Effect of financial resource allocation on dynamics of national innovation system: The case of Iran

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Abstract

Innovation is the process of developing new ideas and putting them into practice. Over the last decades, institutional theories combined with evolutionary theories have led to the Innovation System approach. One of the systemic approach is national innovation system. Understanding the determinants of national innovation system has been an important source of inquiry in the management and economics literatures. Regarding different types of definition of national innovation system we see that there are sort of resources that based on the interaction of institutions in public or private sectors, provide or modify new technologies inside a country. Furthermore, we use the concept of national innovation system as an analytical framework for policy instrument for the optimization of resource allocation. For this issue we use system dynamics method for analysis the dynamics of national innovation system and to find efficient way of allocating resources in this system for optimized level of output.

Keywords: Innovation, National Innovation System, System Dynamics, Iran

Introduction

Understanding the determinants of technological innovation and change has been an important and fertile source of inquiry in the management and economics literatures. Solow and Schumpeter who are the most memorable economists, associate with raising the fundamental questions on the topic of technological innovation. This issue also cause huge interest in management area, in different fields like strategy, organizational theory and organizational behavior (Ahuja, Lampert, 2008).

Innovation (defined as the invention, development, and implementation of new ideas) has always been important for the continued liveliness of firms, regions and economies (Mokyr, 1990). Since innovation is one of the most important way that organizations can adapt to changes in markets, technology, and competition, successful new products, processes, services and etc. are critical for many organizations (Dougherty, Hardy, 1996). We can expand this concept into level of analysis of a nation. One can say because a nation is the aggregation or summation of firms and organizations, thus innovation is one of the most important way to adapt to these days fast competitive world.

It is no wonder that innovation has attracted the attention of an increasing number of scholars from different disciplines. The breadth of insights that has accumulated over time is impressive, and scholarly contributions will no doubt continue to grow. The research that has accumulated offers insights on topics ranging from the types of innovation (e.g. Henderson & Clark, 1990; Roberts, 1988; Utterback & Abernathy, 1975), the economics of R&D (e.g. Freeman, 1974; Schumpeter, 1934), national systems of innovation (e.g. Lundvall, 1992; Nelson, 1993), antecedents and consequences of innovation in firms (e.g. Tornatzky et al., 1983), and the processes whereby innovations unfold (e.g. Burgelman, 1983; Van de Ven et al., 1999). Our objective in this paper is to cover pure innovation system specificaly at a nation level, which means national innovation system.

The study of national innovation systems (NIS) has attracted considerable attention in the last two decades (Lundvall, 2007). While a substantial amount of research has been devoted to the investigation of cross-country differences in technological capabilities and the related institutional and policy framework, much less attention has so far been given to the analysis of the dynamics of national systems over time (Castellacci, 2013).

The focus on the NIS has come about because, although the various industrial countries tend to have similar institutions for developing innovations, e.g. corporate laboratories, public research institutes, private R&D contract firms, and universities, they differ substantially in how these institutions interact to pursue the innovation process; in other words, in the structure of the underlying 'system' (Lee, 2005).

The lack of focus on dynamic aspects is partly explained by the non-availability of time series data for a sufficiently long period of time, and partly by the analytical and methodological difficulties that are faced when it comes to model and empirically analyze the dynamics of complex evolving systems (Foster, 1991).

Optimal resource utilization requires both appropriate allocation of resources and maximal productivity of the allocated resources (Majumdar, 1995, 2000).

This paper does not consider studies that focus on non-technological innovations such as administrative or organizational innovations. The objective of this research is to create policy scenarios to explain the behavior of the institutions under investigation by simulation, and to assess possible outcomes in those varying scenarios. This research shows that it is indeed feasible and fruitful to apply systems dynamics (SD) approaches to analyzing national systems of innovation (Lee, 2005).

One of the purpose of this research is to answer these types of question: Why some countries devote more financial resources to some sectors of innovation system and dismiss the others? Why some countries do differently? Is there any relationship between research and development to innovation, or is just a correlation? Why some countries publish more scientific articles than others while they do not have sufficient patents (as an indicator of innovation)?

In the next chapters we first review the literature of innovation, and concepts of innovation system. Then we propose a sector map model and a system dynamics model. After that we imply some policy to test under which scenarios national innovation system work better and under which work worse. The case we focus on is Islamic Republic of Iran (Iran).

Literature review

Innovation

Economist Joseph Schumpeter, who contributed greatly to the study of innovation economics, first put forward the concept of innovation and defined it to be a procedure introducing a new production function (Schumpeter, 1943). He argued that industries must incessantly revolutionize the economic structure from within, that is innovate with better or more effective processes and products, such as the connection from the craft shop to factory. He famously asserted that “creative destruction is the essential fact about capitalism” (Schumpeter, 1943).

Innovation is the process of developing new ideas and putting them into practice (Drucker, 1998). Innovation can also be defined as the application of better solutions that meet new requirements, inarticulated needs, or existing needs (Maranville, 1992). This is accomplished through more effective products, processes, services, technologies, or ideas that are readily available to markets, governments and society. The term innovation can be defined as something original and more effective and, as a consequence, new, that "breaks into" the market or society (Frankelius, 2009).

Also there are different types of innovation. With this overview of the innovation process covering invention (the emergence of an idea), development (the elaboration of the idea), and implementation (the widespread acceptance of the innovation), researchers of Minnesota Innovation Research Program studied a wide array of settings including administrative innovations, technological innovations, innovations within and across established firms, and innovations within entrepreneurial startups (Garud & Tuertscher, 2013).

Innovation, from a different point of view, can be defined as the successful combination of hardware, software, and orgware, where orgware refers to the various components of the innovation system (Smits, Kuhlmann, 2004). Innovation, as we see, is studied from linear and systemic perspectives. Also there are huge number of papers implying systemic approach is more realistic to study dynamics of innovation and more operationally for policy makers to policy implications (Carlsson et al., 2002). Since our goal is about to use system dynamics approach to study innovation, we should review different systemic perspectives to innovation systems.

Various systems approaches to innovation

One of the earliest system concepts used in the literature is that of input/output analysis (Leontief, 1941), focusing on the flows of goods and services among sectors in the economy at a particular point in time. Here, it is clear what the inputs and outputs are and how the system is configured. The components and relationships in the system are viewed at the meso (industry) level. The links among the components of the system are basically one-way, i.e. the system is static (Carlsson et al., 2002).

Another early approach is that represented by 'development blocs' as defined by Dahmen (1950): sequences of complementarities which by way of a series of structural tensions, i.e. disequilibria, may result in a balanced situation (Dahmen, 1989, p. 111). The basic idea is that as an innovation creates new opportunities, these opportunities may not be realized (converted into economic activity) until the prerequisite inputs (resources and skills) and product markets are in place. Each innovation, therefore, gives rise to a 'structural tension' which, when resolved, makes progress possible and may create new tensions and which, if unresolved, may bring the process to a halt. Thus, while the input/output analysis is static, Dahmen's concept already is dynamic, representing one of the first attempts to apply Schumpeterian analysis. It incorporates the notion of disequilibrium and focuses on the role of the entrepreneur. The output of the system not only grows over time but also changes in character and content. Dahmen's analysis focuses on the inter-war period (1919–1939), not just a single year, and it is highly disaggregated, covering the structural development of 24 different industries in Sweden (Carlsson et al., 2002).

A third but much later approach is widely known as national innovation systems (Freeman, 1988; Lundvall, 1988, 1992; Nelson, 1988, 1993; and subsequently many others). Here, the framework is broadened beyond the input/output system to include not only industries and firms, but also other actors and organizations, primarily in science and technology, as well as the role of technology policy. The analysis is carried out at the national level: R&D activities and the role played by universities, research institutes, government agencies, and government policies are viewed as components of a single national system, and the linkages among these are viewed at the aggregate level. Because of the size and complexity of the system (and therefore, the large number of linkages among components at lower levels of aggregation), the empirical emphasis in the studies carried out thus far is mainly on statics or comparative statics. But there is nothing in principle preventing a more dynamic analysis (Carlsson et al., 2002).

Another approach is represented by Michael Porter's 'diamond', described in his 1990 book (The Competitive Advantage of Nations). The four sides of the diamond are made up of factor conditions (skills, technologies, capital, etc.), demand conditions (especially "competent demand" as represented, e.g. by technically sophisticated customers), links to related and supporting industries, and firm strategies, structure, and rivalry. Each economic activity is viewed primarily as an industry, but is also as part of a cluster of activities and agents rather than as taking place in isolation. Because of the industry focus, Porter strongly emphasizes the role of competition among actors within industries (i.e. market competition) while suppressing non-market interaction with entities outside the industry. In this sense, the system definition is narrower than in the national innovation system approach. Again, the main focus is on a static or comparative static analysis (Carlsson et al., 2002).

A similar approach is represented by 'sectoral innovation systems' (Breschi and Malerba, 1997; see also Malerba and Orsenigo, 1990, 1993, 1995). As in Porter's analysis, the system definition here is based on 'industry' or 'sector'. But rather than focusing on interdependence within clusters of industries, sectoral innovation systems are based on the idea that different sectors or industries operate under different technological regimes which are characterized by particular combinations of opportunity and appropriability conditions, degrees of cumulativeness of technological knowledge, and characteristics of the relevant knowledge base. These regimes may change over time, making the analysis inherently dynamic, focusing on the competitive relationships among firms by explicitly considering the role of the selection environment.

Another system definition is built around the concept of local industrial systems as represented in AnnaLee Saxenian's (1994) study of the electronics industry in Silicon Valley in California and along Route 128 in Massachusetts. Here, the system definition is primarily geographical. The focus is on differences in culture and competition which have led to differences among the two regions in the degree of hierarchy and concentration, experimentation, collaboration, and collective learning which, in turn, have entailed differences in the capacity to adjust to changing circumstances in technology and markets. Thus, the analysis is inherently dynamic, but not in a formal sense.

Finally, the last approach is on the notion of technological systems (Carlsson, 1995, 1997). This concept is similar to Erik Dahmen's 'development blocs' (Dahmen, 1950, 1989) in that it is both disaggregated and dynamic: there are many (or at least several) technological systems in each country (thus, differing from national innovation systems); and they evolve over time, i.e. the number and types of actors, institutions, relationships among them, etc. vary over time (thus, differing from all the other system definitions except Dahmen's). Also, national borders do not necessarily form the boundaries of the systems. In addition, the system definition focuses on generic technologies (Carlsson et al., 2002).

As mentioned earlier, the purpose of this paper is to answer to the question: why some countries have higher innovation output beside low scientific article and R&D activities? This is in comparison with other countries whose intense investment in creating and publishing scientific articles does not lead to desired patent application, the indicator of innovation output. For this reason the systemic approach we use for study innovation process in these countries is national innovation system. Thus level of analysis of the model we proposed later is national.

National innovation system

Over the last decades, institutional theories combined with evolutionary theories have led to the Innovation System approach (Nelson, 2002). The central idea behind the Innovation System approach is that innovation and diffusion of technology is both an individual and a collective act (Edquist, 2001). An innovation system can be defined as all institutions and economic structures that affect both rate and direction of technological change in society (Edquist, Lundvall, 1993). Or as Freeman (1987) puts it: an Innovation System is "...The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies" (Freeman, 1994).

Friedrich List (1841) first introduced the concept of a national system and analyzed how it influenced one country's economic development and technological policies. Christopher Freeman developed the concept of a national innovation system to explain Japan's economic success (Lundvall, 2010; Liu, 2009). Many researchers have developed the concept of a national innovation system. Lundvall (1992), a well-known researcher of the national innovation system, defined it as the elements and relationships that interact in the production, diffusion, and use of new and economically useful knowledge and that are either located within or rooted inside the borders of a nation state. Nelson (1993) saw it as a set of institutions whose interactions determine the innovative performance of national firms. Patel and Pavitt (1994) defined it as the national institutions, their incentive structures, and their competencies, which determine the rate and direction of technological learning in a country. Freeman (1995) regarded a national innovation system as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies. Metcalfe (1995) defined it as a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts that define new technologies (Carayannis, 2013).

The national innovation system is considered a comprehensive analysis framework (Carayannis, 2013). Edquist (2005) criticized the notion as diffuse and lacking theoretical foundation, but Lundvall et al. (2009) stressed its theoretical elements to evolutionary economics. From the above concepts, many researchers have studied the national innovation system in terms of learning by interacting (Lundvall 1992), technology learning (Patel and Pavitt 1998), innovation policies (Caracostas 2008), and policy instruments (Metcalfe 2008). Although it is sometimes vague in theory, many recognize that the national innovation system has become an important and useful tool for analysis of a country's innovation and development (Carayannis, 2013).

Regarding different types of definition of national innovation system we see that there are sort of resources that based on the interaction of institutions in public or private sectors which provide or modify new technologies inside a country. Furthermore, we use the concept of national innovation system as an analytical framework for policy instrument for the optimization of resource allocation. So in the next section we define main resources which are used for innovation.

Main Resources for Innovation

The resource-based view of the firm seeks to explain sustained differences in firm performance by identifying differences in firm resources. A firm with resources that are valuable and rare may generate a competitive advantage over its rivals, thereby resulting in superior financial performance (Barney, 1991; Conner, 1991; Mahoney and Pandian, 1992; Peteraf, 1993; Wernerfelt, 1984). For a firm to sustain its competitive advantage, the resources must also be inimitable and non-substitutable to prevent rivals from replicating the value of the resources and competing away their benefits (Hatch, Dyer, 2004). This concept can also be expanded to national level. A country without valuable and differentiated resources can not achieve a desired competitive advantage and thus can not have sustainable growth. In this point of view we aggregate total firms' resources into three types: financial resources, human resources and research and development activities which are valuable and cost leader of asset of all the firms. These three types of resources are the most necessary, among the resources for innovation process.

Although resources are key component of innovation, but innovation does not occur until firms and aggregation of them, country, have capability to accomplish the process. This capability is called "innovation capability" which we more describe later in this research. In next sections we discuss about these resources and after that bring some insight about innovation capability.

Human Resource

Knowledge workers, or "the creative class" (Florida, 2005), are viewed as core to the competitiveness of a firm in a knowledge-based economy (e.g., Lepak & Snell, 2002). These employees are involved in the creation, distribution, or application of knowledge (Davenport, Thomas, & Cantrell, 2002), and the workers' brains comprise the means of production (Nickols, 2000; Ramirez & Nembhard, 2004). Knowledge workers are the source of original and potentially useful ideas and solutions for a firm's renewal of products, services, and processes (e.g., Amabile, 1988).

Human resource (HR) practices to promote creativity focus on the individual level: recruitment and selection of creative talents, and training and development of employees to become more creative. By recruiting and selecting creative talents, a firm can attract high-potential candidates who have creative personality characteristics (e.g., Gough, 1979; Malakate, Andriopoulos, & Gotsi, 2007). By training and developing staff, a company can develop knowledge and skills for creativity, thereby enhancing their creative capabilities (e.g., Puccio, Firestien, Coyle, & Masucci, 2006; Roffe, 1999; G. Scott, Leritz, & Mumford, 2004).

Given the ease with which human resources can move between firms, it would seem on the surface that it should be difficult to protect human capital from expropriation by rivals.1 However, human capital is most valuable and most inimitable when it is firm-specific and resides in the environment where it was originally (optimally) developed (Hitt et al., 2001; Klein, Crawford, and Alchian, 1978; Lepak and Snell, 1999). The role of human resources in creating competitive advantage through learning is amplified by their intertwined relationship with tacit knowledge. Technical knowledge created through learning by doing in a high-technology environment such as semiconductor manufacturing is partially codified into refinements in process specifications and process control limits. The rest of the knowledge remains tacit in the understanding and skills of the employees. Generally speaking, knowledge acquired through engineering analysis will be codified, while the knowledge residing in equipment operators and technicians, obtained through repetition and experience (observations that amount to informal, natural experiments) is tacit knowledge. This knowledge serves to improve further learning in the form of codification of unknown elements of the process technology.

Where does human capital come from and how do firms manage it to competitive advantage? Human capital begins with human resources in the form of knowledge and skills embodied in people. The stock of human capital in a firm comes from its employee selection, development, and use (Koch and McGrath, 1996; Snell and Dean, 1992).

The human capital embodied in these new employees is not firm- specific so firms work to develop the employees, making investments in specialized human capital that improve their productivity and subsequently improve the rate of learning in the firm. How- ever, hiring and developing human resources is not enough to ensure competitive advantage; deployment is critical (Hatch, Dyer, 2004). But in this paper because of simplification we do not mention the deployment.

The impact of HRM on innovative capabilities of organizations, however, has not been well understood. (Zhou et al, 2013). Although researchers have generally agreed on the importance of human resources for innovation for more than two decades (Schuler, 1986; Schuler & Jackson, 1987; Schuler & MacMillan, 1984; Van de Ven, 1986), the synergy between HRM practices and organizations' innovation has received little attention until recently (Shane & Ulrich, 2004) when the empirical research focusing on innovative HRM systems just began (Agarwala, 2003; Beugelsdijk, 2008; Jimenez-Jimenez & Sanz-Valle, 2008; Laursen & Foss, 2003; Shipton, West, Dawson, Birdi, & Patterson, 2006).

As noted by Subramaniam and Youndt (2005, p. 459), "unless individual knowledge is networked, shared, and channeled through relation- ships, it provides little benefit to organizations in terms of innovative capabilities." A commitment-oriented HRM system may cultivate innovation through creating a cohesive internal environment in which employees trust and share knowledge with each other (Kang et al., 2007). First, a work environment that values teamwork and job security is more likely to cultivate a sense of "public good" or collectivity (Ibarra, Kilduff, & Tsai, 2005), which invites individuals to trust the organization, share knowledge, and innovate with- out private concerns (Moran, 2005). Second, the internal career ladder, cross-functional teamwork, and information sharing may develop internal knowledge and communication protocols that serve as a common cognitive basis for effective communication and knowledge sharing (Gittell et al., 2010; Nahapiet & Ghoshal, 1998). Third, practices such as teamwork, job rotation, and internal career ladder create structural connectedness among employees (i.e., strong ties or norms). These enable the exploitation of more fine- grained, complex knowledge to facilitate innovation (Reagans & Zuckerman, 2001; Reagans, Zuckerman, & McEvily, 2004).

Financial capital

Economic and financial instruments provide specific pecuniary incentives (or disincentives) and support specific social and economic activities. Generally speaking, they can involve economic means in cash or kind, and they can be based on positive incentives (encouraging, promoting, certain activities) or on disincentives (discouraging, restraining, certain activities). Table 1 presents some examples of economic instruments according to these different sub-types (Borras, Edquist, 2013)

Table 1

Example of economic instruments (Vedung, 1998).

Economic means in cash:
Positive incentives (encouraging and promoting): • Cash transfers • Cash grants • Subsidies • Reduced-interest loans • Loan guarantees
Disincentives (discouraging and restraining) • Taxes • Charges • Fees • Customs duties • Tariffs
Economic means in kind:
Positive incentives: • Government provision of goods and services • Private provision of goods and services under government contracts • Vouchers

It has long been argued that well-functioning financial systems are essential for promoting economic and technological progress [see Schumpeter (1911), or a more recent discussion in King and Levine (1993a)]. For instance, financial intermediaries channel savings to investment (Bencivenga and Smith, 1991) and increase the productivity of that investment by allocating funds to the most qualified firms (Greenwood and Jovanovic, 1990; King and Levine, 1993b). However, less is known about how this effect differs within financial allocation to the other resources for innovation.

Research & Development

The contribution R&D makes to economic growth has become both a political and a social issue in recent years. In today's economy, knowledge is one of the main economic assets, and its management and protection have become the cornerstones of corporate strategy in industrialized nations (Hanel, 2006).

the endogenous growth framework considered here implies that in steady state there is a positive impact by R&D intensity on the rate of patenting, by the rate of patenting on the rate of technological change, and by the rate of technological change on the growth rate of output per worker (Zachariadis, 2002).

When looking at the annual growth rate of investment in R&D as a percentage of Gross Domestic Product (GDP) from 1994 onwards in Iran, we perceive a major effort to increase spending on this activity.

Innovation capability

An exceptional amount of research has been devoted to the study of the determinants of GDP and income per capita, and in particular to the role of innovation for the growth and development process. By contrast, only a limited number of studies have empirically investigated the dynamics of innovative capability over time and the main factors that may explain its long-run evolution (Furman et al., 2002; Varsakelis, 2006; Filippetti and Peyrache, 2011). This is a crucial task for future research in this field.

Defining the problem

By observing the data series we find that some countries are very successful in innovation without making much effort in research and development. The figure 1 shows four countries which are in the frontline of this trend: The United States, Germany, Japan and South Korea. Except The United States, the other countries provide patents as an indicator of innovation, much more than scientific articles they published. The reason for the trend of U.S also is because this country always was the immigrant country were students all around the world gather together to produce knowledge and hence publish papers. But in recent years we see that beside maintaining the same amount of articles published, there is a huge increase in patents in The United States.

By comparison Iran, had big investment in Research and development which results in rapid growth in papers published but it fails to be sustain in innovation activities which is key component of competitive advantage and have a critical role in sustainable development of the country.

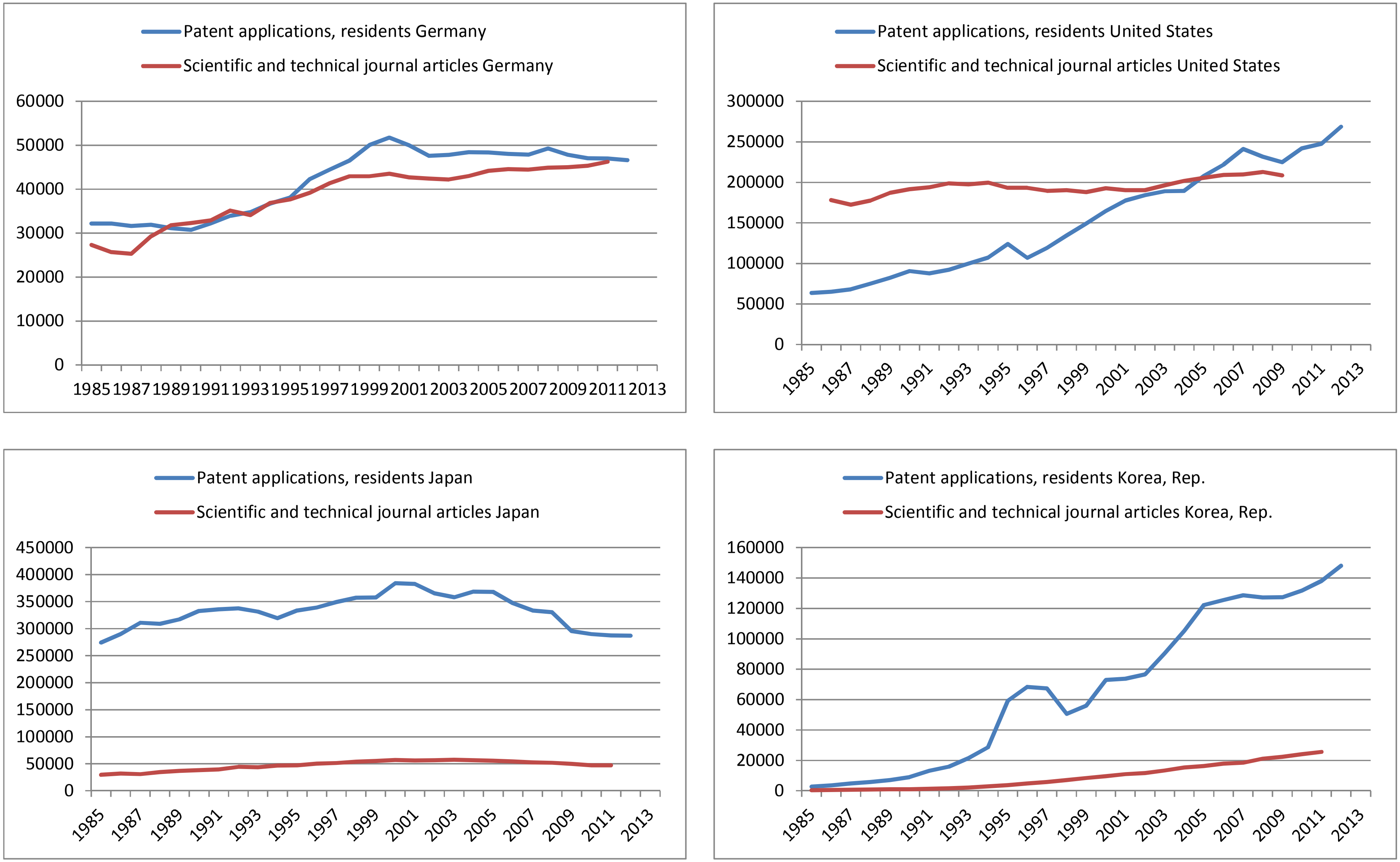


Figure 1 - Trend of patent applications versus scientific and technical journal articles in different countries – source: Databank, World Bank

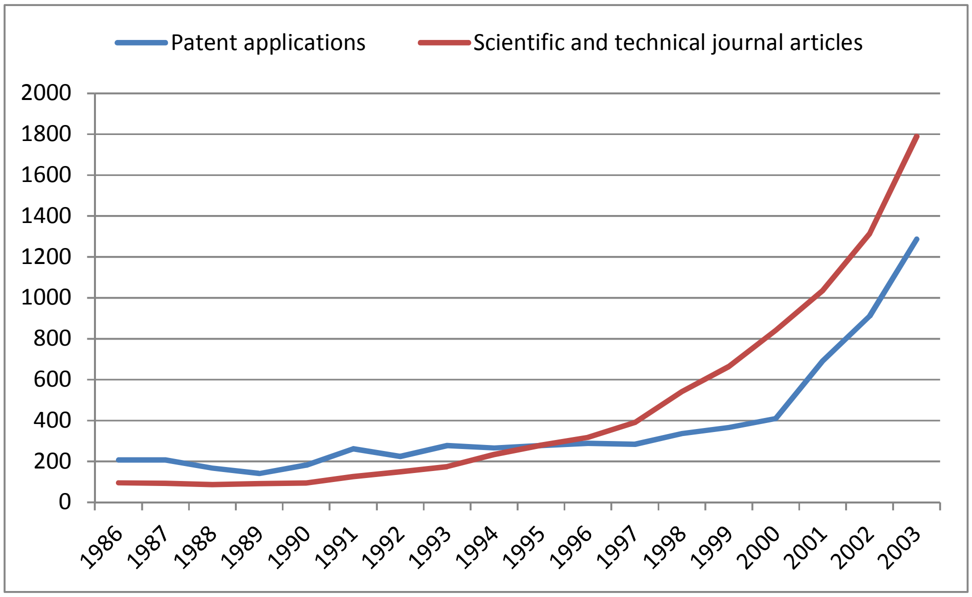


Figure 2 - Trend of patent applications versus scientific and technical journal articles Iran – source: Databank, World Bank

The Model

By reviewing the literature we see that innovation gains feedback from four main sectors: Financial resources, human resource, research and development and innovation capability. We review the literature of these sectors in previous section. Also we can add to them that innovation capability consists of learning capability, R&D capability, resource allocation capability, manufacturing capability, marketing capability and organization capability (Yam et al., 2011). With these assumptions we propose a model which contains these sectors with considering interactions between them.

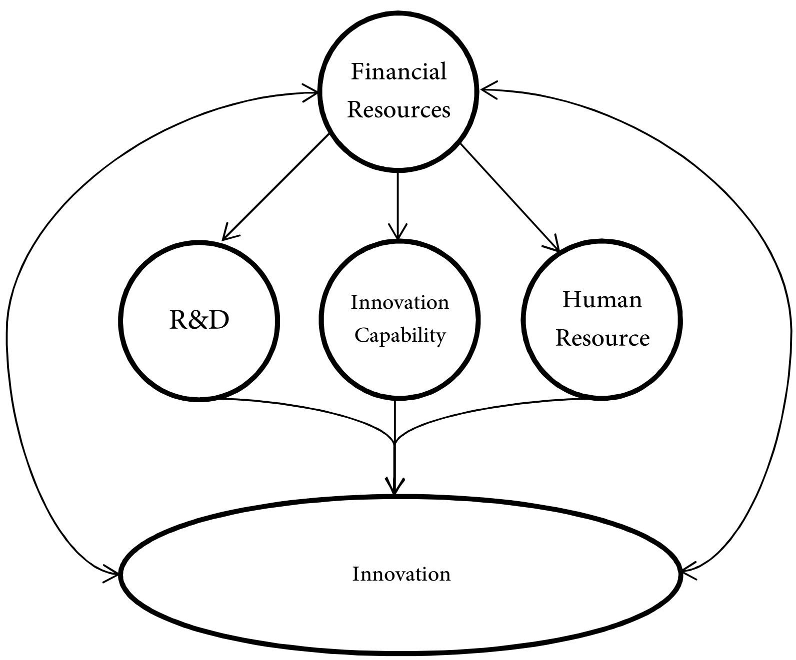


Figure 3 - The proposed sector map for National Innovation System

Figure 3, represents research and development activities, human resources and innovation capability does not evolve in a country, until financial resources support them. This means that allocation financial resources to each sector provide the needed components for innovation. By allocating appropriate financial resource to human resource we can have desired researchers and other people who are directly or indirectly connect to innovation process. Having only human resource is not enough for innovator activities and we need to allocate some part of financial resource to research and development sector, which is the heart of innovation process. The last two sectors do not work efficiently until there are some combination of abilities and infrastructures that we call them innovation capability. By effective allocating financial resources to these sectors we get one step closer to innovation process.

Innovation does not occur until sufficient financial resources are also allocated to processes which involved transferring ideas, articles and patents into prototypes, pilots and at last commercial product or innovative process; there is a link from financial resources to innovation directly. When innovation occurs, the result is a new product or process which is almost tangible assets that can be sold in the market. We can see besides experience and learning that a firm, or at national level a nation, will achieve by innovation, the most important result of innovation is the revenue which is generated by selling innovative products or processes. It is shown in the figure 3 that also there is a link from innovation to financial resources, as we explain the mechanism of this link.

As mentioned above the model has four main sector. Let's first start with innovation capability. As innovation capability increase there is a intention in increasing rate of patenting or increasing rate of innovation. When industry's innovation increases the sales of products grows and it result in growing revenue and budget. Whit budget available, the industry can invest money to increase the innovation capability (Loop R1). This mechanism is shown in Figure 4 .

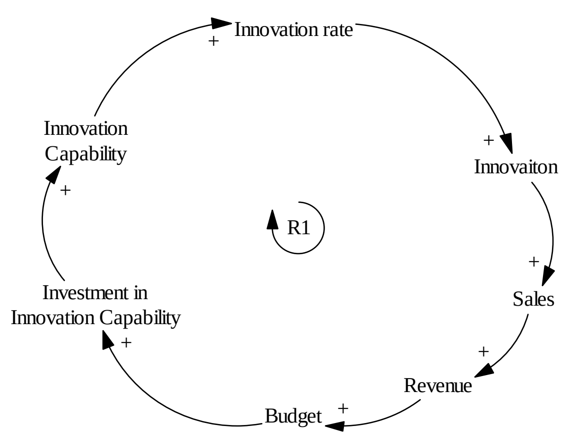


Figure 4 – Loop 1

The same as loop 1, when industry's budget grows up they can invest part of this budget in research and development activities. Therefore active R&D increases and causes more completed R&D. Since many technical and scientific articles arise from R&D activities, the raise of R&D lead to rise of domestic articles. By using domestic articles we mean papers which are published inside a nation. Here we differentiate domestic articles versus foreign articles because the main part of financial allocation to in-house R&D results in domestic R&D and there is a little portion of domestic articles come from research activities outside nation borders. The increase in domestic articles with keeping innovation capability constant we may have increase in rate of innovation (Loop 2). This mechanism is shown in figure 5.

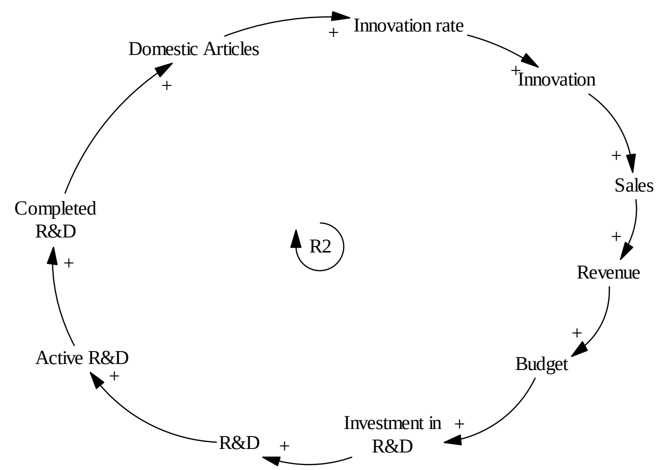


Figure 5 – Loop 2

Same as above discussion, again industry can invest in human resources which can cause two effect. First it can build the basis for having qualified human resource. Secondly it could result in enhanced human resource management. Both effects results in completed R&D which then increase domestic articles and again innovation rate grows up (Loop 3 & 4). The mechanism is shown in figure 6.

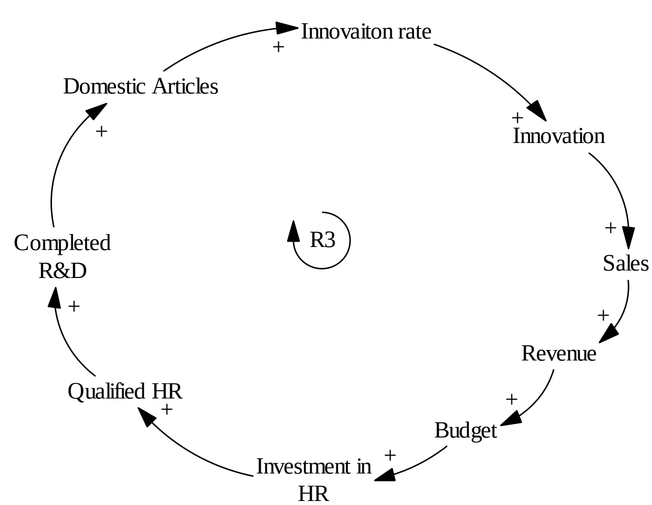


Figure 6 – Loop 3

It is obvious that combination of these reinforcing loops leads to exponential growth of innovation which is impossible in reality. If we think operationally in formulation of budget we might see that investing budget in each sector cause the decrease in budget. So there are three loops then we add to each loop mentioned above (Loops 4,5,6). The combination of causal loop diagrams are shown in whole picture in figure 7.

Figure 7 shows a system dynamics concept that we should notice. Without having loops number 4 to 6, we have three positive loop which have no limit to growth. Thus we see an exponential growth and anything never stops. But this is not true in real world. The mechanism of loops number 4 to 6 shows the real limitations which are around us everywhere. For any activities we do, we must pay for it. The innovation system are not exceptional. As mentioned earlier, budget or financial resources are devoted to invest in some areas. In causal loop diagram, there should be a link from any investment to reduce budget available.

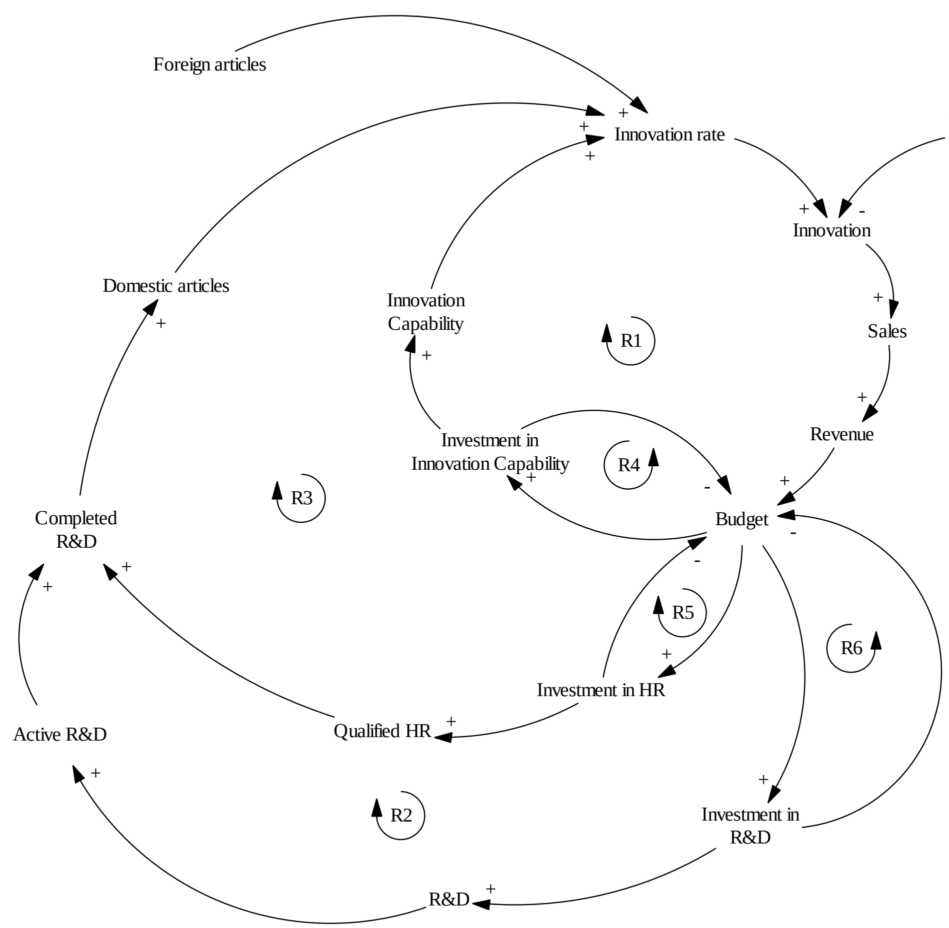


Figure 7 – The casual loop diagram

Model Analysis

In this section, we use simulations to analyze the results of the model introduced above.

The reality check

The importance of reality check for the proposed model is obvious. With the available data we consider checking differences between articles and patents which generated by model with the real one from the source, World Bank data. The period which we consider for reality check is between 1986 to 2003. After 2003 there is lack of data.

First we start with number of published scientific and technical journal articles. In 1986 published scientific and technical journal articles are 96 and increase up to 1789 in 2003. The simulation start with 96 articles in 1986 and end with 1789 in 2003. The trend is the same as the reality curvilinear.

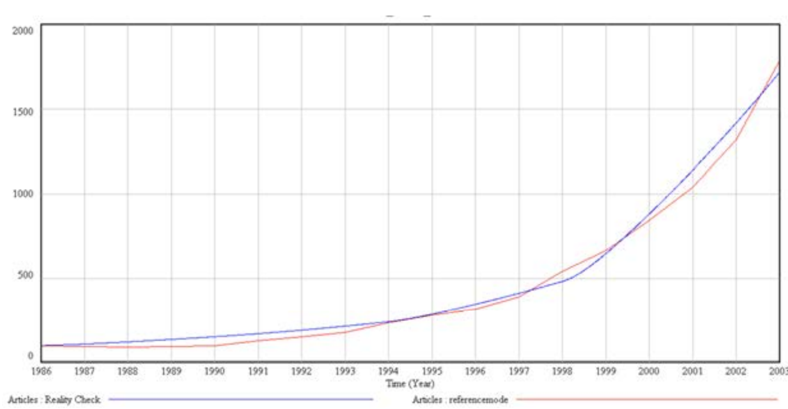


Figure 8 – Reality Check

Secondly is the number of patent applications. In 1986 patent applications is 207 and increase up to 1287 in 2003. The simulation start with 207 in 1986 and end in 2003 with the number 1285. The curve is approximately fit to the reality.

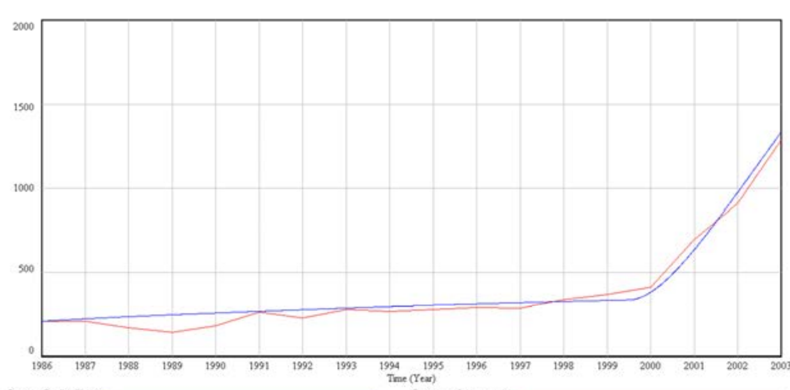


Figure 9 – Reality check and reference mode

Considering both articles and patents we can see the great confidence of the model we proposed, by showing the behavior of variables that fit best with the reality.

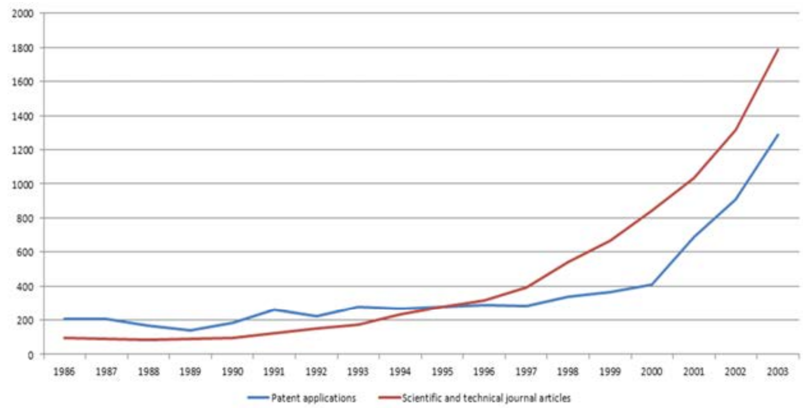


Figure 10 – Patent applications and scientific and technical articles – Source: Databank, World Bank

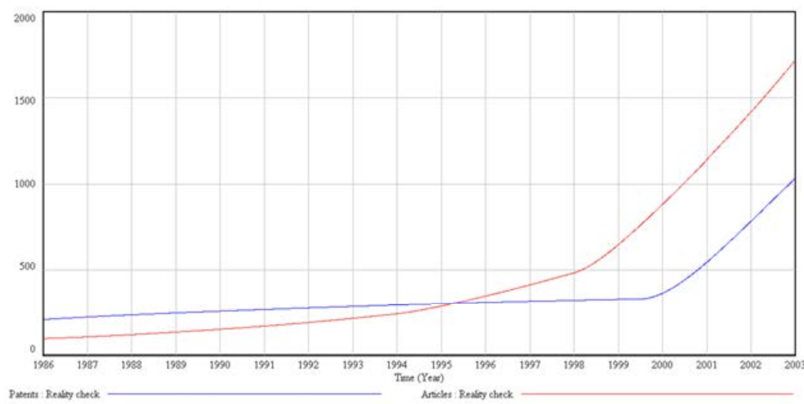


Figure 11 – Reality check of patents and scientific and technical simulation

For the number of researchers, due to lack of data, the only approximation we can achieve is like the figure 12. Something vague about the growth of researchers is that it is exponential or logarithmic. Obviously regarding this trend of researchers we can find the fit between articles and patent in simulations and reality. So we consider this approximation valid for the number researchers.

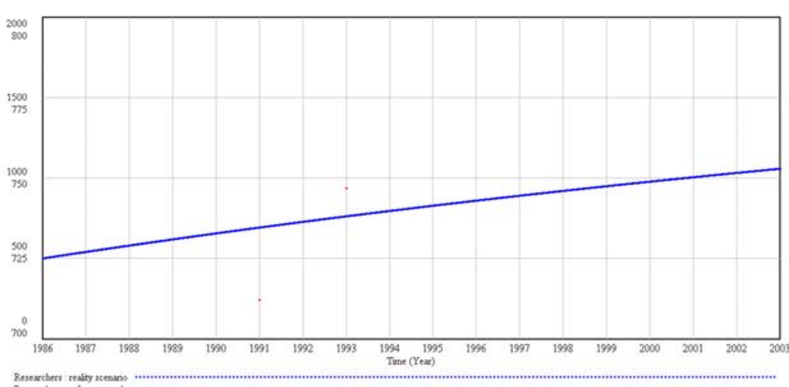


Figure 12 – Approximation of number of researchers

Further analysis

The innovation capability is a variable that is hard to quantify and it is somehow impossible to measure. But in the model we developed we simplified it by assigning numbers range from 0 to 1 which zero means absolutely no innovation capability and 1 is defined the maximum innovation capability one country can have. It is a stock variable with an increase rate and a decrease rate. The increase rate is determined by the investment in gaining innovation capability and two other parameters. The first one is the delay time which means how much on average it takes time to build or capture the desired innovation capability. We use build or capture concept because to remind that the innovation capability is a holistic concept consist of learning capability, R&D capability, resource allocation capability, manufacturing capability, marketing capability and organization capability (Yam et al., 2011). Some of them needed building activities like manufacturing capabilities and some needed capturing and gaining through hiring managerial consultants or learning by participations in management courses and etc. The second factor affecting rate of gaining innovation capability is how much financial resources are devoted to invest in gaining innovation capability. Here we make an assumption by defining the parameter normal innovation capability gain. This parameter tells that on average how much is the cost of gaining one unit (say for example 10 percent) of innovation capability. The next thing we should consider is the amount of money dedicated to innovation capability, which for lack of data and also for simplification we consider it as 0.5 percent of total financial resources devoted to research and development, human resource and innovation capability. We describe the financial resources in more detail later in this paper.

The decrease rate of innovation capability is getting feedback from one of the most important concepts in innovation literature, technology lifecycle. The technology life-cycle (TLC) describes the commercial gain of a product through the expense of research and development phase, and the financial return during its "vital life". Some technologies, such as steel, paper or cement manufacturing, have a long lifespan (with minor variations in technology incorporated with time) whilst in other cases, such as electronic or pharmaceutical products, the lifespan may be quite short[1]. At the end of the life cycle it is presumable that new technologies and hence new innovations bring about. By introducing new product and services there is an unwanted decrease in innovation capability. The stock and flow diagram of innovation capability dynamics is shown in figure 13.

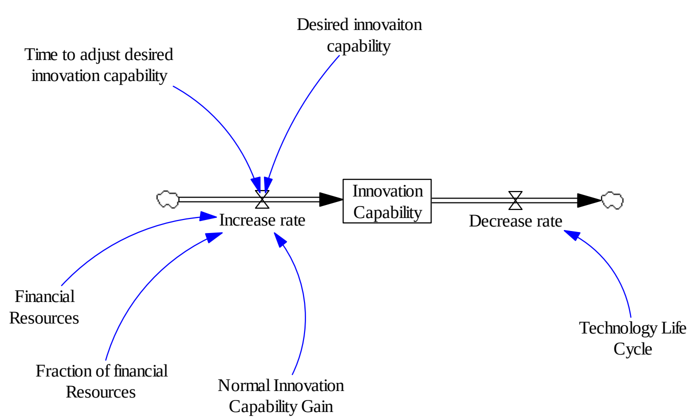


Figure 13 – Stock and flow diagram of innovation capability

[1] http://en.wikipedia.org/wiki/Technology_life_cycle

The argument shows that the innovation capability can be achieved thorough simulation. When we simulate the model by the data we have we see that innovation capability is growing from an initial value (0.3, which we deliberately assign it with signs from Iran's innovation capability) and it shows a goal-seeking behavior and reach to 0.41.

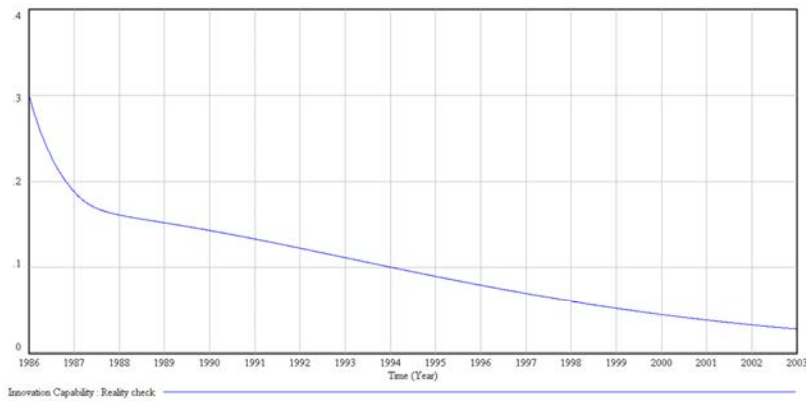


Figure 14 – Innovation Capability, reality check

Innovation capability feeds directly to innovation and patent increase rates. The higher innovation capability, the more patent and innovation we have. For policy implications one might think that if allocating more financial resources to innovation capability there must be more patent as an indicator of innovation and then more innovation. So the key concept that some countries have less scientific and technical journal articles than patents and hence innovation is that they have higher innovation capability. In the next section we test this policy and see the results of that.

Policy implications

The only data we have for budget spending on innovation at national level was R&D expenditure as an exogenous variable (World Bank Databank). To changing the structure of model for policy implications we consider it as an source rate of financial resources for whole innovation process. Before this change in model, R&D expenditure only affect the amount of active R&D which defined by normal active R&D expenditure, a parameter that tells about how much money needed for an active R&D to be completed on average. But here as mentioned, we use data for R&D expenditure to assign them to the financial resource for all kind of innovation activities.

Another implication is for defining five ratios that measure somehow the performance of national innovation system. By tracking these ratios, policy makers can make decision about the policy to how allocate resources to each sector by efficiency parameters we defined. These ratios are: number of researchers to number of articles, number of researchers to research and development activities, research and development activities to innovations, Research and development activities to number of patents and innovations to number of articles. By dividing these ratios to each normal parameter of them we reach to the "efficiency" ratio of them. At last with five lookup functions which are the policy instruments of policy makers, they determine how resources should be allocated to each sector. Assume that b_t is the amount of budget allocated to sector i. We define b_t as:

$$b_t = \frac{a_t}{\sum_{i=1}^{5} a_i}\ Budget$$

where a_i is the factor that is determined by policy makers.

The next thing should be paid attention to is the budget or financial resources and the question that where does it come from. As mentioned earlier the only data for financial resources available is for research and development expenditure. We split it into two parts. First from 1986 to 2003 and second from 2003 to 2008. This is because the data for scientific and technical journal articles and patents is up to 2003. The question we have in policy implications is that what occurs when these kind of resources are allocated differently to other national innovation sectors in Iran. So we decide to describe this effect of resource allocation from 2003 and predict the desired and unwanted behavior up to 2020.

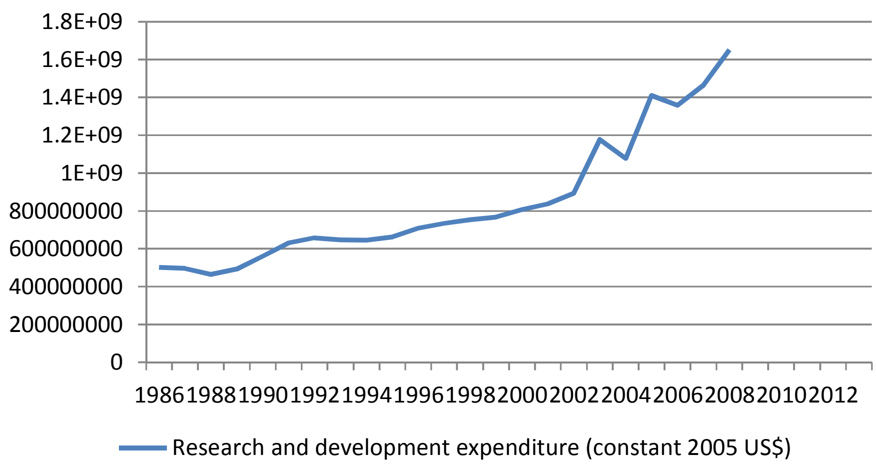


Figure 15 – Research and development expenditure

In the model structure we allocate all financial resources from data exactly to research and development activities until 2003. From then we use a stock variable named “financial resources” which increase with two rates. First with revenue which is the product of demand times price. Second is the R&D expenditure after year 2003. Here demand is the intersection between demand-supply curve in macroeconomics. But as the market here is the innovative product, we presume that are innovative products are sold with an average price for all kind of innovative products.

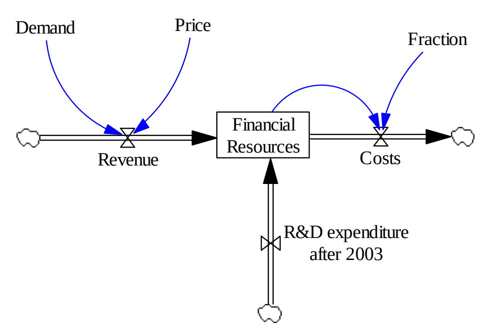


Figure 16 – Stock and flow diagram of financial resources

High extreme conditions

In this scenario we focus extremely to innovation capability and pay attention to allocate more financial resources to this part of national innovation system. The detail of lookup functions for decision making are shown in appendix B. In summary the allocation of financial resources to human resource (researchers) and research and development has declined and for the innovation capability has increased. As we saw the innovation capability was in declining phase but until 2003. After that if allocation was performed in this condition the innovation capability will be like the figure 17.

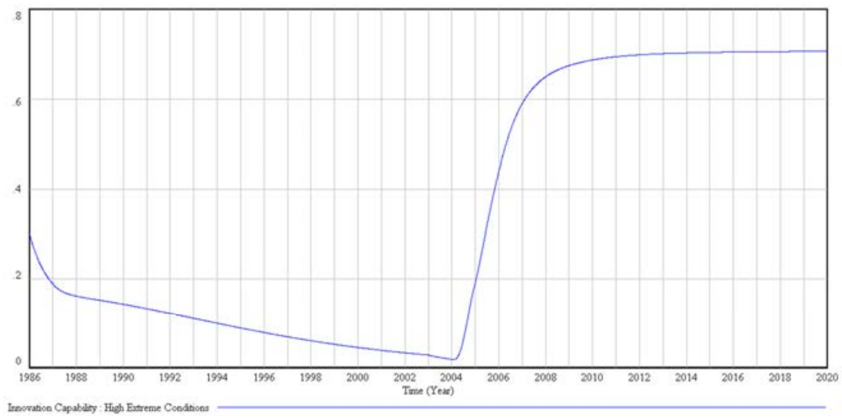


Figure 17 – Innovation capability - High extreme condition Simulation

The rise of innovation capability is fast and accelerating which change from almost zero to 0.7 in six years. We will predict mentally that a growth to patent might occur more than number of published articles. The result is simulated and is shown in figure 18.

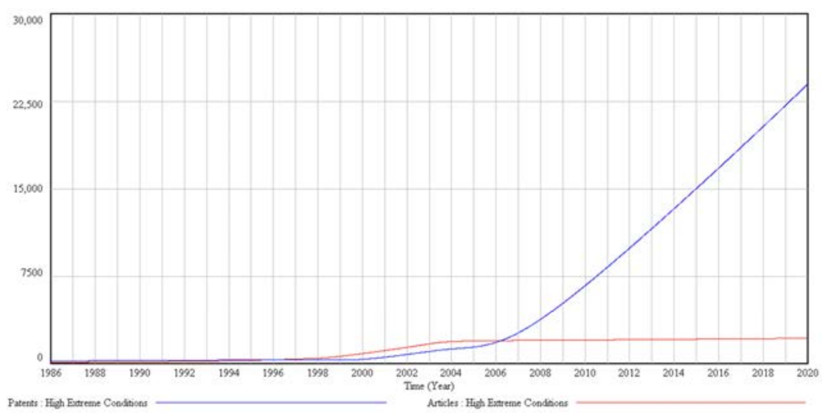


Figure 17 – Number of Patents and Article, High extreme condition Simulation

As we see, allocating less resources to other areas than innovation capability results in not enough published articles.

Low Extreme Conditions

In this scenario the focus changed from innovation capability other sectors of national innovation system. The detail of lookup functions for decision making are shown in appendix B. In summary the allocation of financial resources to human resource (researchers) and research and development has increased significantly and for the innovation capability has declined. As we saw the innovation capability was in declining phase but until 2003. After that time, if allocation was performed in this condition the innovation capability will be like the figure 18.

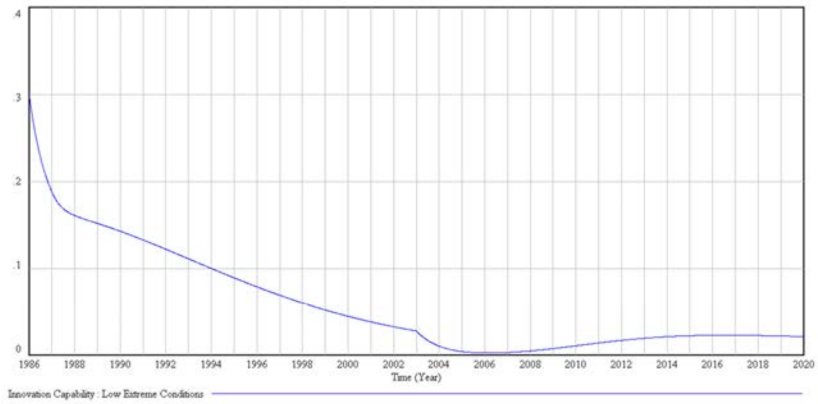


Figure 18 – Innovation capability - High extreme condition Simulation

As it is shown the decline of innovation capability continues until it reach zero which is a very rare phenomenon in real world. from year 2006 it starts to grow until it reaches a fix amount. In this situation we predict that there is a lack of patents and plenty of published articles. The simulation verify the prediction.

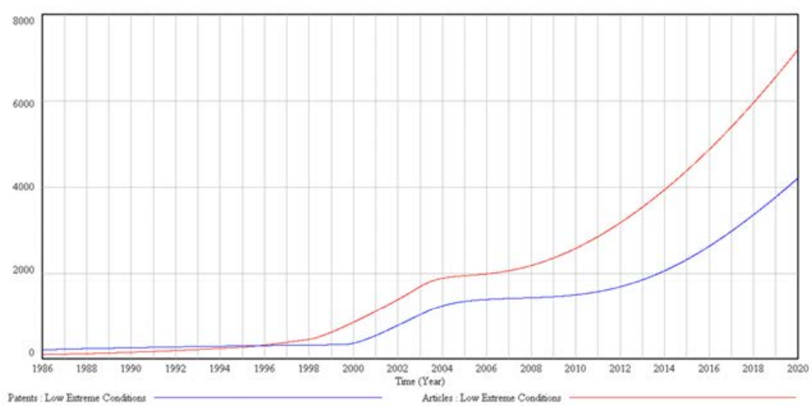


Figure 19 – Number of Patents and Article, High extreme condition Simulation

It is a very bad scenario in which many countries should occur and besides lack of data and the behavior of policy makers we predict that Iran is experiencing this case.

Policy Implications

We propose a balanced financial resource allocation in which three main sectors gain enough financial resources to invest an rise innovation output. The model is simulated and results are shown below.

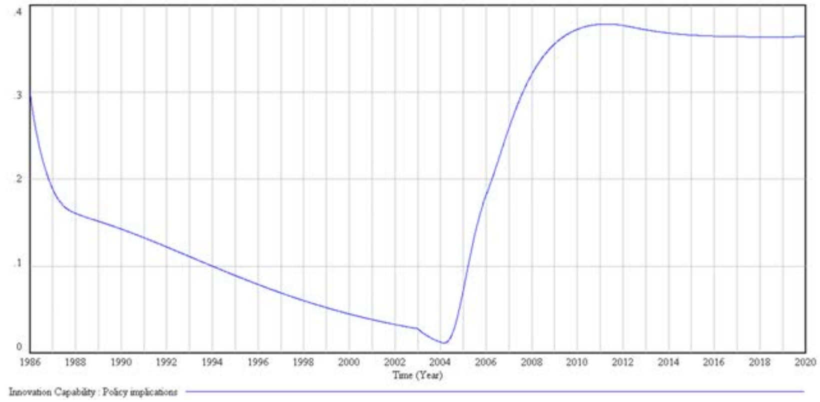


Figure 20 – Innovation capability - High extreme condition Simulation

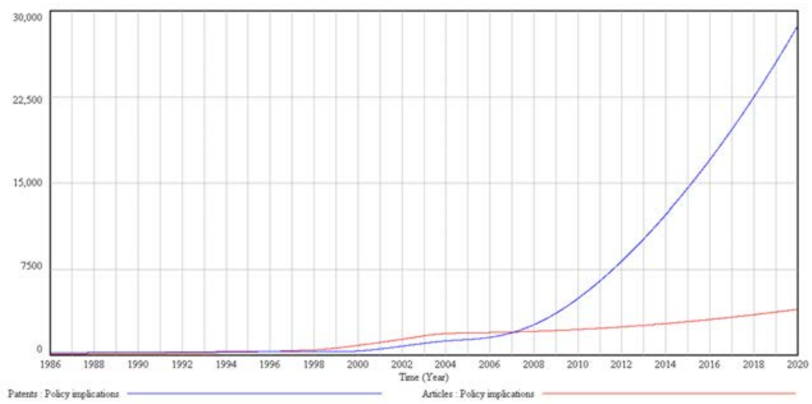


Figure 21 – Number of Patents and Article, High extreme condition Simulation

We see that innovation capability grows but shows somehow overshoot effect and fluctuations stop at 3.8. There is a huge amount of patent generated in 2020 and also about 4000 scientific and technical journal articles. In this scenario not only number of patents increase by comparison with high extreme scenario, but also the number of scientific and technical journal articles have increased much more than the second scenario. This shows an important result and that is linear view to the concept of national innovation which in case might be increasing investment in human resource or research and development activities or even innovation capability, without considering other sectors is not sufficient. This system dynamics model shows us that systemic view beside considering sectors in each innovation systems and specially national innovation system is a key concept which might be missing during policy making.

Discussion and conclusions

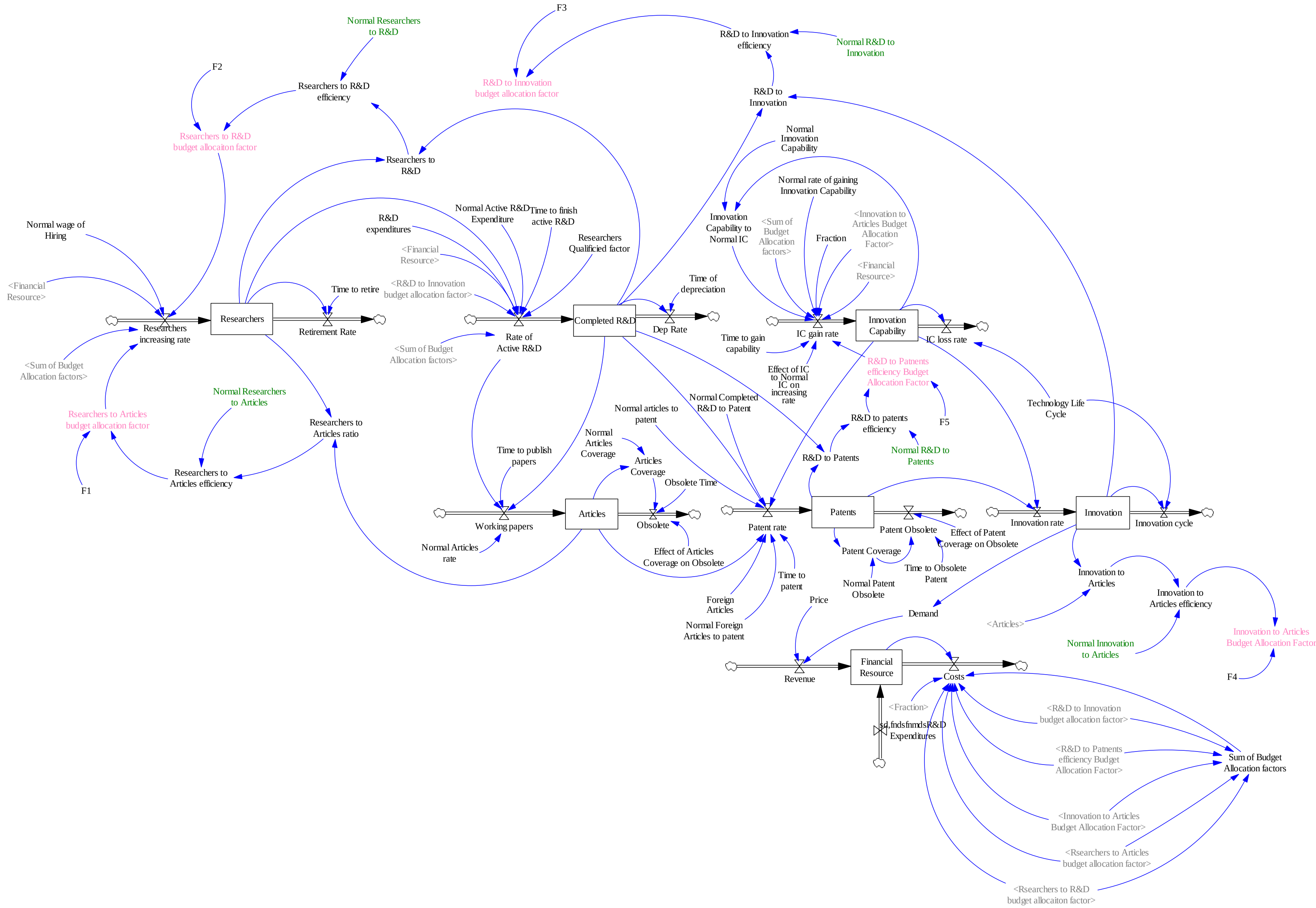
In this paper we review various systemic approaches to study and analysis of the concept of innovation. Some approaches focus on some parts but miss the others and vice versa. Within these approaches, the national innovation system was so comprehensive that many researches select that for studying the ways knowledge become to new product or process and effects of these activities on economies.

National innovation system was studied by many scholars from many aspects like multilevel perspective or functional view. But there is little work on dynamic aspect of this concept yet. The specific aspect that we consider in this paper is the dynamics of national innovation system.

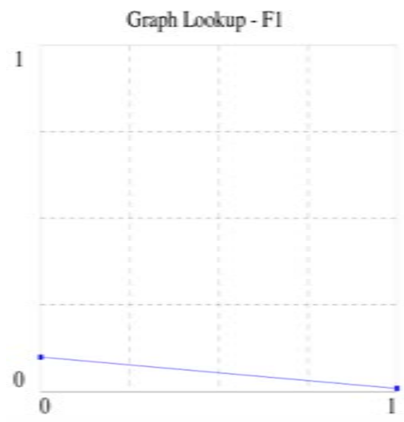
By reviewing literature about innovation systems and specially national innovation systems we find that the system consists of four main sector: human resource, research and development, financial capital and innovation capability. We see that the trend of these parameters are somehow different and therefore the economical output are different. Specially in Iran there is a huge rising of domestic articles which come from research and development does not make any sense with the growth of innovation output and sometime however in declining of innovation capability. For analyzing more detail, we develop a system dynamic model to capture the core mechanism of innovation between sectors we proposed.

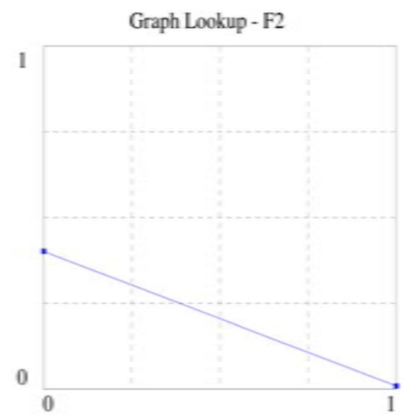
The model we proposed suggest that in a country like Iran the pressure on generating domestic articles to boost innovation is not enough without a minimum innovation capability. It also insist on effective resource allocation, specially financial resource allocation plays a critical role in innovation output. By defining five critical ratio from major outputs of four sectors in national innovation system, gaining insight for decision making in allocating financial resources to sectors, we run two extreme scenarios to validate the model and then propose policy implications for effective financial resource allocation to each sector for national innovation system. The model suggests that allocating almost every financial resource for research and development is not an effective way to produce desire innovation output in almost every countries and specially in Iran.

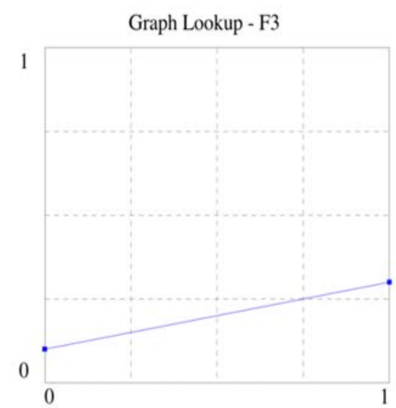
Appendix A ñ The model

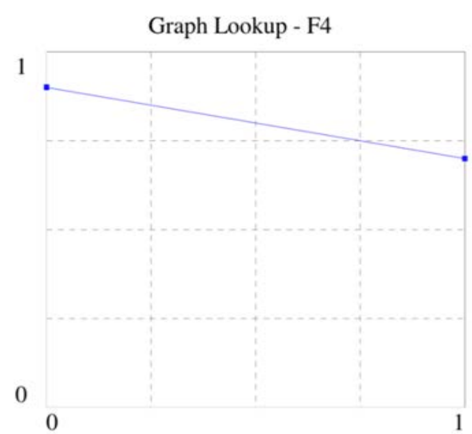


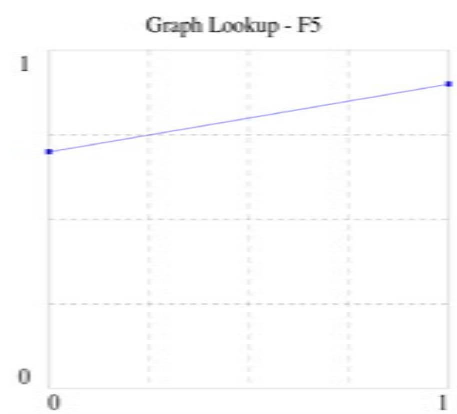
Appendix B ñ The Lookup Tables ñ High Extreme Scenario



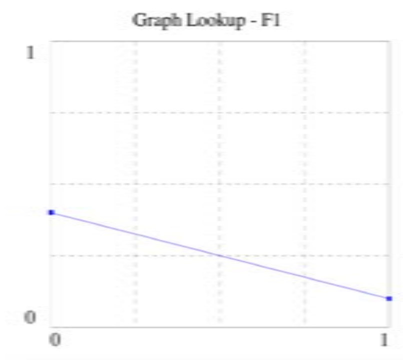


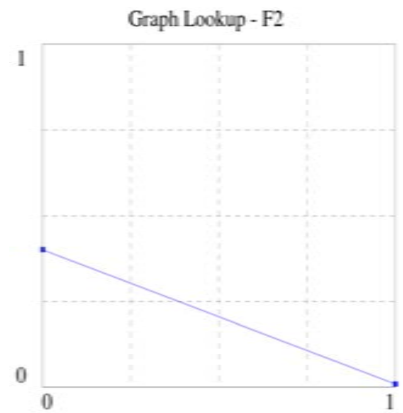


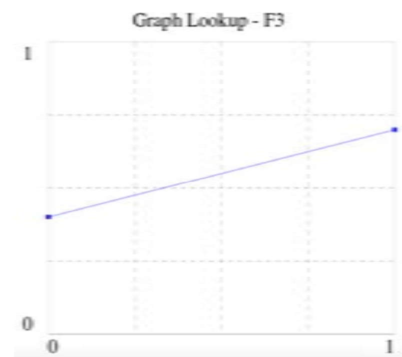


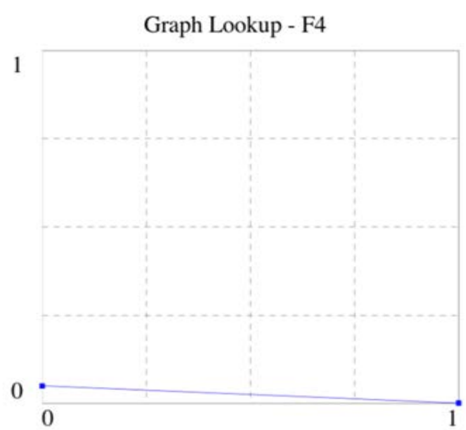


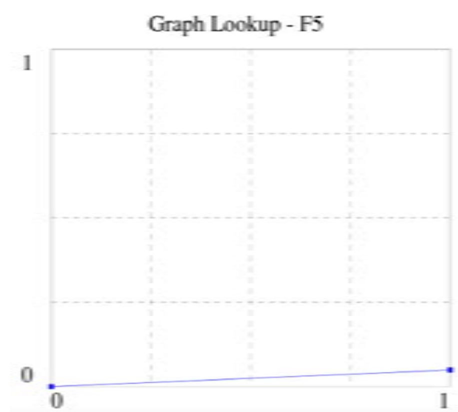
The Lookup Tables ñ Low Extreme Scenario



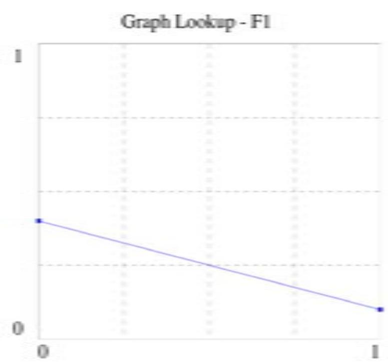


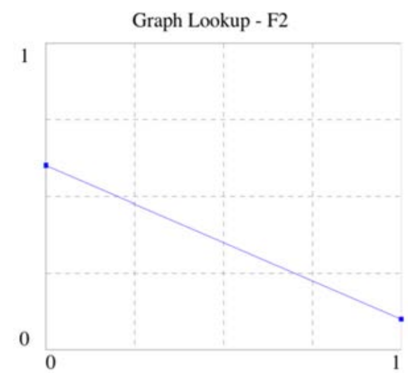


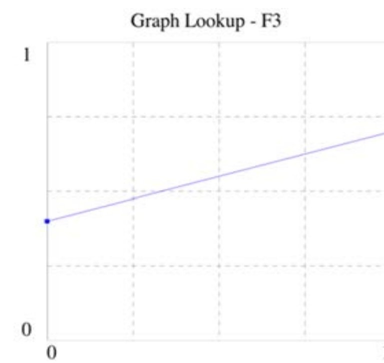


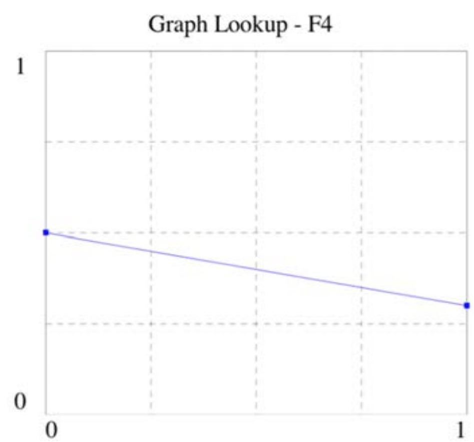


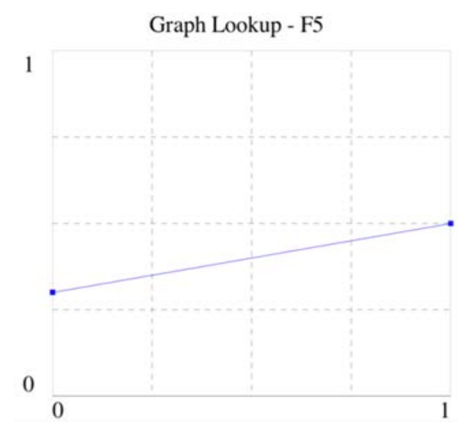
The Lookup Tables ñ Policy Implications











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