970	0.013	0.053	0.003	0.017
IT:Italy	1.294	0.014	0.051	0.006	0.033