AN INNOVATION SYSTEMS MODEL
Using the Systems Thinking Approach

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ABSTRACT

Innovation systems are considered a key factor to enterprises' long-term success as well as an element that can improve national economic and socio-economic problems such as, unemployment and productivity growth. Considering the important role of innovation to the firm and to the country, an innovation systems model has been designed using a systems thinking approach. The aim of the model is to enhance innovation activity in the firms of manufacturing industrial sectors. This model reveals the implications of the firm's strategic decisions and associates the national policy strategies and institutional support to the enterprises innovation activity. The simulation of the designed model can illustrate these implications. This paper's objective however, is to present the part of the model that refers to firm's organisation and strategy which influences innovation activity. Systems thinking methodology has been used to uncover the complexity of the innovation systems framework and reveal the underling structures which generate change. The design and simulation of the model has been made utilising the iThink™ business-modelling package.

1. Introduction

Innovation is a key factor to an enterprise's long-term prosperity (Utterback, 1994; Tidd et al., 1997) as well as one of the elements that improves employment, productivity growth and the economic wealth of a country (Porter, 1990; European Commission, 1996; Aghion and Howitt, 1998; Archibugi et al., 1999). As a result, several studies attempt to describe the nature of innovation, either from the managers' perspective (Garud et al., 1997b; Tidd et al., 1997; Kodama, 1995; Martin, 1994) or the national policy design perspective (Porter, 1990; Lundvall, 1992; Nelson, 1993; Stonemann, 1995). Innovation however, is not a linear process but occurs by interactive relationships and feedback mechanisms between institutional and organisational elements of science, technology, learning, production, policy, firms and potential or actual market demand, which together may be called 'systems of innovation' (Edquist, 1997; Sundbo, 1998).

Considering the important role of innovation to the firm and the country, an innovation systems model has been designed using systems thinking approach. The aim of the model is to enhance innovation activity in the firms of manufacturing industrial sectors. This model reveals the implications of the firm's strategic decisions and associates the national policy strategies and institutional support to the enterprise's innovation activity. Dynamic simulation of the model can illustrate these implications. The model developed has two interlinked layers:

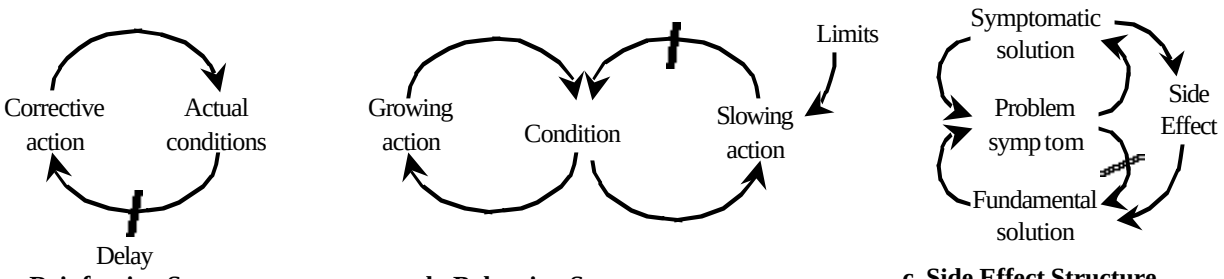
- The layer of the firm that models the internal organisation and the new product design and development processes, has been developed into a concept called the 'creative factory'. This concept of the creative factory, involves several elements such as the firm's strategy, the research effort, the culture, the availability of capital, the technology capabilities, the organisational structure of the firm, the employees participation and the level of risk that the firm undertakes.
- The environment around the firm, which influences the innovation activity of the enterprise has been called 'supply availability'. The 'supply availability' incorporates the supply of new ideas (for instance from entrepreneurs or public research); knowledge and technology (for example, knowledge created in the universities and research institutes); specialised personnel; material; the market demand; the critical mass (for example, related industries and depth of the sector in the country); and economic and infrastructure support.

This paper's objectives, however, are to introduce the concept of the creative factory and then to present the elements that constitute the model of the creative factory under a systems thinking approach. Background literature work will be introduced as part of the outline to the creative factory's elements.

The next section presents the methodology that was used to build the creative factory model. Section three describes the concept of the 'creative factory' and presents the factors that influence it. In addition, section three presents samples of the logical framework of these elements under a systems thinking approach and the conversion of these into a simulated model.

2. Methodology

Systems thinking offers a methodology that gives a framework for understanding the nature and the behavioural characteristics of multi-node systems, of which innovation systems are an example, and also provides a practical way to define managerial problems and design solutions for them. Furthermore, a systems approach provides the researcher and the manager with a dynamic tool that projects the implications of a decision over time (Checkland, 1993; Gharajedaghi, 1999). Senge (1990), however, argues that the use of systems thinking uncovers the complexity of the system by revealing the underlying structures which generate change. He adds that systems thinking illustrates how a complex problem is generated and which factors influence it in one or another way over time. To show these relationships he transforms any problem into simple diagrams – 'generic structures' – which in combination can illustrate the underlying logic of a system (figure 1).



a. Reinforcing Structure **b. Balancing Structure** **c. Side Effect Structure**

Figure 1. 'General Structures' diagrams (Senge, 1990)

Systems thinking models can be designed and simulated using the iThink[1] business-modelling package. The software package's user interface uses simple icons for certain functions such as stocks, flows, converters and arrows (figure 2). These elements translate the generic structures to a dynamic system that can be simulated and its reaction to certain changes over time can be studied. For example, the stock icon presents the outputs and/or inputs of a process. The flows represent the transformation process or the rates of change involved in creating inputs into outputs. Converters are variables or equations that influence the system's logic and arrows declare the connections between the elements. The elements of the model are characterised as 'soft' variables, because they do not have an actual numerical value. However, it is possible to quantify them by assigning to them an index from 0 to 100, which grades their level. Thus, these variables are able to interact and the model allows the role of each to be studied.

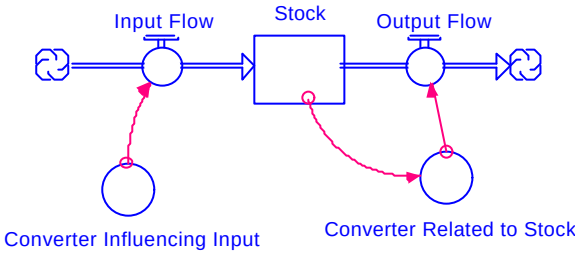


Figure 2. Basic elements of the iThink modelling package

3. The 'Creative Factory'

The creative factory model has been designed around the new product design and development process that a firm may have (figure 3). The creativity of a firm is transformed to new concepts for products and processes, which through the development phase are converted to finished products that are launched into the market. The creativity of a firm however is affected by several factors which interact between them to initiate the creative environment. These factors are identified as: organisation strategy and capital availability, technological capabilities, research effort, organisation culture, organisation structure, risk taking and employee participation. The generation of new concepts feeds the new product development process. After a screening process of these new concepts which is based on the evaluation of the risk taking policy, the capital availability, the strategy of the firm and the technological capabilities, some concepts are selected and are developed to finished products. These may then be introduced to the market. The output of the creative factory is an index of successful new products that are launched into the market and indicates the innovation activity of the firm.

[1] Trademark from High Performance Systems Inc. www.hps-inc.com

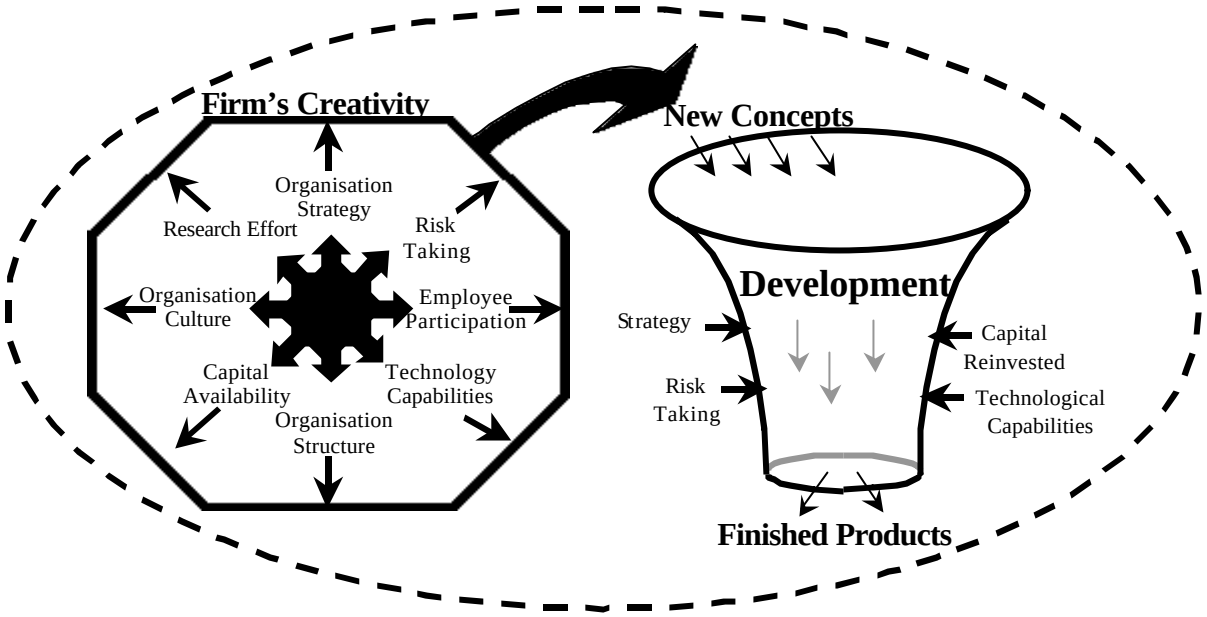


Figure 3. The Creative Factory Framework

The elements that constitute the creative factory are described in this section. Examples of their logic framework or their translation to the iThink modelling package are also given.

3.1. Organisation strategy and capital availability.

Strategy and capital are involved in any aspect of a firm's activity (Tidd et al., 1997). Strategy is designed by the leaders of the organisation and is influenced by the business environment of the firm (Mintzberg et al., 1995). The directions of the strategy show the will of a firm to focus on the creation of new products or to be a follower of others. Additionally the level of capital availability partly depends on the sales that the firm has. Empirical studies show that sales and profits increase at a greater rate in innovative firms than in less innovative ones (Ceserani and Greatwood, 1995). The implementation of a strategy however, requires the employees' participation, availability of capital to be invested and the right organisation culture (Hamel and Prahalad, 1994). Capital is influenced by the productivity of the firm, which depends on the firm's technological capabilities and the participation of the employees. In addition, the cost of research can reduce the availability of capital, a problem that can be solved by collaborative research with other firms or universities and by the participation in national and international research programmes. Organisation strategy influences the screening actions of the product development process, as it shapes the directions of the core business of the firm and in consequence the type of projects that are selected. Additionally capital availability defines the ability of a firm to invest in the development of a project to finished product (Christiansen, 2000).

3.2. Technological capabilities.

The term technology is used in the economic and innovation literature as both the knowledge itself and the tangible expression of this knowledge (Freeman and Soete 1997; Dosi et al., 1988). Evangelista (1999) differentiates technology as disembodied, '*as a stock of knowledge embodied in people or expressed in some codified form*', and embodied '*as the tangible technical assets and intangible operating systems involved in the production sphere*'. A firm that holds a new technology can 'push' to the marketplace new products and processes (Sundbo, 1998). Technological capabilities, therefore, influence the ability of the firm to develop new concepts that require specialised processes or knowledge to produce products (Tidd et al., 1997).

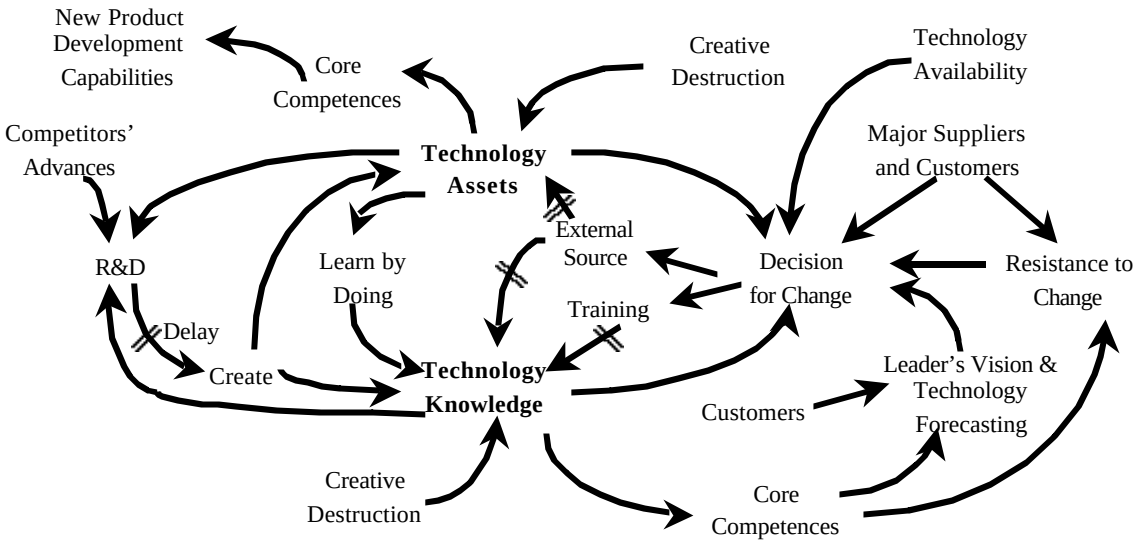


Figure 4. Technology Capabilities Framework

Figure 4 codifies the dual nature of technology and the elements that affect it. Managers can change the firm's technology level according to the needs of the firm in the direction of the core competences of the firm. They can decide to buy new technology from external sources or they can introduce training programmes for the best usage of existing technology. According to the nature of the business, the use of external sources can be translated to investment in machinery, licensing agreements, or consultation of experts (Evangelista, 1996). These can increase the technological capabilities of the firm by creating new technology through in-house research activities, which includes the study of competitors' products and processes, or cooperative research with other firms, universities and research institutes. Another source of technology nonetheless, is the experience that the firm encounter using a problem-solving process applied to existing technological assets. Delays in any change process occur either because of the adaptation period required to integrate the new technology in the firm, or because of the time that is required for the research activity to implement and integrate new technology (Tyre and Orlikowski, 1997). Resistance to managers' decisions however can occur from the current competences that the firm has and the relationships with its suppliers and its customers (Leonard, 1995; Christensen, 1997). The forecasting of technology that a manager considers can be misguided by his/her own previous experiences and knowledge as well as by the demands of his/her customers (Garud et al., 1997a). A radical technology change however can nullify the existing levels of technological capabilities of a firm if it is not ready to respond to this radical technology (creative destruction).

3.3. Research effort.

An organisation can conduct its own research activity by creating research departments or by collaboration with other firms and research institutes or universities (Llerena and Matt, 1999). Research effort can increase proportionally with the research personnel that the firm has, the capital that the firm reinvests and technology assets and knowledge that are available. Because of the cost of research, firms tend to collaborate with other firms or to participate in publicly funded research programmes together with universities and public research institutes (Gemunden et al., 1999). In this case, although the cost of research is smaller, all the members share the results, which reduce the profitability of their use. In addition, delays could become more frequent because each institute has different objectives and priorities (Gambardella and Malerba, 1999).

3.4. Organisation culture.

In the early 1980s, business people were attracted to the literature concerned with organisation culture (see for example: Peters and Waterman, 1982; Deal and Kennedy, 1982), although academics had drawn attention to its importance much earlier (see for example: Eldridge and Crombie, 1974; Turner, 1971). As these studies have shown, the right organisational culture can give solutions to many problems that a firm is facing when on the other hand, many of these problems are originating from the wrong culture that a firm has. Hussey (1997) therefore, argues that culture creates the right organisational climate, which fosters creativity.

The combination of internal organisational elements, such as structure, risk, knowledge and employee satisfaction (Silverzweig and Alle, 1976) and external factors, such as national culture and business environment (Brown, 1995) influences the index of culture in the organisation (figure 5). The management's vision of cultural change is however the internal factor that leads the change (Schein, 1992). The influence of these factors to the organisation change nonetheless depends on the value of 'ease to change' which takes a value according to the difference between the existing culture and the desired one, and the strength of the existing organisational culture (Brown, 1995; Sathe, 1986).

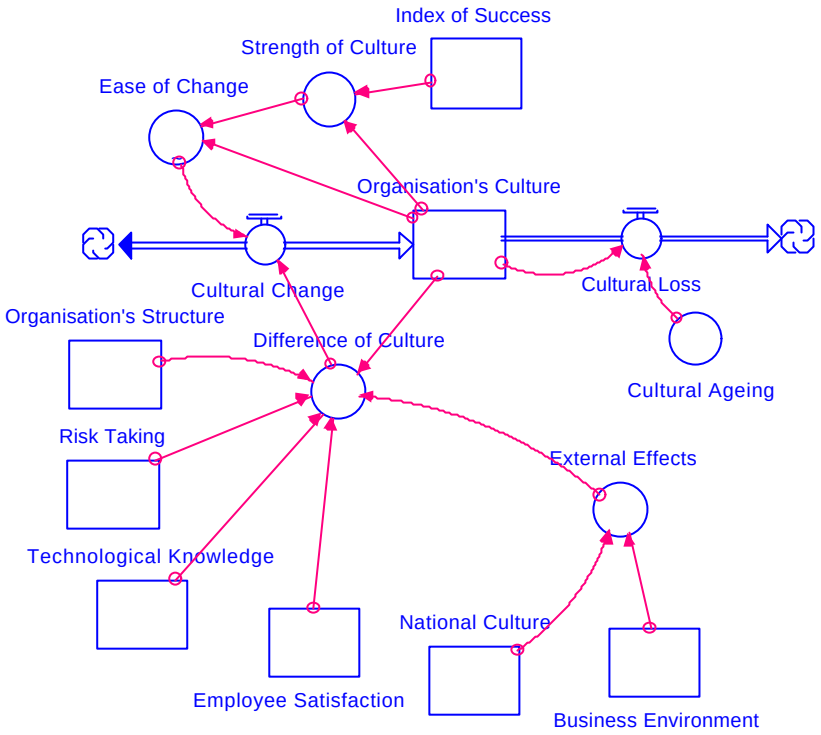


Figure 5. Organisation's Culture Model designed in iThink software.

3.5. Organisational structure.

Several studies have been published which attempt to identify the organisational structure that best promotes innovation (see for example: Peters and Waterman, 1982; Ashkenas et al., 1995; Nadler and Tushman, 1997; Tushman and Anderson, 1997). The studies criticise bureaucracy, top-down one-way communication, 'brick-walls' that block communication and they support the use of teamwork, flattening hierarchies and spread of decision responsibility. Most of them raise attention to the danger of disorganisation (chaos), mentioning that each business should develop a structure that fits its strategy, and introduce a 'loose-tight' structure. The 'loose-tight' structure is based on the adhocracy organisation (Mintzberg, 1995), which supports the decentralisation of decision making, introduces project-teams, but initiates some bureaucracy to gain a degree of control and provides both the freedom to create and the discipline to turn creativity into real innovation (Fairtlough, 1994). The innovative organisation allows the free communication of ideas and the interaction, formal and informal between the employees of all teams and all levels within the organisation.

Figure 6 illustrates the model of organisation structure presented using iThink software. In this sub-system, organisation structure is controlled by the management's decisions to change structure, bureaucracy levels and decentralisation of the firm. Factors such as the organisation's culture and the business environment affect the structure as well and can support or resist attempted changes (Nadler and Tushman, 1997). Bureaucracy and decentralisation are kept in balance with disorganisation, which is created by conflicts in personal or organisational levels. The time that the change takes for implementation depends on the firm's size and the existing levels of decentralisation and structure. The changes in addition are limited by the availability of capital necessary for the changes to be implemented. Finally the flow of ideas in the firm are proportional to the organisation's structure index,

though the relationship between the good ideas and disoriented ideas that flow inside the organisation depends on the organisation's knowledge.

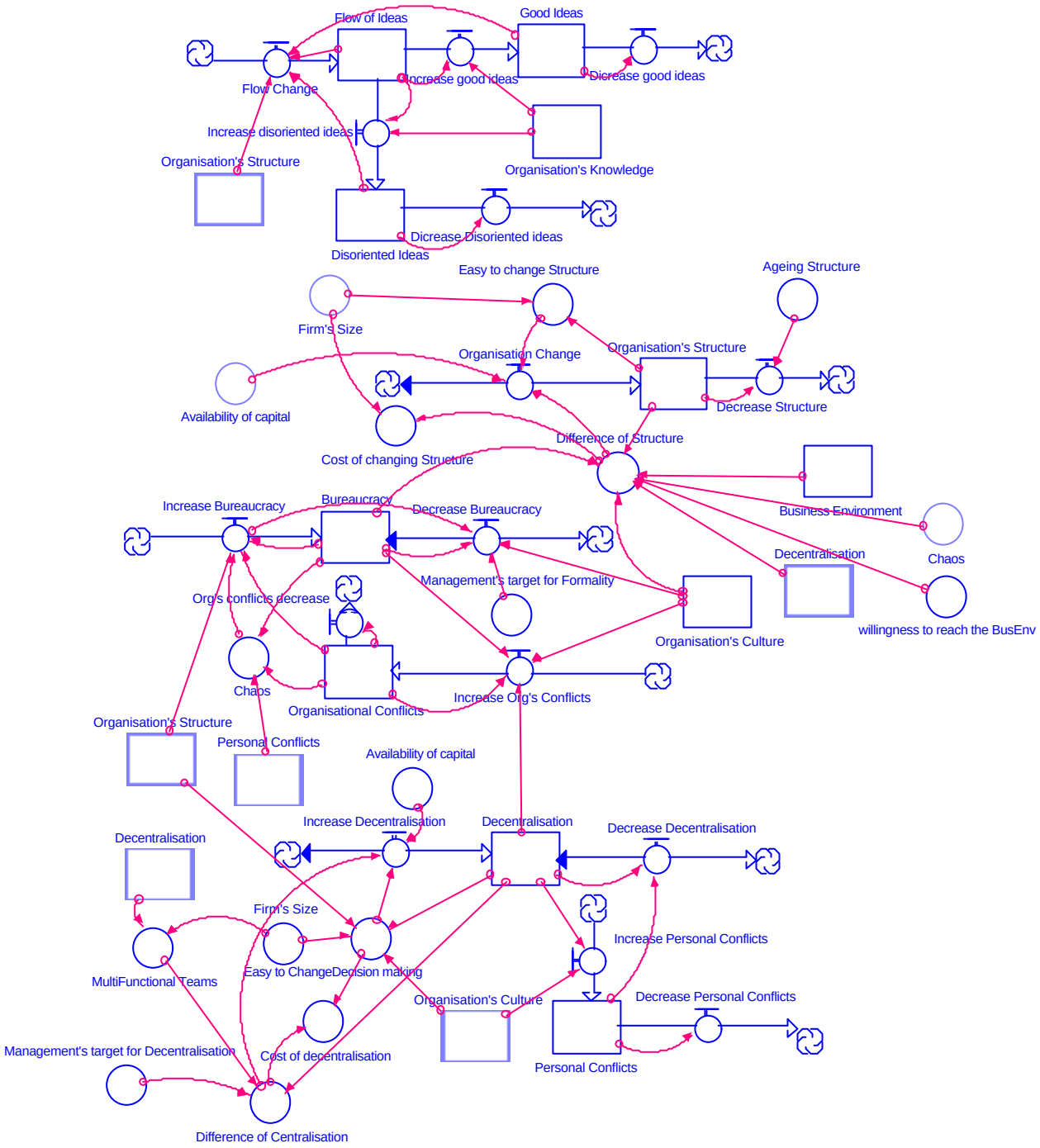


Figure 6. Organisation Structure model in iThink business modelling package.

3.6. Risk taking.

Miller and Friesen (1982), in their research of innovation in 'conservative' and 'entrepreneurial' firms find a high correlation between innovation and risk. O'Reilly and Tushman (1997), in addition, analysing the results of their survey in high technology firms conclude that two main elements stimulate creativity: (a) the support for risk taking and change, and, (b) the tolerance to mistakes.

The level of uncertainty and risk involved with innovative projects lead to most firms preferring to carry out more defensive R&D projects such as imitative innovation, product differentiation and process innovation (Freeman, Soete, 1997). In addition, Augsdorfer (1996) illustrates in his research that due to the extent of this attitude of the manager (i.e. to 'kill' high risk projects), many researchers and engineers continue to work 'under-the-table' (bootlegging). The existence of this phenomenon can lead sometimes to innovations that are more radical by individuals who may start-up new companies. Freeman and Soete (1997) nonetheless mention that R&D scientists and engineers who attempt to overtake this attitude are often overoptimistic. This is evident by their estimations about expected rate of return and project completion time when attempt to convince accountants and managers about their projects viability. Keynes as early as 1936 has identified this standpoint and he refers to the 'animal spirit' that often surpasses the measurable and planned decisions of the managers. He argues that *'if the animal spirits are dimmed and the spontaneous optimism falters, leaving us to depend on nothing but mathematical expectation, enterprise will fade and die – though fears of loss may have a basis no more reasonable than hopes of profits had before'* (Keynes, 1936: 161). Figure 7 illustrates the above relationships. Additionally, it shows how tolerance to mistakes can reduce fear among the employees to try new ideas and increase the risk that the firm can take. Failures however have a cost that often is uncontrollable and can lead the firm to collapse.

Figure 7. Risk Taking Framework

3.7. Employee participation.

Employees are an important factor when implementing any change programme in the organisation. Additionally, they are the ones who create ideas and develop them into new products. The organisation needs a reward system that will keep the satisfaction of the employees high, reduces conflicts because of injustices and keeps balance by not creating indifferent behaviour (Deal and Kennedy, 1982). The availability of cash to finance the reward system however, limits its implementation. Finally, a tolerance to mistakes and failures policy should be developed so that fear of punishment will not prevent employees from proposing new ideas and participating in risky projects (O'Reilly and Tushman, 1997).

3.8. New Product Design and Development.

The new product design and development process is the centre of the innovation process of any firm (Wheelwright and Clark, 1992). Through this process a firm develops new products and processes that they introduce into the market. Hence, this quantifies the innovation index of a firm. The input of the process is the firm's creativity that generates new concepts (figure 8). Creativity is affected by several factors such as organisation strategy and capital availability, technological capabilities, research effort, organisation culture, organisation structure, risk taking and employee participation. These factors direct creativity of the firm to higher or lower levels as they are influenced by the managers' decisions, their interrelations and the firm's external factors. The new concepts that have been generated are screened on the basis of their risk, the firm's strategy, the capital availability and the technological capabilities of the firm. The screening output identifies the projects that proceed to development. The developed

projects are introduced to the market. Some succeed in the competitive environment and enhance the innovation index of the firm, which in turn is the output of the creative factory model.

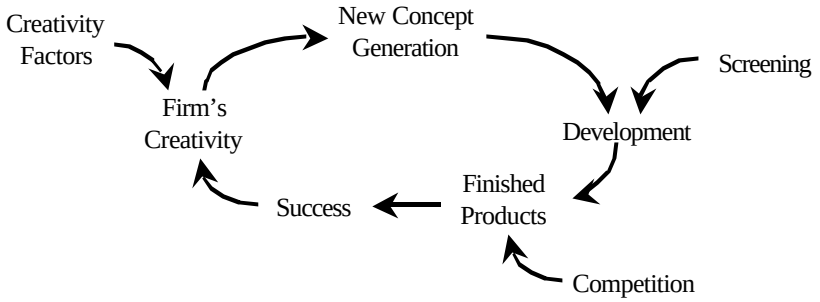


Figure 8. New Product Design and Development Framework

4. Conclusion

During the last two decades, there has been continuous debate about how possible it is to control and enhance innovation activity in a firm and a nation. This is because innovation has been identified as the factor for an enterprise's long-term prosperity and an element that provides solutions to social and economic problems of a nation. Innovation activity is a result of interactive relationships between institutional and organisational elements of science, technology and learning as well as a firm's strategies, which together are called systems of innovation. Many studies identify the complexity and the chaotic relationship of the factors that influence innovation. A systems thinking approach provides a tool that uncovers the complexity of the problem and reveals the structures that generate change.

This paper presents the factors and their main interrelationships that constitute the creative factory concept. The modelling of the creative factory shows that using a systems thinking approach it is possible to model the elements that affect innovation activity in a firm and create an index that indicates the innovativeness of an enterprise. In addition using the iThink business-modelling package it is possible to simulate this model and provide managers with a dynamic tool that monitors the effects of their decisions on the innovation activity of their organisation.

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