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Innovation : A Literature Survey

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Abstract

What is innovation? To what point is it an economical phenomenon? What are the ways it is being modeled? This survey aims to cover all the main work that has been published on the topic from as many angles as possible. First, early definitions will be presented along with the main work around its characteristics, functions, types, etc. Also what stimulates and hinders technological change will be discussed. Then, there will be an expository on the agents relevant to the process: who they are, what is an entrepreneur and what role the financier or the banker held in history. Following this, the concept of exogenous knowledge (the pool from which innovation are picked from) and endogenous knowledge will be contrasted. To conclude the first part, a few concepts pertaining to innovation will be presented: appropriability, spillovers, diffusion of innovation, experimentation/imitation, etc. In the second part, the survey will look more in depth at models involving in a way or another innovation. The models will be divided into 4 major categories, which are industrial organisation, macroeconomics, game theory and production functions. The conclusion of the survey will address such issues as the different opinions pertaining to competitive market/capitalism and innovation and even opposite point of views about the value of progress.

1.Introduction

What is innovation? Little is known about the subject because even if it is not a new concept in literature, it has seldom been the main purpose of analysis. Most papers and textbooks consider innovation as an exogenous shock in their model of employment, market structure, etc. even the papers on intellectual property rarely give something more than a vague definition of the concept of innovation. Because of its nature of complement in most of the works, there is no unique definition or unique way to model technical change. Therefore, authors define innovation through the purpose they require from it or their need of the moment. Also, most of the models presented in Part II do not address innovation directly but rather through growth with technical change (Romer (1986)), patent races (Reinganum (1980) and Scotchmer (2004)) or productivity growth (Griliches (1998)), for example. This observation was quite a surprise because innovation or technological creativity is often viewed as a "key ingredient of economic growth"(Mokyr (1990)). Why a so important notion in economics has not been more studied or formalized is still a mystery. The beginning of an explanation could be the difficulty to define the concept, and thus to search for it in empirical studies. In recent years, one popular attempt to empirically assess the impact of innovation was to do an econometric study of the influence of R&D expenditures on productivity. An example would be Griliches' (1998) paper. For a good survey on those attempts, one should refer to Link (2007). This survey will try to present the usual definitions of numerous fields such as industrial organisation, game theory, macroeconomics, etc., and the evolution of those definitions through times.

One of the first theorists who took innovation into account was Schumpeter(1935) in the beginning of the 20th century in his book "Theory of Economic Development" (1935). Even if his theory was more about economic development than innovation, the ideas he proposed have been implicit in most of the works along the century and are still currently used. The expression "Schumpeterian technical change" is widely used and can be briefly summarized as the opinion that the creation of new ideas largely occurs at an autonomous rate, but that the implementation of these new techniques by entrepreneurs can be explained by economic phenomena. In this survey, there will be no distinction between the concepts of innovation, technological progress and technical change. There is no unique definition of innovation and no unique way to introduce it in a model, most of the authors will redefine it to serve their purpose. The point of this survey will therefore be to try to distillate the essence of what previous authors meant by innovation and to synthesise it succinctly. To do so, this work is divided in two main parts. The first one covers the most common definitions of innovation, those that are, most of the time, clearly enunciated in seminal works, beginning with Schumpeter's and climbing up to more modern ones. At the same time, the concepts used by the authors of the definitions will be exposed, not only because they are inherent to the definitions but also because some of them bring valuable insight on innovation. Those approaches of the matter will then be compared and contrasted to the new contribution of

Amarante, Ghossoub and Phelps (2011). Moreover, the first part will stray a little from the pure concept of innovation to assess other notions. For example, if one says that in its more basic form, innovation is simply the application of a new idea, then is the concept of an idea also is an economic matter or not? There are in fact, two possible answers to that question and they will be both discussed below. In the second part, the main models pertaining to innovation will be presented. Their pros and cons will be listed and contrasted when possible, to the newly proposed definition. They are divided among four main families: production function models, industrial organisation models, macroeconomics models and economic history, and game theory models. However, it is often the case that some of them are in more than one group. There are also some exotic models that do not fit in any of the categories but are interesting enough to be presented. Usually, innovation is not the core subject of the papers from which these models are taken from, and thus there is not much to do else than expose how innovation is introduce in the model and how it affects its mechanics.

Before getting into the core of this work, let us follow the steps of Tufano's 2002 survey on financial innovation and enounce some basic remarks about innovation. First of all, "Innovate" is defined in *Webster's Collegiate Dictionary* as "to introduce as or *as if* new," with the root of the word deriving from the Latin word "novus" or new. Also, economists use the word "innovation" in an expansive fashion to describe shocks to the economy (e.g., monetary policy innovations) as well as the responses to these shocks (e.g., Eurodeposits). Moreover, innovation includes many steps, such as invention and diffusion. Boldrin and Levine (2008) describe a two-phase process as "First comes the research and development or invention step, aimed at developing the new good or process; second comes the stage of mass production, in which many copies of the initial prototype are reproduced and distributed". Finally, one should be aware that the term invention can be an overly generous, because most innovations are evolutionary adaptations of prior products. One should not underestimate the significance of the "as if" in the definition because almost nothing is completely "new". Also quite interesting as introductory remarks are Nordhaus' (1969) stylized facts on technological change:

1) Technological change is the major source of growth of per capita income.
2) Although in most modern price and growth theory technological change is (often) treated as exogenous, this must be interpreted as an analytical convenience rather than as a serious statement about the economic system.
3) Invention is an activity with substantial external economies, meaning that knowledge is a commodity with the property of being expensive to produce but cheap to reproduce (non-rival, non-exclusive) (a more complete description of Nordhaus'(1969) model will be provided further in the present work).
4) Many economists have argued that there is a bias in the inventive process toward labour-saving inventions. This idea has been generalised by the theory presented below of factor price induced technical change.

5) An invention has an economic life which most of the elements and phases will be presented throughout this survey.

2. Part 1 Innovation and pertaining concepts in the literature

Let us begin by the end and commence by stating the new contribution of Amarante, Ghossoub and Phelps (2011), this will allow further comparisons to be easier. In their model, everyone in the economy face a set of publicly-known possible states of the world for future period. Since everybody knows about those states, they all have a subjective probability distribution on them. Then agents known as entrepreneurs "think" about new possible states. Hence, the innovation is both the set of new space proposed by the entrepreneurs and an asset which pays contingent on those states. Clearly, this definition has many pros, the major one being its generality. Although those terms will be more defined later let us say that the definition suggested by Amarante, Ghossoub and Phelps can easily be applied to almost any kind of innovation, whether it is a financial, a process or a product innovation. Not all definitions we are about to see can achieve this. The entrepreneur then takes his innovation to a financier for him to invest in the asset. This concept was already anticipated in the work of Schumpeter: Theory of economic evolution (1934).

Boldrin and Levine (2008) define innovation as the first time a good is actually produced or an activity is employed. In Schumpeter's book (1934), production is described as a combination (or a recipe) of the different inputs: labour and land. To produce something else or something differently, it is done by simply combining inputs in a new/different way. Thus, an innovation is nothing more than a new combination of inputs or a new recipe. For Schumpeter, innovation encloses five cases: 1) A new good or a new quality of an old good (this will later be described as product innovation), 2) A new method of production which is not necessarily derived from a new scientific discovery but maybe only from a new management or marketing idea, for example Ford's assembly line, which will later be described as process innovation, 3) Opening of a new market opportunity, 4) Conquest of new resources, 5) Realisation of a new market structure or organisation like a monopoly. The idea that market structure is important for innovation, mostly for inventive incentives is one of the premises of the industrial organisation school of thoughts, but again this matter will be discussed later on. One other significant aspect of Schumpeter's theory is the idea of creative destruction which says, that new combinations always ruin or completely replace the previous ones. In part 2, recent models of creative destruction will be presented. Then, the next interesting aspect of Schumpeter's theory is its anticipation of the difference between an entrepreneur and a capitalist, and the significant importance of the banker for the capitalist system. For the author, the capitalist is only the owner of capital, whereas the entrepreneur is the one who creates the new combination. Sometimes, they are the same or if the entrepreneur commercialise himself his innovation, he can become a capitalist, but most of the time they are two distinct agents. Because the author describes an enterprise as the execution of new combinations and also their realisation or implementation in exploitation, the entrepreneur is nothing without production means, that is when the banker enters the scene. In Schumpeter's theory, the banker plays the same role as the financier in Amarante, Ghossoub and Phelps's (2011) model. Because the entrepreneur does not initially produce anything (except in rare cases where he is already an in-place capitalist or a rich heir), he needs credit to "reroute" the purchasing power necessary to put in place his factory. Schumpeter's model also describes why the entrepreneur is an isolated character. Although this notion is more deeply discussed in Mokyr (1990), the contribution of Schumpeter (1935) is note wise. The latter says that the normal economic agent follows his experience, with the economical circuit being in a kind of inertia and the novelty being an obstacle to the regular flow. Thus, the execution of new combinations is a peculiar function, a privilege of people less numerous than those who would have the opportunity to do the same. Everyone has in himself the capacity to be an entrepreneur/innovator in the same way, everyone has the possibility to sing, but only the most talented one become singers. Why is it so hard to stray from the main stream? For Schumpeter (1935) there are 3 key reasons: 1) the agent straying from the usual path lacks for his decision the data that he usually knows very well. This can be looked at in parallel with the Knightian uncertainty present in the Amarante, Ghossoub and Phelps model. 2) It is objectively harder to innovate than to continue the usual pattern, 3) there is usually a negative reaction to innovation from the social environment. Finally, another important matter that we will be treating later, but that Schumpeter broached, was the exogenous character of the idea rather than of the innovation. As mentioned, Schumpeterian innovation involves an autonomous idea generation but an economically explained innovation. Hence, for him, the entrepreneur does not create or find new possibilities; they are always present, forming a rich heap of knowledge constituted by professionals or scientists. They are known previously by someone else and if there are writers they are spread by them. Therefore, the innovator and the entrepreneur are also two completely distinct persons for Schumpeter. One interesting point to mention is that Schumpeter's book has been criticized by many of his contemporary peers for incensing too much the entrepreneur. Following Schumpeter, J.H. von Thünen (Link (2007)) set forth an explanation of profit that clearly distinguishes the function and reward of the entrepreneur from that of the capitalist. Thünen identified entrepreneurial gain as profit minus (1) interest on invested capital, (2) insurance against business losses, and (3) management wages.

There are many other authors who wrote about the identity of the innovators. For example, in Von Hippel's book entitled "The Source of Innovation" (1988), an innovator is defined as : "the firm or individual that first developed a scientific instrument innovation to a state proved functionally useful, as indicated by the publication of data generated by a scientific journal". Hippel (1988) then suggests that technological change comes from multiple sources in opposition to the common idea that it comes mainly from manufacturers. The reason why one might think that innovators are mostly manufacturers comes from the fact that the association of a manufacturer with an innovation is usually much more public than that of others such as users. For example, in the course of marketing an innovation, manufacturers may advertise “their” innovative device even if they are not the initial inventor. Von Hippel’s theory on the functional source of innovation stipulates that innovators could be categorized according to their functional relationship through which they derive benefit from a given product, process or service innovation. What the author discovers is that the source greatly varies from an industry to another. In some fields users develop most innovations, in others however, suppliers of related components and materials are the typical sources of innovation. In other fields, conventional wisdom holds and product manufacturers are indeed the typical innovators. In the remainder of his book, Von Hippel (1988) explores why the variation in the functional sources occurs and how it might be predicted. The author’s explanation for the great variation in the source of technological change arise from his analysis of the temporary profits (economic rents) expected by potential innovators. A successful innovator’s rent may come in the form of cost savings and/or increased prices and/or increased sales obtainable during his period of temporary and partial monopoly. Thus, he contends that one could predict the most likely source of a future innovation by looking at which functional category would most likely benefit from it. However, the task of calculating expected economic rents from a not already invented product is quite a daunting endeavour. To achieve it, Von Hippel’s strategy was to study several innovation categories in details and try to understand the thinking and options available to potential innovators in these fields. Hence, a great proportion of the Von Hippel’s book is allocated to case studies and ex-post analysis. To what extent this inferring approach is subject to the hindsight-bias is discussable.

The entrepreneur as the main actor in technological change has been around for a while. Quoting Link (2007): “[an entrepreneur is] someone who specializes in taking responsibility for and making judgmental decisions that affect the location, the form, and the use of goods, resources, or institutions”, define entrepreneurship as referring to perception of opportunity and the ability to act on that perception. Bianchi and Henrekson (2005) surveyed the literature on different mainstream/neoclassical modeling techniques that have been used to capture the entrepreneurial function in the economy. For them, entrepreneurship is not management, but it also involves more than just alertness and boldness. They also believe his importance hinges on the fact that the real world is filled with Knightian uncertainty because human cognitive abilities are severely limited relative to the available information, and also because human action is an open-ended process rather than the result of dynamic optimization. Hence, they give the following definition of entrepreneurship: “the ability and willingness of individuals, both on their own and within organizations to: i) innovate, i.e. perceive and create new economic opportunities; ii) face uncertainty, i.e. introduce their ideas in the market by making decisions on location, form and the use of resources and institutions; and iii) manage their business by competing with others for a share of that market” (Bianchi and Henrekson (2005)). For a long time, the task of including the entrepreneur in a neoclassical model was impossible; even Barreto (1989) has recently contended that it was indeed infeasible. Consequently, Bianchi and Henrekson (2005) explain that economic theory ignored the entrepreneur because of the challenge to include it in a model. In their survey, they have identified three crucial attributes of entrepreneurs that have been stressed in more substantive modeling efforts: i) they are (generally speaking) "more talented", ii) they have greater tolerance towards risk-bearing and iii) they are innovators (either as individuals or as firms involved in R&D activities). They then label three categories of entrepreneurship modeling according to which of these attributes were more emphasized. First, the talented entrepreneur models: an example being Lucas's (1978) paper which focused on the coordinating function of the entrepreneur. This basic feature goes way back to Say (1845) and has commonly characterized the entrepreneur in economic theory until recently. This category can be called the managerial approach of entrepreneurship. The entrepreneur is merely seen as a peculiar form of labour input, but instead of entering the production function, it transforms it in the following way: $y = g(f(l, k))$ where g(.) is increasing and concave. However, this approach clearly contrasts with the generally accepted fact, by authors as lauded as Knight (1921), Schumpeter (1934) or Kirsner (1997) and also by the majority of the scientific community, that entrepreneurship is much more than just a managerial input and cannot be considered as simply as a different form of labour. Second, the risk-bearing entrepreneurs: the influential work of Kihlstrom and Laffont (1979) adds the element of riskbearing to the neoclassical general equilibrium model. Now, the entrepreneur is no longer only a manager but "takes the responsibility of an enterprise". This model can be seen as a refinement of Lucas model because not only does the entrepreneurs differ by their g(.) function but also by their risk aversion. They forego a fixed wage in exchange of risky profits and also decide how many workers to employ. At the equilibrium, there is a unique cut-off level of an agent risk aversion such that all agents with risk aversions smaller than it will be entrepreneurs and the rest will be workers, also the less risk-averse entrepreneurs will hire more workers in order to bear more risk and achieve more profits. Third, the innovative entrepreneurs' model: more recently, endogenous growth theory has developed some Schumpeterian ideas, focusing in particular on the process of innovation related to R&D activities. The models have two key features: "individuals are continuously faced with opportunities for developing new products, i.e. the dynamics of growth (technical progress, demographic change) always create "disequilibria" and thus potential profits. Second, individuals differ in their ability to exploit these emerging opportunities. The first feature is modeled assuming an exogenous rate of technical progress and the second one by defining an ability parameter which mitigates the risk of creating new businesses: the more talented agents are, the less likely they are going to undertake an unsuccessful enterprise (Bianchi and Henrekson (2005)). In the competitive equilibrium of this model, people with low ability only manage already existing firms, people with high ability only set up new businesses and people with intermediate ability either manage businesses they started or trade for higher quality businesses (dismissing their current one). One can see the major contribution of the simple and intuitive formalization of the idea that has been the central point of the analysis of Schumpeter, Kirzner and Schultz, i.e. the existence of individuals with special abilities to innovate and capture profit opportunities. However, for the first time the principal flaw of many models to be presented in part II arises: the exogeneity of the technological progress and the focus on risk rather than knightian uncertainty. In Appendix 1, one can refer to the summary and assessment of many authors mentioned in the Bianchi and Henrekson survey. Finally, the authors conclude their work by stating that all these contributions highlight and formally analyze only one particular feature of entrepreneurship, each and that if one wants a theory that captures the essentials of it, these models are too restrictive, since the entrepreneurial function is far more complex: “We conclude that an individual real-world entrepreneur, even if highly stylized, cannot at present be modeled in mainstream economics, since he or she *does* elude analytical tractability. In this sense, the neoclassical entrepreneur is (still) not entrepreneurial” (Bianchi and Henrekson (2005)). There is therefore still place for a broader model including all the features and dealing with kngithtian uncertainty and endogenous innovation.

Based on the definitions of the economic agents relevant to innovation that were just presented, one could divide the theories of entrepreneurship in two categories: supply side theories and demand side theories. Supply-side theories of entrepreneurship emphasize the role of the entrepreneur in production and distribution of goods and services for which there is an independently determined demand. It is certainly the older of the two approaches because earlier inquiries into the subject tended to focus on the following question: “Given the pattern of demand for existing goods and services, what role does the entrepreneur play in the market place?” (Link (2007)). The demand-side theory of entrepreneurship emphasizes the role of the entrepreneur for existing goods and services by introducing new goods and services or new combinations of existing goods and services. The equivalent question for this group would be: “Given the pattern of supply for existing goods and services, what role does the entrepreneur play in the marketplace?”. For example, in Schumpeter’s (1935) model of a circular flow, where the economy is in a kind of inertia, the process of carrying out new combinations is a disturbance of the circular flow. Thus, his theory would be a demand-side theory of innovation and so would be Amarante, Ghossoub and Phelp’s as well. In Norhaus’ book entitled “Invention, Growth and Welfare” (1969), the author gives a completely different definition of those two concepts. For the latter, the supply-side theorist consider the supply of invention to be determined by state of knowledge and by the inclination of autonomously supplied inventors, whereas the demand-side ones are more profit-oriented and hold economic necessity to be the mother of invention. What both authors agree on is that the correct view must be a synthesis of the two schools of thought. We will see how Nordhaus (1969) tries to achieve such a synthesis in the presentation of his model in part II, the section on production function model of innovation.

There are many accepted characteristics of innovation and the remainder of this section will try to stress the most known and relevant ones. Almost, every author who will be presented in this survey, but mostly the IO group such as Scotchmer (2004), from which the following description comes, considers that an innovation is the result of the addition of an idea and of investments. Thus, it can be represented by a triplet of the form (v, c, p) where v is the social value or the per period consumer's surplus with competitive supply of the innovation, c is the cost of developing and commercializing the idea and p is the probability that a certain way to "discover" the innovation succeeds. This last notion is implicit in many patent races models where each firm tries to be the first to create the innovation. If the social value is eternal and the supply is competitive, the discounted social value of the innovation is thus v/r. The profit per period is generally seen as a proportion of the social value $\pi \cdot v$ with π being between 0 and 1. If the patent or the innovation has a finite lifetime of T periods, then the total profit for the innovator or the entrepreneur would be $\pi \cdot v \cdot T - c$. The exogenous property of the idea will be discussed below. However, this kind of technical definition of the innovation process achieves a good balance between the limits on human imagination and the incentive problem of marshalling resources. Another largely accepted characteristic of innovation is its public good (non-rival and non-exclusive) nature. Many authors like Scotchmer (2004), Mokyr (2002), Nordhaus (1969) and Reinganum (1989), agree with this while a few like Boldrin, Levine and Quah (2002) do not. Economic theory teaches us that the main consequence of such an assumption is that innovation is under-produced in a market economy because the positive externalities cannot be fully appropriate by the innovating firm. The ideas of appropriability and spillovers will be explored more deeply in the next section and the consequences of the public good attribute will be revisited in the conclusion of this survey. Like it has been mentioned earlier, one can divide innovation in two main categories: process and product innovation. In Atkeson's (2007) paper, that will be presented below, the author studies those two subdivisions and describes them as follow: "Our model includes two forms of innovation: innovation to increase the stock of this firm specific factor (firm has a stock of some firm specific factor that determines its current profit opportunities, examples: productivity, managerial skill, product quality, or brand name in an existing firm) — process innovation and innovation to create new firms with a new initial stock of the firm specific factor —product innovation". Put another way, process innovation is directed towards reducing the firm's marginal cost of producing a specific product while product innovation aims at creating new goods and new industries. In Tufano's (2002) survey on financial innovation and Link's (2007) survey also observe the generality of this distinction.

Like it has been described earlier, the innovation process requires in most of the models an idea that needs investment to be transformed into a marketable innovation. Usually, economists consider the innovation process to be an economic phenomenon but not the generation or occurring of the idea. However, no model of the process could be built without some assumptions about the origins of these ideas. There are two ways this concept has been modeled in the past. The first and oldest way views that the idea creation is exogenous. One can describe this conceptualisation as if there were a pool of basic, pure knowledge or ideas the scientific community extends by doing its professional work. Meanwhile the potential entrepreneurs are continuously assessing the market potential of the ideas floating in the pool, marketing them as they become profitable. This way of modeling the process clearly follows Schumpeter's vision for which the entrepreneur and the inventor are rarely the same person. It is also the way Nordhaus (1969) describes the process in his book. For him, it is important to distinguish between two kinds of knowledge; general and technical. The distinction refers to the usefulness of the knowledge in producing either more knowledge (the general kind) or more goods (technical knowledge). The production of these two kinds of knowledge goes as follow, pure research generates general knowledge when labour and capital inputs are combined with general knowledge. Invention occurs when labour and capital inputs are combined with general knowledge to produce technical knowledge. In Nordhaus' book entitled "Invention, Growth and Welfare" (1969), the second type is obviously emphasized. This concept of basic and applied research is widely spread in the field and is used, among other places, in Scotchmer's (2004) book "Innovation and Incentives", which depicts a model capable of explaining basic research even if this research has no market value in itself. The second option of exogenous occurring ideas considers there is no pool at all and the innovations just appear in entrepreneurs' minds usually by a stochastic process. For example, Loury (1979) uses a Poisson distribution to model the appearance of ideas, but other papers uses exponential, normal, Brownian, etc. distributions. However, because it left more space for endogeneity, this way leaded to the first endogenous modeling of ideas occurrence. One way to modify the stochastic process in order to achieve such a goal could be by introducing endogenous variables, most of the time R&D expenditures or by research good accumulation models. Indeed, innovation comes from purposive, profit-seeking investment in knowledge by firms involved in R&D activities, sometimes modeled following the patent race literature in industrial organization (see Tirole 1998). Also, the innovation completely displaces previous products or leaders in an industry, allowing the winner to enjoy some monopolistic power until another innovation arrives. Finally, one can see that this issue can be synthesized by the idea of the "standing on the shoulder of giants" followers and Schumpeter's "creative destruction" concept adepts with the latter being the exogenous generation type. However, this process in itself is really not Schumpeterian because there is no "new man" involved in novel and extraordinary activities, but rather a large scale, routinized, (almost) predictable path of innovation via investments. This conception does not find a proper justification in Schumpeter's theory but rather in one of his early critics, namely Solo (1951): "Innovation is more realistically analyzed as an ordinary business activity than as the extraordinary efforts of new firms and new men; invention and innovation are subject to costs and result in revenues like any other business activity; and both are carried out in competitive struggle by firms which are at once producers and innovator' ". An example of a model using such a creative environment is found in Reinganum's (1989) paper on patent race. A particular invention is sought simultaneously by a number of identical potential inventors (firms). Another aspect of endogenous idea generation is the "standing on shoulder of giants effect" present among other places in Hoon and Phelps (2001). This effect introduces cumulativeness of innovation, a process which, according to Scotchmer (2004), could take three forms: 1) the next innovation could not be invented without the first, 2) the first one reduces the cost of achieving the next one and 3) the first accelerates the development of the second. The more realistic hypothesis would be that maybe some ideas originate from thin air, without using previous research, like the wheel, fire, etc. and other ideas are issued from an ongoing process of basic scientific research building on previous endeavours. One could question the inclusion of fire in the category of innovation but as it has been seen, innovation is not only the discovery of a natural phenomenon or scientific theory but also its implementation and adoption through industrial, domestic, etc. uses. There is also a last way knowledge enters models. A good example for it is in Romer's (1986) model of endogenous technological change considers that knowledge has an input good that enters into the production function the same way labour or capital does except that it has increasing marginal productivity. Atkeson (2007) combines the use of a research good with a stochastic process of innovation.

Another note wise contribution of Tufano's (2004) paper is its list of the functions of a financial innovation. Although the innovation this authors focus on is the financial one, his contribution to the concept is interesting and unique. Tufano (2004) defines a financial innovation as "the act of creating and then popularizing new financial instruments as well as new financial technologies, institutions and markets... (they) are optimal responses to various basic problem or opportunities, such as incomplete markets that prevent risk shifting or asymmetric information". Hence, according to him, financial innovation has 6 functions:

(1) Innovation exists to complete inherently incomplete markets.
(2) *Innovation persists to address inherent agency concerns and information asymmetries:* Much of contracting theory (or the security design literature) explores how contracts can be written to better align the interests of different parties or to force the revelation of private information by managers. This extensive literature has been surveyed by Harris and Raviv (1989), and is also covered in Allen and Gale (1994, pp. 140-147).
(3) Innovation exists so parties can minimize transaction, search or marketing costs.
(4) Innovation is a response to taxes and regulation While many authors have pointed out the link between taxes and innovation, Miller (1986) is often cited on this point.
(5) Increasing globalization and risk motivate innovation.
(6) Technological shocks stimulate innovation.

Let us now address the issue of what stimulates and what hinders innovation and present the ideas of a historical economist, J. Mokyr as he listed them in his book entitled "The Lever of Riches" (1990). The author synthesizes the factors determining the propensity of a member of a society to invent and which factors make others want to adopt the invention (however, the less relevant ones for a theoretic model will be discarded for examples: life expectancy, nutrition, geographical environment, etc.): 1) Willingness to bear risks: the structure of preferences regarding risk of the economic agents clearly affects the incentive and deterrent to innovate. 2) Path dependency: this factor encloses both the concept of spillovers and knowledge accumulation that will be covered later, 3) Labour costs: the initial hypothesis stipulates that a high cost of labour input stimulates technological creativity. Historically, many authors (for example H. J. Habakkuk (1962)) have observed the fact that technological innovations are biased towards the augmentation of the capital-labour ratio, i.e. labour saving. However, there has been a generalisation of this hypothesis that will be discussed below in what has been labelled the factor-price induced models of innovation. 4) Science and technology: this factor is about the size of the pool of knowledge or metatechnological knowledge (as Mokyr (1990) calls it) from which innovations are drawn. There is a classical distinction made by Francis Bacon between inventions that depend on a state of knowledge and those that could have been made at almost any time. The lack of new basic scientific discoveries and thus the depleting of the pool of knowledge mentioned earlier could, in the long term, hinder the occurring of new innovations of the latter type. 5) Social environment: Clearly, if an individual lives in a society where, because of religion or mores, innovation or change in itself is seen as wrong, his propensity to spend time innovating could be lowered. There is a collective set of valuations that determines the relative prestige of various activities or attributes within a society. For example, in ancient Greece, sports and learning where lauded, whereas in the Roman Empire, the highest value was placed on administrative and military skills. Therefore, innovations like philosophy or the catapults were more likely to appear in those civilizations respectively. Also, when one thinks more broadly, it is only recently that production is no longer an occupation for slaves or the lower class. The creative energies of the best educated and most successful persons where thus channelled elsewhere and they became philosophers, priest or generals instead of entrepreneurs or engineers. The transition in an era where economical success is seen as greatly valuable could be one social explanation of the steep acceleration of product and process innovations in recent years. 6) Institutions and property rights: For Mokyr (1990), the fear of brigand stealing the fruit of your work or of the prince giving away your successful start up to one of is relative, clearly deters one to invest his time and money in an idea that could lead to an innovation. This, of course, is the point of view of a historical economist, however, industrial organization theorists also believe that property rights and mostly intellectual property are primordial to the innovation process, their ideas and models will be presented in the second part of this survey. 7) Politics: The type of government in place also affects the incentives to innovate. As Mokyr (1990) states it: “A strong, centralized government secure enough to withstand riots and political pressure from coalitions representing losers (Mokyr’s conceptualization is that by shifting the market structure or market leaders, innovations always create winners and losers), may have been able to resist the pressures exerted by the technological status quo. Yet it is equally plausible that a weak government that succumbed to demands to legislate technological progress away would be powerless to enforce such laws, and thus by default leave the decision to market forces. It seems that as a general rule, then, the weaker the government, the better it is for innovation. With some notable exceptions, autocratic rulers have tended to be hostile or indifferent to technological change”. 8) Demographics: on this point, Mokyr quotes the Simon’s (1983) model of economies of scale in technological change. It contends that the size of the population determines the supply of potential inventors, the size of the market for the improved or cheaper good, the importance of specialization, etc. On the opposite, following what Schumpeter said, Mokyr (1990) describes the principal hindrance to innovation as conservatism. However, he goes further and distinguishes between individual and collective conservatism. Collective conservatism is what has been seen in the social factor above and when interests groups have a stake in maintaining status quo. However, the most interesting definition of personal conservatism is what is called bounded rationality, i.e. the inability of individuals to process and manipulate large amounts of information. Thus, one could be repulse by the added complexity a new innovation could generate.

Before getting into a more formal description of the models involving innovation, a few more concepts might be interesting to analyse. Some will be referred to in the second part while some are only presented for the insights they give on innovations and everything that surrounds it. Let us begin by the notion of spillovers that is pervasive in almost all models below. The first thing to note is that it is a weaker form of the non-exclusive characteristic of public goods. Spillovers are the diffusion of the innovation information through the industry and the public knowledge. There are many ways this notion has been modeled before. Sometimes the technology level of a firm is a function of its R&D expenditures and of the technology level of the rest of the firms in the industry (as in Atkeson (2007), Griliches (1998), Nordhaus (1969) and Reinganum (1981)) usually through catching a proportion of the rivals' research endeavours. Sometimes buying a good is enough to be able to reproduce it and thus the innovator has a monopoly only for the first sale (Boldrin and Levine (2008), Quah (2002)). In such a model, the value of the innovation is thus the market value of the first unit of the new product. Reinganum's (1981) paper modeled a cooperative game where the firms can share research trough wanted spillovers which leads to a lower level of aggregate R&D and a later innovation. Appropriability describes the characteristic of an innovation to prevent such leaking out and whether or not ideas can be obtained without paying the current owner. Therefore, a completely appropriable innovation is one on which the innovator would build a monopoly as long as the innovation does not become obsolete. The most common view on appropriability is that: "If a firm cannot expect to appropriate the full value of the knowledge it generates, its R & D effort will be correspondingly reduced. The patent system is an attempt to mitigate the disincentive of nonappropriability. However, the social value of an innovation may exceed the monopoly rents. Hence patents may provide only a partial remedy" (Reinganum (1981)). Other ways of preventing spillovers are trade secrets, copyrights, etc. (for a description of all of them, refer to Scotchmer (2004) chapter 3). However, to quote Scotchmer: "Intellectual property rights are inherently difficult to enforce, since they are exclusive rights to "information," and information has the character of a public good". For Boldrin and Levine (2008), spillovers are not costless and this is the reason why they contend that innovation does not require intellectual property. For them, innovation is not disembodied: "We argue, instead, that ideas have value only insofar as they are embodied in goods or people, and that there is no economic justification for the common assumption that ideas are transmitted through costless spillovers" (Boldrin and Levine (2008)). Goods embodying new idea may mean several things; it could be the new good in the strictest sense (like in the model where by buying one good, an agent can become a producer by copying it), or a set of capital tools needed to produce it, or a body of knowledge embodied in people and goods needed to replicate the innovation. It lives through the scientist team, the engineer team, the production machine blueprints, etc. that generates it and there is a significant enough cost to transmit the innovation to someone else so that there is a way for the innovators to make a profit. Spillovers can have many consequences on a model, from endogenous growth (Atkeson (2007)), to competitive efficiency (Boldrin and Levine (2008)), to accruing innovation (Aghion, Harris and Howitt (2000)). Finally as Griliches mentioned: "The problem is much more complicated when we realize that we do not deal with one closed industry, but with a whole array of firms and industries which "borrow" different amounts of knowledge from different sources according to their economic and technological distance from them. The concept of such a "distance" is very hard to define empirically." (Griliches 1998).

There is also an important body of knowledge that covers the process of diffusion of innovations. Rogers (1983) defines diffusion as "the process by which an innovation is communicated through certain channels over time among the members of a social system". To stress the importance of such a conception, one should examine the following contribution of J. Mokyr (1990). The author makes the distinction between innovation and invention. For him, an invention should be defined as an increment in the set of the total technological knowledge of a given society, which is the union of all sets of individual technological knowledge. Therefore, at any moment there is a large gap between average and best practice technology; reducing this gap by disseminating the techniques used by producers at the cutting edge of knowledge is technological progress without invention. Rogers (1983) describes the four main elements pertaining to diffusion. First there is the innovation and its characteristics, an obvious bigger relative advantage, a better compatibility with previous technologies and less uncertainty around it are all factors accelerating the innovation. Uncertainty surrounding an innovation can be reduced when it is less complex, has more triability and more observability (as define by Rogers). The second one is the communication channel attributes. For example, the more the individuals are similar the more the innovation diffuses rapidly. The third element is obviously time, Rogers describe the usual impact of time has being S-shaped with a rapid first wave of adoption, then a plateau and finally the pacing of late adopters. The last element is the social system, which is defined by Rogers as a set of interrelated units that are engaged in joint problem-solving to accomplish a common goal. This social system is composed of a social structure, system norms, opinion leaders and change agents. For more details of this model, refer to "Elements of Diffusion" (Rogers (1983)). There are many other factors that can accelerate or hinder the rate of diffusion. For example, in the case of financial innovation, Molyneux and Shamroukh (1996) investigated the networks and bandwagon effects. The core of their hypothesis is that the larger the number of firms that have adopted the innovation, the more information about the innovations true cost/return characteristics is available and disseminated from adopters and nonadopters, and the greater the number of subsequent adoptions by firms, an opinion also shared by Oren and Schwartz (1988) and Chatterjee and Eliashber (1989). A synthesis of their paper can be found in the Appendix II. Also, mathematical diffusion models can be used to provide insight into the structure of diffusion processes of financial innovations (that is, Mansfield (1961); Floyd (1968); Blackman (1972); Mahajan and Peterson (1978); Jeuland (1981); Lilien, Roa, and Kalish (1981); Easingwood, Mahajan, and Muller (1983); Mahajan, Wind, and Sharma (1983)). Most of these models are extensions of Mansfield (1961) logistic curve model. Von Hippel (1988) contended that the process of diffusion is the responsibility of a specific class of consumers he calls "lead users". According to him, long time users are badly equipped to assess new utilisations of a product or new goods because they are too much used to the way things already are. He describes lead users as having two characteristics: "1) lead users face needs that will be general in a marketplace but hey face them months or years before the bulk of that marketplace encounters them, 2) Lead users are positioned to benefit significantly by obtaining a solution to those needs"(Von Hippel (1988)). The idea behind the concept is that users who expect high rents from a solution to a need under study should have been driven by these expectations to attempt to solve their need. This work in turn will have produced insight into the need and perhaps useful solutions that will be of value to inquiring market researchers. Von Hippel (1988) empirically validated his method by observing that users who identified themselves as dissatisfied with existing products were more likely to be involved in developing new products responding to their needs. Also, a great mean by which innovations are disseminated is the licensing of patents, a process by which a firm or individual owning a patent on an innovation allows another party to use the innovation in exchange for a monetary benefice. One of many economists studying this concept is Reinganum (1989) using game theory and market structure models. The latter states that a key determinant explaining why firms might delay the adoption of innovation is a perceived declining adoption cost with the number of adopters. There is also a recent phenomenon called patents pools, where a group of firms join together all of their patents to get access to everyone else's one. In Scotchmer's (2004) book, this phenomenon is described thoroughly. Finally, like it was mentioned earlier, another way innovations can diffuse is trough the copy process described in Boldrin and Levine's (2008) paper in which once one has bought a good, he possesses everything he needs to copy it and become himself a rival of the innovating firm. Of course this model is a quite extreme modeling of reality that has many uses in theoretical models such as the one of Quah (2002).

Above, the issue of the origin of ideas has been presented; some works also look at the question from another point of view. They study the process of creation of ideas and sometimes of innovation by itself through the notions of experimentation and imitation. A simple model of experimentation is Acemoglu's (2008) in which the firm receives information about possible projects and can decide to experiment any of them at any time. This theoretic game model is described in Part II of this survey. This model of sequential information also shares a number of common features with the recent work of Bolton and Harris (1999 and 2000) and Keller, Rady and Cripps (2005). They describe the experimentation process as follow: firms receive signals from projects, the more positive the signal is, the likelier the project will end with an innovation.

A type of innovative model where experimentation takes an all other meaning is the evolutionary type model. In this model, there are no profit maximisation, no rational decision making, etc. The analogy depicts firms as animals, roaming the jungle of business, "decision rules" are genes and the firms with better genes survive. Mutation of those genes through innovations occurs by experimentation and natural selection with only the fittest and most adaptive firms surviving. A deeper look at these kinds of models will be taken further in the survey. "At each instant, a firm can choose one of three possible actions: 1) experiment with a project, 2) copy a successful project 3) wait" (Acemoglu (2008)). Present in this quote is a second element, imitation, opposite to experimentation but surely as significant. One way this concept is modeled was covered when Boldrin and Levine's (2008) work was described. In the present case, imitating a project leads to a higher probability of leading to an innovation. Thus, imitating is the other way a rival firm can benefit from a particular firm's investment in R&D, the other way being through the public good or non-perfect appropriability of the technical change. One can differentiate spillovers and imitating because imitating is much more in the idea of purposeful, strategic copy while spillovers are a more automatic diffusion of it. Another applied model of imitation to be seen is the one of Aghion, Harris and Howitt (2000) where firms copy each other's process innovation in a breathtaking competitivity race.

Boldrin and Levine's (2008) paper also emphasizes the significance of the indivisibility attribute of innovation because of its consequences on the optimality of the competitive equilibrium. This concept is also presented in the works of Arrow (1962) and many others. Indivisibility, as defined by Boldrin and Levine, is "in contrast to other capital goods that can often be produced in variable quantities, an idea must generally be produced whole. Two first halves of an idea for a drug are certainly not worth the same as the first and second half of the idea". Indivisibility might or might not make a difference for competitive pricing depending on multiple factors. When there is no indivisibility, the technology in Boldrin and Levine's model is a convex cone. Thus, by modifying this assumption, indivisibility can sometimes be binding and sometimes not. It is also a characteristic which loses its significance with the economic progress because a sole idea loses in relative importance. In part II, an application of this concept will be presented through the presentation of Boldrin and Levine's (2008) model. Finally, a notion that came back a lot in the lectures preceding this survey was the Hicks neutrality of innovation. Like it was mentioned earlier, with the labour reducing bias of technical change, innovation tends to modify the capital-labour ratio of production. The concept of Hicks neutrality was first put forth in 1932 by John Hicks in his book "The Theory of Wages". An innovation is considered to be Hicks neutral if it does not affect the balance of labour, and capital in the products production function. This concept is mostly useful in production function model and for an example of an application; one should refer to Shell's (1966) article presented below.

3. Part 2 The Four Main Groups of Innovative Models

During the research that led to this survey, it was obvious that most of the innovative models could fall in one of the four following categories: Industrial organization, production function models, macroeconomics and game theory. Industrial organization models mainly focus on the firm's profit maximisation and the influence of institutions on the incentives to innovate. Game theory models emphasizes on the interrelations and strategies in an industry, production function models concentrate on the effects of innovation and R&D on the productivity of firms and finally, macroeconomics models look at the global effects of technological progress on economies. Of course, no model is completely included in only one category, for example, most of game theory models involve a profit maximisation feature and almost all macroeconomic models involve a production function. However, by looking at the purpose of the paper, it is most of the time clear in which category a model falls. Also, there are some models that do not abide to this taxonomy and do not fall in any of the categories. This part of the survey is structured as follow, the main features of each category and the principal questions it tries to answer will be presented, and then, a few examples of models related to the category will be exposed. For each of the models, there will be a small comparison of the pros and cons of the model with the contribution of Amarante, Ghossoub and Phelps (2011).

3.1 Industrial Organization

The main premise of the Industrial Organization models lies with the basic idea of the (v, c, p) concept already described. Entrepreneurs face a pool containing all available ideas mankind ever had and will ever have. This is what Mokyr (1990) called metatechnological knowledge. If all these ideas were valuable at the moment, they would all be developed in innovations instantly. Since, proponents of this category emphasizes the profit maximisation process, the main purpose of their study is about ways to stimulate the incentives to innovate through institutions, intellectual property and market structure. Examples of topics investigated by them are patent races (which is also a common subject of game theorists), first mover advantage, monopolistic competition, intellectual property etc. The theory behind intellectual property rights is quite relevant because in order to patent an innovation the patent office must have a definition of what it is. Scotchmer (2004) in her book gives the 4 attributes a technological change must have to be patentable. First the object must concern a patentable subject matter, to do so, it must be a machine, a manufactured product, a composition made from two or more substances or a process for manufacturing objects. In recent years, this requirement has widened to include; computer code, life forms, management techniques, financial assets, etc. The second attribute is utility -- that is, an invention must offer some positive benefit to society. The third and four attributes are novelty and non-obviousness, they are self-explaining.

Let us start by re-exploring the (v, c, p) model described above because it is really the core of the industrial organization methodology. The version presented here is mostly the one of Scotchmer's book "Innovation and Incentives" (2004). Let us recall that the form (v, c, p) is a triplet where v is the social value or the per period consumer's surplus with competitive supply of the innovation, c is the cost of developing and commercializing the idea and p is the probability that a certain way to "discover" the innovation succeeds. This last notion is implicit in many patent races models where each firm tries to be the first to create the innovation. Also, if the social value is eternal and the supply is competitive, the discounted social value of the innovation is thus v/r, the profit per period is generally seen as a proportion of the social value $\pi \cdot v$ with π being between 0 and 1. If the patent or the innovation has a finite lifetime of T periods, then the total profit from it for the innovator or the entrepreneur would be $\pi \cdot v \cdot T - c$. This creative environment is present in many works: Green and Scotchmer (1995), O'Donoghue, Scotchmer and Thisse (1998), etc. It has the advantages of having a clean separation between the exogenous process that generates ideas for innovations through a form of serendipity and the decision whether to invest in them. However its major flaw is that it considers only a vague notion of objective risk and completely ignores the largely accepted presence of Knightian uncertainty. For the instance, how does one calculate the value of v or p? How can one assess the value of an innovation before it is completed?

Scotchmer (2004) seminal book often mentioned before is utterly representative of the industrial organization approach. While the book covers many topics and many models, this section will try to expose the major ones. The first interesting model involves the (v,c,p) construct. It aims at exploring how patents can help choosing the best option among two innovation ideas. Suppose that two firms have substitute ideas (v_i, c_i) i = 1, 2, p = 1 that are similar enough such that only one can be patented, because the other one would be infringing. Firm 1 idea is better if $\frac{v_1}{r} - c_1 \geq \frac{v_2}{r} - c_2$ but in order to identify the better idea, information about both v's and c's must be aggregated and compared. However, to do so is most of the time practically impossible. According to Scotchmer (2004), a patent system will not generally aggregate the information and will not necessarily limit investment to the best idea. For a patent of length T the firm's prospective patent reward is $\pi v_i T$. Therefore, there are two possible outcomes in this situation, both of which may be inefficient. If the patent values are high enough, both firms may enter a patent race, each winning with probability one-half. This case implies large duplication cost which are most of the times inefficient, except when the project is uncertain (the case where p is smaller than one) where having two firms investing for the main idea reduces the time before the innovation becomes available. On the other side, if the patent values are relatively low, then it may be that only one firm enters the race, but there is no guarantee that it will be the right firm because it cannot evaluate whether its prospective innovation will provide more surplus at a lower cost than that of the rival. Thus, it results from this simple industrial organization model that patents are rather inefficient. To solve this conundrum, Scotchmer (2004) in chapter 2 explores multiple contests solution like a simple commitment to pay, a Vickrey Auction (second price) or a prototype contest. A prototype contest gives the firms the possibility to demonstrate their ideas by developing prototypes and then choosing among them the most efficient (as define earlier). Of course this contest has a high cost in duplicated investments and the sponsor still needs a commitment to pay ex post, avoiding the temptation to negotiate a low price once the prototypes are delivered. If the sponsor cannot commit to pay a price above development cost the innovators will not invest, even when the innovation would be socially desirable.

The second relevant model of the book "Innovation and Incentives" is one pertaining to how profitable intellectual rights should be. Even if "it is tempting to think that strengthening intellectual property rights is always a good idea if it leads to more innovation. That view is short-sighted" (Scotchmer (2004)). The author gives two reason why this is true. First, strong intellectual property rights increase the deadweight loss (inherent in all forms of monopoly) on innovation, even those that would be forthcoming with weaker rights. Second, strong intellectual property rights lead to an inefficient duplication of R&D costs as more firms vie for possession of those rights. Suppose that the ideas space can be represented by the figure in appendix 3 (Scotchmer (2004 p.99)), each idea (v, c) can be represented as a point in the space. Remember that the intellectual property protection provides profit equal to $\pi v T$, the thick line on the graph. The profit thus depends on v and T. All ideas being under the line are profitable enough for investment. Suppose now that T is augmented, the line rotate counter clockwise and more ideas become profitable. However, the lengthening of the patent also includes a raise of the deadweight loss and thus reduces v. If the deadweight loss is $\rho v, \rho \in (0,1)$ then the idea social value would be $\frac{v}{r} - \rho v T$. Duration is not the only policy lever available to government to tune incentives. The breadth of a patent defines the limit another invention must not cross to not infringe the patent and thus to be expose to lawsuits. To widen or reduce the breadth of the patent varies π and therefore moves the line the same way T does. It also involves the same deadweight loss. The choice of the best policy is a very convoluted question. Gallini (1992) uses a ratio test in order to compare long and thin patents with short and wide ones.

The last model taken from Scotchmer's (2004) book that will be presented in this section is a patent race because they are representative of both industrial organization treatment of innovation and of the utilisation of the (v, c, p) construct. A patent race occurs when multiple firms pursue the same targeted invention or similar inventions with each one infringing on the others potential patent. Therefore, only one firm will receive the intellectual property right. Clearly, patents race increase the probability of innovation when inventors have different ideas for how to solve a targeted problem and it also accelerates progress as it will be shown. Let P(n) be the probability that at least one firm succeeds in each period when there are n firms participating, P(n) being strictly increasing in n. Suppose also that each firm will continue to race in successive periods until one succeeds, and that the cost in each period is the same. It follows that the expected time to discovery is 1/P(n) = $\sum_{i=1}^{\infty} iP(n)\big(1-P(n)\big)^{i-1}$. The value of the discovery must be discounted from the time it occurs. Thus, if we define Π as the value of the patent at the time of the discovery, the expected discount value of Π is $\Pi\sum_{i=1}^{\infty}(\frac{1}{1+r})^{i}P(n)(1-P(n))^{i-1} = \Pi\frac{P(n)}{1+r}\sum_{i=1}^{\infty}\left(\frac{1-P(n)}{1+r}\right)^{i-1} = \Pi\frac{P(n)}{P(n)+r}$ in a similar way, the expected cost to n firms that remain in the race until there is a success is $\frac{nc}{r+P(n)}$ (see Scotchmer (2004 chapter 4)). Therefore, the total expected profit for all firms together is $\frac{\Pi P(n)-nc}{r+P(n)}$ and the individual profit is $\frac{\frac{1}{n}\Pi P(n)-c}{r+P(n)}$. Assuming there is no barriers to entry or exit, there will be firms entering the race until $\Pi P(n^{*}) - n^{*}c = 0$. In this simple model, firms do not choose their R&D investments which could influence the likelihood of innovation this period. In the game theory section, a more complex race patent with elaborate strategies will be presented. Since $(n^{*}) > P(1)$, $\frac{1}{P(n^{*})} < \frac{1}{P(1)}$, a patent race accelerates innovation.

They are many more industrial organization models presented in Scotchmer's book such as a model showing how licensing and a fixed cost can help to produce proprietary products efficiently (Chapter 6) or a model using the triplet construct and deriving from its implication the optimal number of entrepreneurs/firms in a patent race or more widely on an innovation endeavour (Chapter 4). Clearly the simplistic approach of summarizing the innovation process with three variables does not have any of the theoric possibilities the Amarante, Ghossoub and Phelps theory has. It is perfect to study innovation from a profit maximisation angle but it does not really define what an innovation is and it does not at all assess the role of uncertainty. However, one way one could maybe cope with these flaw would be to substitute the p of (v, c, p) with a non-additive probability or a appropriate capacity which would introduce the uncertainty regarding the outcome of the innovation process. Also, there is still the question of the exogeneity of the provenance of the innovation since in most industrial organization models, firms can just decide whether or not to participate in the race or in the development effort.

Another author saw earlier that would enlist in the industrial organisation category would be Von Hippel (1988) and his functional source of innovation theory. The author's theory stipulates that innovators could be categorized according to their functional relationship through which they derive benefit from a given product, process or service innovation. What the author observes is that the source (being users, manufacturers or suppliers) greatly varies from an industry to another. Let us also recall that the author's explanation for the great variation in the source of technological change arise from his analysis of the temporary profits (economic rents) expected by potential innovators. A successful innovator's rent may come in the form of cost savings and/or increased prices and/or increased sales obtainable during his period of temporary and partial monopoly. Thus, he contends that one could predict the most likely source of a future innovation by looking at which functional category would most likely benefit from it. However, the ability to predict the functional sources of innovation on the basis of firms' preinnovation expectations of rents requires that correlation exist between such expectations and the functional role of innovating firms. More specifically, two conditions must hold:

1) It must be difficult (expensive) for innovators to adopt new functional relationships to their innovations: "If role switching were frequent or inexpensively accomplished, innovators might switch to the functional role that offered them the best innovation-related return. And, under such conditions, we would only be able to predict the functional locus of innovation in a weak sense, that is, "the developer of x innovation will become a user" rather than able to make the stronger statement "the developer of x innovation will be a firm or individual that currently is a member of the user community" " (Von Hippel (1988)). There are two reasons why one could believe that functional switching is not common: i) as can be seen in the case data contained in the appendix of Von Hippel's book, role switching occurred in only a few instances in the samples examined. ii) The switching of functional roles appears to be often both difficult and expensive because of specialisation.
2) Innovators must have a poor ability to capture rent by licensing their innovation-related knowledge to others : an innovator should have only two routes toward capturing rents from an innovation : (1) exploiting the innovation himself while preventing others from doing so; (2) licensing others to use this innovation-related knowledge for a fee. Ability to license efficiently, however, allows an innovator in any functional locus to (in a sense) tax licensees in different functional loci according to their differing abilities to benefit, thus diminishing the crucial differences (specialisation) stated in condition 1.

For condition two to hold, Von Hippel needs to show that patents and trade secrets legislation are not effective to protect one's intellectual property and thus licensing is not a problem. In order to do so the author refer to many studies such as the one from Levine et al. (1984) and the seminal one by Cohen, Nelson and Walsh (2000) (which results are available in appendix 4), among others. Since most of the studies show that the majority of entrepreneurs prefer other mechanisms than patents and licensing, Von Hippel concludes that both conditions generally hold. The following step in the author's empirical model was to test the relationship between the functional source of innovation and expected innovation rents. His general strategy for estimating rents that firms might reasonably expect if they were to develop specific types of innovation was to study several innovation categories in detail and to try to understand the thinking of and options open to potential innovators in these fields. Innovators capture temporary rents from their successful innovations by first establishing some type of monopoly control over their innovation and then using this control to increase their economic return. Von Hippel then proceeds to five empirical case studies each using tests of reason that show the validity of his assumptions. A test of reason is the comparison of the data on the sources of innovation with the ranking he made from an empirical analysis of the expected economic rents of each of the possible source. The author concludes that he can see two general reasons why the rent expectations of potential innovators could differ significantly as a consequence of the functional relationship they hold to an innovation opportunity. First, the abilities of firms to protect and benefit from identical innovation-related information can differ as a consequence of functional role and the second one has to do with the industry competitive structure. Firms having user, manufacturer and supplier relationships to a given innovation often come from different industries. These industries may have different structures (concentration, competition, legislation, etc.) and thus different expectation on the potential economic rent.

Boldrin and Levine are two of the major theorist of innovation. Because they approach the phenomenon from different angles, they will appear two times in this part, the first one here in the industrial organization section and another time in the macroeconomics section. The model presented here is drawn from their book "Boldrin and Levine Against Intellectual Monopoly" (2008). The premises of this book is that innovation are not disembodied objects, they live through the scientific or engineer team that developed it or through the blueprints. In either way, it takes time and money to be transferred to another team or plant. Since the communication of ideas is costly they are not perfectly non-exclusive and thus inventors can make a profit large enough to cover their costs even in the absence of intellectual property. They stray from the mainstream because instead of considering the cost of producing an idea as a fixed cost, they emphasize that it is similar to producing any other capital good. The book also broach innovation's attributes such as indivisibility and public good and their consequences on equilibrium and modeling. Indivisibility occurs because in contrast to other capital foods that can often be produced in variable quantities, an idea must generally be produced whole. In their model, one has to assume that an invention has already taken place. In other words, there is currently a single copy of all that is needed to reproduce the innovation whether it is the first copy of the product, the engineer team or the blueprint. Let us suppose that every subsequent item produced through this template is a perfect substitute for the first template itself and also that an item requires only a copy of itself and no other inputs to be reproduced. At any moment in time, any resource has two alternative uses: consumption or reproduction. They also assume that there is no other cost of producing copies. Therefore, as soon as the first unit is sold, the innovator is possibly in competition with his customers. This is the case where there is absolutely no intellectual property whatsoever. The rent of the innovator is then derived through the ordinary theory of perfectly competitive equilibrium. Boldrin and Levine suppose that there are currently k>0 units of the product available and that independently of how many of these units are consumed during the current period, βk units of the same product will be available tomorrow, with $\beta > 1$. The value of *K* units of the good to a representative consumer is *u*(*k*) , where *u* is strictly increasing, concave, and bounded below. This infinitely lived representative consumer discounts the future with the discount factor $0 \leq \delta \leq 1$. The authors also assume that the technology and preferences are such that feasible utility is bounded above. As is standard in the theory of competitive equilibrium, the price of consumption is determined by marginal utility $p_t = u^{'}(c_t) = u^{'}(k_t)$. Similarly the price q_t of the durable good k_t can be computed, it is just the present value of future prices at which the good will sell.

$$q_t = \sum_{i=0}^{\infty} (\delta\beta)^i p_{t+1} = \sum_{i=0}^{\infty} (\delta\beta)^i u'(\beta^i k_t)$$

In other words, even when forced to compete with many other people all with access to the same reproduction technology, the initial owner of the resource will earn the present value of all future sales of the good. Under the assumption of positive marginal utility $p_t > 0$, and so it must be that $q_t > 0$ for all t. Hence, even without intellectual monopoly, and in the face of fierce competition of purchasers, innovations always command profits. In this case, the price of the idea decreases at a speed that depends on the ratio between $u^{'}(\beta^i k_t)$ and $u^{'}(\beta^{i+1} k_t)$. The authors then conclude that "This simple analysis clarifies that competitive rents can be substantial and that there is no question that innovation can occur under conditions of perfect competition" (Boldrin and Levine (2008)). However, introducing the first unit of the new good entails some cost C > 0 for the innovator, thus the innovation will be produced if C< q_0 which is the price of the initial unit sold in a competitive market. They do not address the question whether a socially valuable innovation that would be developed under monopoly is possibly overlooked in competitive markets. The remainder of the book considers expansions of this model. For example cases where the reproduction technology increases, where the good is perishable or where there is a reproduction cost are analysed. However all these developments respect the basic intuition presented in the model above and thus its presentation covers the aim of this survey which is to expose the principles of different innovation modeling. One should refer to the Boldrin and Levine's (2008) book for a more complete analysis. The conclusion of the authors is that "Trivial ideas are cheap to communicate, but of course they are also cheap to create. Complex ideas are expensive to create, but they are also difficult to communicate, so they are scarce and will command a substantial premium for a long period of time". Even if there is a small part on ideas of uncertain value which is more precisely a measure of risk rather than uncertainty as defined by Knight, this book, as much of the industrial organization works, does not consider this aspect of innovation. Also the other common flaw of pervasive exogeneity is present. We can thus classify this model as a proper profit maximisation approach to innovation and a good champion of competitive markets as generators of innovation but with a relatively limited theorical contribution.

3.2 Production functions

The early attempts of economists to model technological change was based on production function models in which the output (Y) of an economic unit (a firm, a country, an industry, etc.) is represented simply as a function of capital (K), labor (L) and a form or another of a productivity or technological level measure (A) : $Y_t = \quad g(A_t)F(K_t, L_t)$. The most common example is the Cobb-Douglas production function with linear productivity :

$$Y_t = A_t * K_t^{\alpha} * L_t^{1-\alpha}$$

This formalization of the theory led, in the early 1960s, to a lot of papers where researchers estimated empirically matters such as the impact of investments in R&D on productivity growth, under the implicit assumption that R&D is an input into innovation and innovation leads to technological change. To do so, authors estimated the total factor productivity (TFP) which is the remainder of output growth that is not explained by growth of labour or capital. Of course, those estimations are rather imprecise because then the TFP encloses much more than just technological progress. The innovation conceptualization implicit in the approach of this category is also quite simplistic. There are no such things as imagination or exogenous constraint to innovation, as long as the economic unit is pouring money in R&D, the productivity increases. A good example of such a model is presented in Nordhaus' (1969) book "Invention, Growth and Welfare" where the function $g(A_t)$ expands to include also a proportion of the rivals' level of technology in a spillover model. It also states a common assumption which is that $g(A_t)$ is being concave in A. Whether or not this assumption is realistic regarding the recent data is unclear. A seminal as well as global study on the subject was performed by Griliches in his 1998 paper. The author combine the basic model developed above, using a Cobb-Douglas production function and also combining it with a model of spillovers as described earlier. The main observation of Griliches was the difficulty to distinguish the real effect of R&D investments from the other factors. He describes three major issues in the measurement of a knowledge capital:

1) The fact that the research and development process takes time and that current research and development may not have an effect on measured productivity until several years have elapsed forces one to make assumptions about the relevant lag structure***.***
2) Past research and development investments depreciate and become obsolete. Thus the growth in the net "stock" of research and development capital is not equal to the gross level of current or recent resources invested in expanding it.
3) The level of knowledge in any one sector or industry not only is derived from "own" research and development investments but also is affected by the knowledge borrowed or stolen from other sectors or industries. Thus, the productivity of industry *i* will depend also on the research and development investments of industries j and *h,* among others.

Let us quickly review some of the major papers who's model fall into this category. In first comes the knowledge capital model of firm productivity used by Ericson and Pakes (1995). In this paper, the active force is an entrepreneur/firm exploring a speculative idea; a perceived profit opportunity in some industry. The quantity of investment, together with parameters describing the evolution of the market and the competition, determine the distribution of outcomes form the exploratory activities of an active firm in each period. Suppose that the only distinction among firms is their achieved state of "success" (index of efficiency, $\omega \in Z$, n exploiting it. ω is a measure relative to the rest of the industry well-fare. Therefore, a higher ω indicates that the firm is in a stronger position relatively to the rest of the industry. Hence, ω is dependent on the firm's investment decision and on autonomous factors shifting the demand or cost parameters of all firms in the industry. Let us denote the industry structure at any point of time by $s = \{s_{\omega}\}_{\omega \in \mathbb{Z}} \in \mathbb{Z}_{+}^{\infty}$; s provides the number of firms at each possible ω state. Thus, the state couple, (ω, s), determines the entire distribution of the firm's current and future profits. Ericson and Pakes also assume that the firm's profit is decreasing (weakly) in s and increasing (weakly) in ω. There is a set of states, $\Omega^{e} \subset \Omega$ at which new firms may enter the industry after making a sufficient investment. The firm's level of investment in R&D is denoted by $x_t \in \mathbb{R}_{+}$ is chosen to maximize the expected present discounted value of profits of all information available at t. The authors assume "this information to include the history of all past states and of the firm's own past investment decision, the current state and the probability laws governing the evolution of that state over time, including the law governing the impact of the firm's own investment on that evolutionary pattern". Each period, the firms has a probability, increasing in its investment expenditures, to access a better state and a probability to access a worst state, following the stochastic process : $p(\omega'|\omega, x)$ (the probability of shifhting into state ω' conditional on being in state ω and investing x. The profit function is $\Pi(\omega, s) = A(\omega, s) - c(\omega) * x$. From these basics and many more technical constructs and technical assumptions the authors build the decision sets and maximisation problems for both the incumbent in the market and the potential new firm/entrepreneur entering the market. From there, they derive a Markov-perfect Nash equilibrium for the optimal actions of all agents. The dynamics and solutions are however exterior to this survey because not relevant to the innovation process and one should refer to the Ericson and Pakes (1995) paper for more details.

One can see from this model that innovation in this context is "a source of continuous dynamic competitive pressure that forces all firms in the industry to struggle to maintain profits and survive" (Ericson and Pakes (1995)). This aspect of the theory was missing in the industrial organization approach and is nicely modeled here. To summarize the model and emphasize points not clearly enunciate in the above paragraph, let us recall that in this model a firm/entrepreneur already in the industry or contemplating entering it, has a speculative innovation idea he projects to develop. However, this agent cannot know ex-ante the value of this idea relatively to the achieved standards of the industry. It must be tried and have time, money and effort invested before competitiveness of the idea can be precisely known. Therefore, knightian uncertainty fits perfectly well in this environment but is never dealt with. There is no way presented in this model in which the entrepreneur could share the risk/uncertainty he faces, he must bear it all on his shoulder. This must be why the entrepreneur discounts his expected profit and do not use a form of expected utility. Also, it is assumed that the entering entrepreneur can always have the funds necessary to do so. Clearly, those two flaws could be corrected by an approach based on the one by Amarante, Ghossoub and Phelps (2011). However, the depth and subtleties of the mechanics present in this model should not be overlooked. The dynamic of the ongoing stochastic innovation process is also surely an interesting contribution worth a deeper look.

The next model is another one from Boldrin and Levine, it is not drawn from one of their papers but rather from a course they gave. It has many applications in macroeconomics and is greatly interesting by its use of a production function innovation which is of the factor saving type already mentioned. The main characteristic of this type of model is its straying from the classic hicksian neutrality because by definition an innovation in those models aim at altering the input mix for a given level of output. Indeed, a labor-saving technological change results in a higher capital-to-labor ratio; a capital-saving technological change leads to a lower capital-to-labor ratio; and a neutral technological change results in an unchanged capital-to-labor ratio. Link in his 2007 paper emphasizes that input-saving technological change "implicitly assumes that technology leads to cost reducing changes in the production process, rather than to new or improved quality products". In Boldrin and Levine model, consumption is produced by activities using labour and capital as inputs, capital is produced from capital and labour reproduces itself. The particularity of the model is that capital comes in an infinite sequence of different qualities. The production function is $z = (k, l)$ where k is an infinite vector of different quality capital and l a scalar denoting labour. Labour requirement diminishes with the quality of capital. Like in an endogenous growth model where human-capital accumulation is determined endogenously, the agent maximising utility in this model has to decide between two alternatives for using his investments. He can choose to reproduce capital or to improve it. Under the usual assumptions on the utility function and the production function, the agent maximises its utility under its resource constraints in order to reach the competitive equilibrium. Boldrin and Levine then derive and prove an extended version of the Welfare and Existence theorems. This framework describes one of the most common ideas about innovation, the intuition that it is driven by the exogenous constraint imposed by nature. Mankind creativity reacts to exterior factor. For example, if it were the capital prices that were high, one can also imagine a model where innovation in management or somewhere else would change the labor-capital ratio the other way, the sense of the innovation being driven by fluctuations of the inputs price. This method will also be revisited from a different angle in the endogenous growth section of the next category.

Finally, there are many more examples of production function models but it would be too long to expose them all. However, some of them are worth being summarized. The Aghion, Harris and Howitt (2000) step-by-step model of innovation suppose that two firms producing substitute goods compete in an industry. Each firm produces using labor as the only input, according to a constant returns production function, and takes the wage rate as given. A firm engages in R&D in order to decrease its relative cost. Each time a firm's technology advances by one step, its unit labor requirement falls by a factor $\gamma > 1$. Thus, the relative cost of a firm i that leads its rival by n steps is $\frac{c_i}{c_j} = \gamma^{(-n)}$. Innovative advance happens at a rate determined by R&D efforts which increase the likelihood of an advance at each period, the authors use a Poisson distribution to model this process in their paper. Agion and al. (2000) use this framework to study many phenomena such as spillovers, catching up and the effect of competition on innovation. The latter will be discussed again in the conclusion. They also differentiate the cases of very small and very large innovation the latter being the case where the maximum permissible lead is one step and it gives an advantage so big that it automatically leads to a complete monopole, until the rival catches up. Also, there is the model presented in Shell's 1966 paper where invention enters the production function the same way as capital or labour inputs : $Y_t = F(A_t, K_t, L_t)$, with the growth in the stock of technical knowledge satistfies the differential equation $A_t = \sigma\alpha_t Y_t - \rho A$, where $0 \leq \alpha \leq 1$ is the fraction of output currently devoted to invention and σ is the proportion of inventions that are successful because according to Shell " invention is a particularly risky form of social investment. In my model, a given fraction of inventions is "successful," thus removing the difficult decision problems associated with uncertainty (risk)". One can see that the nuance between risk and uncertainty is seldom made. The last term (ρA) represents the obsolescence property of invention. This decay in technical knowledge is possibly caused by the imperfect transmission of technical information from one generation of the labour force to the next. The author then uses this model to explore matters such as the public good property and hicksian neutrality and their consequences. To conclude, all these production function models also have limited theorical applications because of the simplicity of their construction. Indeed, in them innovation is nothing more than a parameter of a function. This can hardly lead to a theory of the entrepreneur decision process. However, most of them are interesting by the dynamics of the innovation process rather than by the conceptualization of the technological progress in itself.

3.3 Macroeconomics and economic history

The premises of this category are quite wider than those of the latter ones. To take a look at, for example, the factors listed by Mokyr (1990) in his book, one will see that the incentive factor promoted by the Industrial organization is only one in many others that macroeconomics and historian economics study. The approaches of macroeconomics and economical history are together in this section because most of the lectures made on the latter explained historical technological evolution through the utilisation of macroeconomics models. The core of the theoretical work done on innovation by macroeconomist pertains to the productivity of production. This concept is often described by the total factor productivity concept (TFP) which has already been defined when describing the empirical research last section. Many models and theories described earlier in this survey could enter this section. Also in Mokyr's book "The lever of riches: technological creativity and economic progress" (1990), the following definition of innovation used by macroeconomists is given: "By technological progress I mean any change in the application of information to the production process in such a way as to increase efficiency, resulting either in the production of a given output with fewer resources or the production of better or new products". He also adds that in most economical theories, a rational agent maximizes his utility under constraints and thus can do nothing about theses constraints. However, technical changes are an attack to the limits because it pushes back what is attainable. As mentioned he also lays down his stimulating factors, a few have already been mentioned earlier. The point is that there is no formal modeling in his work, only an analysis of the macroeconomic factors which can hinder or boost innovation. Still, there are some relevant facts that are worth mentioning, especially about the dynamics of invention. Mokyr questions the use of the usual equilibrium toolkit to analyse technological change, obviously because, as it will be exposed in the next models presentation, innovation is most of the time the exterior factor that disturbs the inertia of equilibrium. A number of historians and an economist had therefore suggested using a concept of evolution to describe the dynamic aspects of technological progress. A good example of that is the evolutionary model of innovation of Nelson and Winter (1982) presented below. Historical analysis lack theoretical foundations and are therefore not longer discussed. Hence, let us step in the presentation of some representative innovation modeling in a macroeconomic framework.

Probably the first formal macroeconomic model involving innovation, the Solow growth model is well known and therefore do not need to be expose here. The Solow model assumes an exogenous productivity factor that influence production through the production function. It has already been exposed that this productivity factor (usually the A_t in $Y_t = A_t F(K_t, L_{t)})$ can be defined as growing regularly or through a stochastic process. However, an application of this framework that emphasizes more the role of the inventive process, like the one found in the Boldrin and Levine work, tries to endogeneize the technology progression. The premise of such theories is that "technical advance comes from things that people do not merely a function of elapsed calendar time" (Romer (1994)). The Boldrin and Levine model is only one in many attempts to do this. Let us now present some other types of such endeavours. First, there is the Hoon and Phelps model of their 2011 paper in which they study policy shocks in an endogenous product innovation model. They assume that the homogenous final good is produced competitively by assembling a range of produced intermediate inputs according to the production function $Q = [\int_0^n x_i^{\propto}]^{1/\propto}$ with alpha being between 0 and 1. Q is the output of the final good and x_i is the quantity of intermediate input i, and n is the number indicating how many types of intermediate inputs are present. They also assume that no labor is directly required to produce the final good. There is another sector, characterized by monopolistic competition, which produces a range intermediate inputs with only labor. Developing a new variety of the intermediate input requires R&D costs in labor wages. There is also a spillover effect and a research good (K_n) which both lead to the effective number of units of labor required to the development of a new design being a/K_n. Thus the R&D cost to produce a new product is given by $v^f a/K_n$ where v^f denotes the labour wage. Once the design of an intermediate input has been developed, the firm faces a constant marginal production cost. Provided this environment, the authors then derive the competitive equilibrium and the labor supply and demand for the two cases of a small economy and of a closed economy. Using their parameters Hoon and Phelps (2011) also derive conditions (on alpha and r) the economy must satisfy in order to generate innovations. The two policy shocks studied with this framework are an introduction of R&D subsidy financed by consumption tax and an introduction of payroll tax to maintain higher debt-to-GDP ratio. They show that policies can have significant effects on employment and innovation's rate. This model is also a good example of the standing on the shoulder of giants' effect, meaning that later innovations can benefit from a larger stock of ideas thus requiring less R&D labor input to create a new idea, or an economy that has been growing more rapidly in the past demands less labor input now to create a given flow of new ideas.

Another model of endogenous technological change can be found in the paper of Romer (1986) which presents a fully specified model of long run growth in which knowledge is assumed to be an input in production that has increasing marginal productivity. In contrast to physical capital that can be produced one for one from forgone output, new knowledge is assumed to be the product of a research technology that exhibits diminishing returns. There is also a usual spillover effect in this model. He considers a two period model where each of the S identical consumers have a twice continuously differentiable, strictly concave utility function $U(c_1, c_2)$ defined over the consumption of a single good in each period. Let the consumers be given an initial endowment of the output goods in period one. The author also suppose that production of the consumption goods in period 2 is a function of the state of knowledge, denoted by k, and a set of additional factors such as physical capital, labor, etc. denoted by the vector x. Those other factors are assumed fixed in order to focus the analysis on the technological dimension. k will be treated as a stock of disembodied knowledge, i.e., knowledge in books. If one wants to assume that all knowledge is embodied in some kind of tangible capital such as conventional physical capital or human capital, k can be reinterpreted throughout as a composite good made up of both knowledge and the tangible capital good. Assume that there is a research technology that produces knowledge from forgone consumption in period 1. The spillover effect is modeled by representing the technology of firm i in terms of a twice continuously differentiable production function F that depends on the firm specific inputs $k_i\ and\ x_i$ and on the aggregate level of knowledge in the economy ($K = \sum_{i=1}^{N} k_i$ with N firms in the economy). In order to guaranty the existence of equilibrium, F must be assumed concave. By adding homogeneity to the function F, it follows that it exhibits increasing return to scale. To strengthen this result, the author also assumes that F exhibit global increasing marginal productivity of knowledge from a social point of view. Hence, the equilibrium for the two periods model is a standard competitive equilibrium with externalities. After solving for the firms and consumers maximization problem, Romer (1986) then extends its model to infinite horizons. This simple model shows the most basic way macroeconomics has modeled innovation. It can be easily expanded to introduce risk by introducing a parameter defining a proportion of invested consumption that turn into knowledge. However, because of its minimal description of states and choice spaces, it would be hard to introduce uncertainty or a financier agent.

The last of the macroeconomic endogenous technological growth model to be presented in this survey is the one by Lucas (1988). In fact, this paper contains three models, one emphasizing capital accumulation and technological change, one emphasizing human capital accumulation and one covering specialized human capital accumulation through learning by doing. The first of these models is used by Lucas to assess the validity of the neoclassical theory to account for innovation using the ordinary macroeconomic model where technology enters a Cobb-Douglas like production function, while growing by a fixed exogenous parameter through time. As he conclude "it is not exactly wrong to describe these differences by an exogenous, exponential term like *A(t)* neither is it useful to do so. We want a formalism that leads us to think about individual decisions to acquire knowledge, and about the consequences of these decisions for productivity. The body of theory that does this is called the theory of 'human capital', and I am going to draw extensively on this theory in the remainder of these lectures" (Lucas (1988)). Throughout this survey it has been clear that modern economics theory approach has two main flaws. The first one is its inability to deal with knightian uncertainty. The second one is the pervasive exogeneity of the innovation process. Lucas's answer for the second one is therefore the human capital theory. Here is how he applies it to the question. The premise of human capital theory is the fact that the way an individual allocates his time over various activities in the current period affects his productivity, or his *h(t)* level, in future periods. Suppose there are N workers, with skill levels h ranging from 0 to infinity. There are also N(h) workers with the skill level h so that $N = \int_0^\infty N(h)dh$. Suppose a worker with skill *h* devotes the fraction *u(h)* of his non-leisure time to current production, and the remaining 1 - *u(h)* to human capital accumulation. Then the effective workforce in production is the sum $N^e = \int_0^\infty u(h)N(h)hdh$ of the skill-weighted manhours devoted to current production. Thus if output as a function of total capital K and effective labor $\mathrm{N^e}$ is $\mathrm{F_N(K, N^e)}$, the hourly wage of a worker at skill h is $\mathrm{F_N(K, N^e)h}$ and his total earnings are $\mathrm{F_N(K, N^e)hu(h)}$. Lucas also adds a spillover effect by taking into account the average level skill or human capital $h_a = \frac{\int_0^\infty hN(h)dh}{\int_0^\infty N(h)dh}$ that will enter the production function $Y = AK(t)^\alpha\,[u(t)h(t)N(t)]^{1-\alpha}h_a(\mathrm{t})^\gamma$, where A is still the technology level but is now constant. The human capital is acquired through the following equation $\dot{h}(t) = h(t)G(1-u(t))$ where G is increasing and G(0) = 0. Lucas then proceeds to the resolution of the competitive equilibrium. By solving the matter of exogeneity this way, Lucas strays away from the concepts of innovation, nonetheless, there might be the beginning of an answer in this essay and that is what he concludes.

Atkeson's (2007) paper presents present a general equilibrium model of the decisions of firms to innovate and to engage in international trade. The question he tries to answer is: How has the expansion of opportunities for international trade changed firms' incentives to engage in innovative activities? To do so, he describes a model with the two kinds of innovation already mentioned: product and process innovations. It is closely related to several papers in the literature, Hopenhayn's (1992) model in which firms' experience exogenous random shocks to their productivity, Luttmer (2006), Irarrazabal and Opromolla (2006), etc. Let us suppose a discrete time environment with two countries (home and foreign). The households in each country are endowed with L units of time. Production is structured as follow, there is a single final nontraded good that can be consumed or used in innovative activities, a continuum of differentiated intermediate goods that are produced and can be internationally traded subject to a fixed and a variable trade cost, and a nontraded intermediate good that is called the research good. This research good is produced using a combination of final output and labor, and is used to pay the costs associated with process and product innovation, as well as the fixed costs of exporting. The productivities of the firms producing the differentiated intermediate goods are determined endogenously through equilibrium process innovation, and the measure of differentiated intermediate goods produced in each country is determined endogenously through product innovation. Households in the home country have preferences of the form $U_t = \sum_{t=0}^{\infty} \beta^t \log(C_t)$ (the foreign households have similar preferences but consumption is denoted C_t^*) and they face an intertemporal budget relatively to their endowments $\sum_{t=0}^{\infty} Q_t(P_t C_t - W_t L) \leq \overline{W}$ where Q_t are intertemporal prices, W_t is the wage in home country, P_t is the price of the home final good and $\overline{W}$ is the initial stock of assets held by the household. Intermediate goods are differentiated products each produced by heterogeneous firms indexed by *z*, which indicates their productivity. A firm in the home country with productivity index z has productivity equal to $\exp(z)^{1/\rho-1}$ and produces output $y_t(z)$ with labor $l_{t(z)}$ according to the CRS production technology: $y_t(z) = \exp(z)^{1/\rho-1} l_{t(z)}$. The output of this firm can be used in the production of the home final good, with the quantity of this domestic absorption denoted $a_t(z)$. Alternatively, some of this output can be exported to the foreign country to be used in the production of the foreign final good. The home final good is produced from home and foreign intermediate goods with a constant returns production technology of the form :

$$Y_t = [\int a_t(z)^{1-1/\rho} dM_t(z) + \int x_t^*(z) b_t(z)^{1-1/\rho} dM_t^*(z)]^{\rho/(\rho-1)}$$

where $M_t(z)$ is the measure of operating firms in the home country with productivity less than or equal to z. The author then solves for the competitive equilibrium of both the foreign and home country. The research good in the home country is produced with a constant returns to scale production technology F that uses X_t units of the home final good and L_{mt} units of labor to produce Y_{mt} units of the research good according to Y_{mt} = F (X_t, L_{mt}). Productivity at the firm level evolves over time depending both on idiosyncratic productivity shocks hitting the firm and on the level of investment in productivity improvements undertaken within the firm. Productivity at the firm level evolves over time depending both on idiosyncratic productivity shocks hitting the firm and on the level of investment in productivity improvements undertaken within the firm. We model the evolution of firm productivity as follows. At the beginning of each period t, every existing firm has probability δ of exiting exogenously, and corresponding probability 1 − δ of surviving to produce. A surviving firm with current productivity $\exp(z)^{1/\rho-1}$, and that invests H (z, p) = h exp(z) c(p) units of the research good in improving its productivity in the current period t, has probability p of having productivity $\exp\,(z+s)^{1/\rho-1}$ and probability 1 − p of having productivity $\exp\,(z-s)^{1/\rho-1}$ in the next period t+1. They assume that c(p) is increasing and convex in p, and h is a positive constant. New firms (or new products) are created with investments of the research good. Investment of n^e units of the research good in period t yield a new firm in period t+1 with initial productivity $\exp\,(z)^{1/\rho-1}$ drawn from a distribution over z given by G. Therefore, the product innovation and process innovation decision can be solved with Bellman equations (this survey being more interested by the mechanics by which innovation is modeled, one should refer to the paper for a complete resolution of the model). This model is a great contribution to the innovation theory because of the creative way by which it is modeling different aspects of the inventive process. Product innovation, process innovation, spillovers, stochastic shocks to productivity and endogeneity are all present as well as, for the first time, an international sector.

Finally, there are two opposite theories about innovation, one who emphasizes its creative destruction characteristic and one that emphasizes more the standing on the shoulder of giants effect. The latter has been studied during the presentation of the Hoon and Phelps (2011) paper. The foundation of the former can be traced to Schumpeter and its vision of capitalism. According to him, the essence of capitalist economic development is the process of the creation by innovation of a new economic paradigm by the destruction and total replacement of the existing one. A modern example of a model involving this kind of dynamic can be found in Aghion and Howitt (1992) paper which "departs from existing models of endogeneous growth in emphasizing obsolescence of old technologies induced by the accumulation of knowledge and the resulting process or industrial innovations"(Aghion and Howitt (1992)). They assume there are four classes of goods: land, labour, consumption good and a continuum of intermediate goods $i \in [0,1]$. There is also a continuum of identical infinitely lived individuals, each endowed with one unit of labour. There is disutility for supplying labour, a unique interest rate r and also a fixed supply of land H. The consumption good is produced using land and the intermediate goods, subject to constant returns : $y = \int_0^1 (\frac{F[x(i)]}{c(i)}) di$, x(i) being the flow of intermediate goods, F' > 0, F''<0 and c(i) being a parameter indicating, for given factor prices, the unit cost of producing the consumption good using the intermediate input i. Each intermediate good is produced using labour only, according to the linear technology : x(i) = L(i) where L(i) is the flow of labor used in the intermediate sector i.

Labour has also the alternate use, research which produces a random sequences of innovations. The stochastic process of the arrival of these innovations follows a Poisson distribution with parameter λn where n is the flow of labour used in research and λ a constant parameter given by the technology of research. An innovation consists of the invention of a new line of intermediate goods more efficient for producing consumption goods. Specifically, the use of the new line reduces the cost parameter c(i) by the factor $\gamma \in [0,1]$. The most modern intermediate technology is always the one used, without any delay in the adoption of the invention. A successful innovator obtains a continuum of patents, one for each intermediate sector, each one granting the holder the exclusive right to produce the newly invented intermediate good in that sector. In this model, the innovation process is endogenous (a firm employing z in research will have a Poisson parameter of λz), and the decision to invest is subject to a profit maximisation problem. The innovator always has to sell the patent to a "new" intermediate firm that will be a monopolist until a better invention is made. The model thus represents the Schumpeter's idea: "Each innovation is an act of creation aimed at capturing monopoly rents. But it also destroys the monopoly rents that motivated the previous creation" (Aghion and Howitt (1992)). There are interesting macroeconomic results in this paper such as:

"Proposition 3: The amount of research performed in a positive balanced growth equilibrium
(a) decreases with the rate of interest r
(b) increases with the arrival parameter
(C) increases with the size of each innovation (i.e. decrease with v)
(d) increases with the total labor endowment N"

3.4 Game theory

For game theorists, the decision to participate in the process of innovation can be seen as a game with its own strategies, pay offs and equilibrium. The main idea is that multiple firms compete to be the first one to complete an innovation in order to patent it (a patent race) or to engage in a competition with other firms for the leading position in an industry. Models of this category rely a lot on profit maximisation for decision taking just as industrial organization ones. However, they differ mainly because game theory models emphasize a lot on complex strategies for the firms and the search for Nash equilibrium or one of its extensions.

The first model to be presented is from Acemoglu, Bimpikis and Ozdaglar (2008) paper and is mostly about intellectual property and the efficiency of patents to reach optimal allocation. It has already been discussed that this idea is not accepted by everyone. Boldrin and Levine (2008), Quah (2002) and many others have taken position against it. Nonetheless, this hypothesis is another common point between IO theorists and Game theorists. The model is structured as follows, there are 2 symmetric potential innovators contemplating a pool of ideas.

Each firm receives a private signal on which of these projects is more likely to lead to an innovation and can decide to experiment with any of these projects at any point in time. The optimal allocation and the symmetric equilibrium involve sequential experimentation. The two firms maximise the present discounted value of profits. Let us assume that Let us denote the time interval between two consecutive periods by delta> 0, assume δ to be small. Each firm can implement (experiment with) one of M potential innovation projects, let us represent the set of projects by M = [1,...,m]. Each firm receives a private (positive) signal ψ element of M indicating the success potential of one of the projects. The unconditional probability that a project will be successful (when implemented) is small (close to 0). Conditional on the positive signal the success probability of a project is p > 0. They assume that the two firms always receive signals about different projects. The success or failure of experimentation by a firm is publicly observed. When experimentation is successful, they refer to this as an innovation. At each instant, a firm can choose one of three possible actions: (1) experiment with a project (in particular, with the project on which the firm has received a positive signal); (2) copy a successful project; (3) wait. Once the choice is made, a firm cannot change his made and undertake another action. This captures the fact that commitment of intellectual property and financial resources to a specific idea is necessary for success. Payoffs depend on the success of the project and whether the project is copied. During an interval of length δ, the payoffs to a firm that is the only one implementing a successful project is $\delta\pi_1 > 0$, the payoff of a copied project is $\delta\pi_2 > 0$ and the payoff of an unsuccessful project is normalized to zero. They assume $\pi_1 > \pi_2 > p\pi_1$ and they define the present discounted value of profits as $\frac{\pi_j}{r}$ j = 1, 2. Let a history up to time t (where t = k δ for some integer k) be denoted by h^t . A strategy for a firm is therefore a mapping from its signal ψ and the history of the game up to time t, to the probability of experimentation at a given time interval and the distribution over projects. History up to time t can be summarized by two events $a_t \in \{0,1\}$ denoting whether the other firm has experimented up to time t, $m_t \in M$denoting which project it has chosen in that case, and $s_t \in \{0,1\}$ denoting whether this choice was successful. Although this is a game of incomplete information, the only source of asymmetric information is the identity of the project about which a firm has received a positive signal. According to the authors, it is therefore sufficient to focus on the subgame perfect equilibria in this game. This equilibria is a strategy profile $(\hat{\sigma}_1, \hat{\sigma}_2)$ such that $\hat{\sigma}_i$ is the best response to $\hat{\sigma}_{-i}$ in all histories $h^t \in H$ for i = 1, 2. Even if the firms are symmetric, there are cases of symmetric and asymmetric equilibria. For the details on the resolution of these equilibria and for expansions such as continuous time, multiple firms and the application to patents, one should refer to the paper. Acemoglu, Bimpikis and Ozdaglar conclude that patents may improve the allocation of resources by encouraging rapid experimentation and ex post transfer of knowledge across firms.

Next, the Persson, Norback's (2007) paper studies the impact of increased product market competition and strengthened competition policy on the incentive for and pattern of innovation and innovation for entry. Their model includes the following characteristics: "there are several incumbent firms competing in oligopoly fashion in a product market. Moreover there is an entrepreneur outside this market who invests in an innovative activity that could lead to the creation of a unique productive asset, which increases the profit of the possessor and decreases the profits of the rival firms" (Persson, Norback (2007)). It is a three period model, in the first period, nature determine the intensity of competition C. In the second one, the entrepreneur decides on the amount to invest in the innovative activity, a bigger investment increasing the likelihood of a successful invention. In the third period, given successful innovation, the incumbent firms compete to acquire the rights on the entrepreneur's innovation (innovation for sale) or, if no sale occurs, the entrepreneur has the opportunity to enter the market himself (innovation for entry). In the final period, firms compete in an oligopoly market. The authors use this framework to assess the impact of competition on the incentives for innovation. They found that increased competition can stimulate and hinder innovation. The reason is that the value of the invention depends on the advantages it gives to the buyer. In a market more competitive, even the smallest advantage can have a big influence on a buyer's profit. On the other hand, more competition implies a smaller price and thus less profits to be made in the market. One can see a graph of the game representing this model in appendix 5. The backward resolution of the Nash equilibrium can be found in the paper, as well as the strategies and optimal strategies for each player. This model has a lot of common point with the one of Amarante, Ghossoub and Phelps (2011). For example, there is a specific agent responsible of the creative innovation: the entrepreneur. He is contemplating and idea that requires investment (however the way the investment is designed is not the same in both models), and then he tries to sell this idea to someone else. In Amarante, Ghossoub and Phelps however it is not at an incumbent firms but at a financier that the entrepreneur tries to sell its idea. It is always surprising how all of the models that involve trying to define the value of an innovation before its entrance on the market never mention uncertainty. It is however hard to find a more uncertain activity than the venture investments.

Finally, Reinganum (1981), a really proficient author in game theory and innovation, published numerous papers that were often referred to by many authors from various categories of this survey like, for example, Boldrin and Levine, Scotchmer, etc. This survey will present two of her most quoted paper but it is only a small part of the body of work she generated. The first one is her 1981 paper, in which she describes a patent race. The models goes as follows, there is two identical firms. The player i wins if he perfects the innovation before the other player j. Then, the winner of the race receives a patent whose worth is the present value (or expected present value in case of a stochastic reward stream) of the stream of rents accruing to a monopolist in the innovation's industry. Also, knowledge is accumulated through R&D activities and time to completion of the innovation is determined by a random variable whose distribution depends on the knowledge accumulated by the firm. In this paper, the author uses an exponential distribution for this random variable. Therefore, the probability that firm i succeeds at or before time t is $1 - e^{\lambda z_i(t)}$ where $z_i(t)$ is the accumulated knowledge.

There is also a date T at which the invention becomes completely obsolete it serves as limit on the lifetime of the patent. A pure strategy for i is therefore a function of both time t and the current levels of knowledge. The noncooperative game result is a Nash equilibrium where each firms accumulate knowledge at an optimal rate given the other firms strategy. Reinganum (1981) also studies the case in which negotiation and/or contract enforcement are not prohibitive and therefore when cooperative games are possible. She also includes in her model a parameter to express the embodiment attribute of knowledge. The firms receive the present value of the patent as long as either one of them succeeds at completing the design of the invention. Since firms i and j jointly choose the rate of knowledge accumulation, the probability that the innovation is completed at or before t is now $1 - e^{\lambda(z_i(t)+z_j(t))}$. Reinganum finds that the Nash equilibrium in this case involves a higher rate of R&D investment than with noncooperative rivals. However, when the knowledge is not completely embodied meaning that it is transferable between firms, the results are less robust. The cooperative rivals may innovate before or after noncooperative rivals. She then concludes the paper with a discussion on the optimal level of investment, stating that rivalry leads to quicker innovation but can also lead to overspending in research, and a discussion on the public good attribute of knowledge, introducing the notion of spillovers in a way similar to those expressed above. One can see that this model is the basic patent race that has been mentioned before. The patent race is present in industrial organisation theory but not as much as in game theories field where it is the core of the approach to innovation. Therefore, it was unavoidable to present at least a basic one even if the conceptual contribution of it is limited. In her 1989 paper, Reinganum presents another form of patent race in which the firm who commits the greatest expenditure in R&D today will obtain the invention first. Therefore, the race can be represented by a kind of auction model where a strategy for firm i is a bid x and a Nash equilibrium is a vector of bids with the property that no firm would want to change its bid unilaterally. The firm with the largest bid is the winner. A peculiar aspect of this model is that no resources are expended until the winner is determined. She then extends the model to cases where the firms are asymmetrically placed like, for example, in the challenger/incumbent case. She also studies the timing and diffusion aspects of innovation. The former is described through the process of licensing in the context of oligopolistic production. The diffusion discussion is about trying to explain why firms may delay the adoption of a profitable innovation. The key determinants, according to Reinganum (1989), are the declining adoption costs and the perception that the benefits of adoption decline with the number of previous adopters.

3.5 Others

The two last approach of innovation this survey will present before the concluding remarks are conceptualizations of innovation that do not fall in any previous category. The first one has already been mentioned and is called the evolutionary model of innovation. This theory has many proponents but only three will be presented here. The two first are Nelson and Winter and their book “An Evolutionary Theory of Economic Change” (1982). The main idea is that “firms at any time are viewed as possessing various capabilities, procedures, and decision rules (the genes) that determine what they do given external conditions. They also engage in various search operations (mutations) whereby they discover, consider, and evaluate possible changes in their ways of doing things. Firms, whose decision rules are profitable, given the market environment, expand; those firms that are unprofitable contract” (Nelson and Winter (1982)). The first model of their book involves a number of firms producing an homogenous product, using the two classic inputs : labor and physical capital. In any period, a firm is characterized by its capital stock (K) and the production technique it is using, which is described by a pair of input coefficients. The use of coefficient to describe a production technique goes back to Schumpeter. The firm’s activities that aim at improving the available technology for production are called searching. It invokes a pre-existing set of technological possibilities (the usual ideas pool) that the firm explores. The probability distribution of designing new techniques can be influenced by the firm’s R&D expenditures in searching. If a firm is successful in discovering a new technique, it is allowed a random draw in the set of potential ideas. The authors also assume that if a firm is profitable enough, it will do no searching at all. Moreover, they see the set of potential ideas as constantly growing with more productive ideas because of exogenous events. Instead of searching, a firm can also engage in another activity called imitation. The probability to transfer the existing technique to itself depends on the proportion of the industry production produced by this technique. Imitation is always of the best practice in the industry and is another way of modeling spillovers. Another author who also adopts the analogy between the inventive process and Darwinian evolution is J. Mokyr in his 1990 book “The Lever of Riches”. He states that in the evolutionary theory of innovation, there is no profit maximisation or rational thinking. Firms have a determined and fixed way of doing things, if this way is a good one than the firm survives and others imitate it. If the techniques of the firm are badly adjusted to the market conditions the firm disappears. Even the R&D expenditures decision can be seen in this way. If the firm spend too much or not enough then it is fated to fail. According to Mokyr, “The idea or conceptualization of how to produce a commodity may be thought of as the genotype, whereas the actual technique utilized by the firm in producing the commodity may be thought of as the phenotype of the member of a species” (Mokyr (1990)). There is a large literature on models and applications of this kind of theory but has an analogy, it is a good way to expose a concept but it has a limited ability to explain it. Clearly, the innovation process and the biological evolution have similarities but they are not the same phenomenon. Therefore the theory of the latter cannot be blindly applied to the former.

The second of the uncategorized theory is the constraint-based notion of innovation. Its premise had already been described earlier. It is that men generate innovation in order to push back their limitations and therefore, those limitations are the source and the incentive of the creative process. An application of this concept to a more modern context is presented by Silber in his 1983 paper on the constraint-based notion of innovation. The industry in which the author applies this concept is the one of financial innovation. However, it is a more general idea that could be applied to almost any type of innovation. In its application, Silber states that its main hypothesis is that "new financial instruments or practices are innovated to lessen the financial constraints imposed on firms" (Silber (1983)). Among the most important external constraints for financial institutions are government regulations. But the market and the competition from other firms are also other examples of constraints. Especially, if a firm possesses a market power it can generate huge pressure on the rest of the industry by setting the price. There also exist internally set constraints for financial firms like a target rate of growth for assets or a self-imposed liquidity ratio. Therefore, new sources of funding and new uses for those funds are designed when exogenous changes in the environment stimulate the search for new policy tools. Although financial innovation is generally not as expensive as the development of new technology (in a more technical sense), there is still a considerable expense for the design of new contracts, running a new secondary market or installing requisite computer equipment. The incentives to pursue such an endeavour therefore depend on a sustained increase of the potential profit that overcoming the constraint can provide. To validate its theory, the author then proceeds to the presentation of empirical evidence. He first refers to the study by Ben-Horim in which he successfully explained new bank products during the years 1952-70 observation. Then, Silber studies the years 1970-82 where he observes that the constraint-induced theory seems appropriate to explain the dynamics in at least half of the cases.

4. Conclusion

In the first part of this survey, many concepts surrounding innovation were presented. Their number and the quantity of other related concepts that did not made the cut are the proofs that the literature on innovation is vast and rich. However, it has been clear since the beginning that while there is a large coverage of innovation's related matters such as its sources, functions, characteristics, diffusion process, etc. there is still not a clear and commonly accepted definition of the phenomenon. It has been shown how each field: macroeconomics, game theory, industrial organization, etc. has its own definition with its own shortcomings and advantages. In most of the models seen in the second part, it was clear that the role played by the entrepreneur was poorly defined. It was also often mentioned in the literature that ambiguity and uncertainty (knightian) were intrinsic to innovation but that no model was trying to introduce them rigorously. The majority of the models use expected profit maximisation to represent the decision making process of the entrepreneurs. However this makes little sense without a proper treatment of uncertainty. How can one define a probability distribution for the profits flow of a not yet completed innovation? Moreover, it has been seen that most of the work done before had pervasive exogeneity which clearly undermine the explicative potential of the model. Therefore, this survey must conclude that there is definitely a place for a new conceptualisation of the inventive process, one that would complete and maybe unify all those seen above.

Also, the question of interconnections between competitive markets and innovation is utterly present in the literature. Boldrin and levine in their 2003 paper argue that there is no clear answer whether competitive markets are better for innovation than monopolies and copyrights. According to them, in the absence of unpriced spillovers, the competitive equilibrium without copyrights and patents may fail to attain the first best only because ideas are indivisible. This could cause socially valuable ideas failing to be produced. However, they show that in the absence of indivisibility or if indivisibility is not binding, competitive market succeed in obtaining optimality. For Reinganum (1981) the opportunity of a supernormal profit, offered by intellectual protection, acts as a spur to innovative activities. Also, in the model she developed in her 1981 paper, the existence of rivals provides incentive to "overspend" on R & D, since only the first to succeed is rewarded. On an industry level, rivalry means that research effort will be duplicated as firms run parallel projects. However, it may be optimal to run parallel projects, since each additional project increases society's chances of obtaining the innovation at an earlier date. On the other hand, the public good aspect of knowledge generation is well known. If a firm cannot expect to appropriate the full value of the knowledge it generates, its R & D effort will be correspondingly reduced. The patent system is an attempt to mitigate the disincentive of nonappropriability. However, the social value of an innovation may exceed the monopoly rents. Hence patents may provide only a partial remedy. While it is clear that the Nash equilibrium and the socially optimal rates of investment in R & D do not coincide (neither with private nor public knowledge), it is not always clear a priori in which direction the bias acts. If knowledge is a pure public good and the social value of the innovation is high enough, then firms unambiguously underinvest as compared to the social optimum. In their “step by step” model, Aghion, Harris and Howitt (2001) also try to answer this question. According to them, the desire to escape competition is the greatest incentive for innovation. However, a more competitive market means smaller rents and thus smaller profits possibilities. They find that when they allow the product market competition and imitation to be varied together, the maximal (innovation) growth rate is always achieved by allowing the maximal degree of competition. Persson and Norback (2006) synthesize these two aspects of competition by using the framework developed in their paper. They also found that increased competition can stimulate and hinder innovation. The reason is that the value of the invention depends on the advantages it gives to the buyer. In a market more competitive, even the smallest advantage can have a big influence on a buyer’s profit. On the other hand, more competition implies a smaller price and thus less profits to be made in the market. Hence they have established an inversely U-shaped incentive for innovation for sale when increasing the intensity of competition by increasing the number of firms. Aghion and al (2001) empirically documented this inverted U-shaped relationship between product market competition and innovation in the UK, using the privatizations during the Tatcher regime, the EU single-market program, and the investigations performed by the Monopoly and Merger Commisision. They also provide a theoretical model explaining this pattern. In their modeit, the incentive for innovation can increase when the intensity of competition increases since pre-innovation rents from innovations are reduced by more than the post-innovation rents of innovations. This “escape competition effect” stimulates innovations.

Finally, innovation does not only have proponents. Some theorists mention the fact that more innovation means more complexity and thus more uncertainty. For example, Tufano in his 2002 paper states that “there are other arguments that innovation leads to complexity that in turn leads to bad business decisions and social costs”. Given that markets are incomplete, one might assume that innovation that gives participants greater freedom of choice (in terms of spanning) would enhance social welfare almost by definition, in the sense of being pareto-optimal. Unfortunately, this is not the case. For example, Elul (1995) studies the welfare effects of financial innovation in incomplete markets. Elul shows that the addition of a new security may have “almost arbitrary effects on agents’ utilities.” The introduction of a new security can “generically make all agents strictly worse off, or all agents strictly better off, or favor any group of agents over another.” This aspect of innovation is quite interesting, especially for one looking at innovation from a decision theory side.

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Appendix

Appendix 1 Summary and assessment of the contributions

Idea	Main contribution	Pros	Cons
"talent for managing" *(coordination role)*	Lucas (1978)	1. formalization of a basic idea (J.B. Say) 2. model of occupational choice	1. no precise meaning of talent (not testable) 2. entrepreneurship as factor of production
"tolerance towards risk" (*mechanism to allocate risk*)	Kihlstrom and Laffont (1979)	1. equilibrium analysis with entrepreneurship 2. formalization of Knight's idea 3. explanation of how wealth relates with entrepreneurship	1. no distinction between risk and uncertainty 2. not robust to the opening of capital market
"capacity to capture new profit opportunities" *(innovation)*	Holmes and Schmitz (1990)	1. "disequilibrium" analysis 2. precise idea of entrepreneurial abilities 3. occupational choice	1. exogenous technological progress 2. no uncertainty
"working in the R&D sector" *(innovation)*	Segerstrom et al. (1990) Aghion and Howitt (1992)	1. endogenous technological progress 2. formalization of "creative destruction"	1. no explicit modeling of entrepreneurs 2. no distinction between entrepreneur and inventor

Contribution	Why entrepreneurs?	Who is the entrepreneur?
Lucas (1978)	Production requires coordination	Those more talented in managing
Kihlstrom and Laffont (1979)	Production is risky	The less risk averse
Holmes and Schmitz (1990)	New profit opportunities always occur	Those talented in capturing opportunities
Aghion and Howitt (1992)	Growth requires innovation	Firms involved in R&D activities

Appendix 2 Diffusion of Financial Innovations: The Case of Junk Bonds and Note Issuance Facilities Phil Molyneux and Nidal Shamroukh 1996

External Influence

Exogenous factors (e.g., changes in regulations, demand-related factors, advances in technology) make an innovation desirable for a certain group of banks with the timing of adoption being a function of firm-specific characteristics.

⇓

A proportion of these banks adopt the innovation based on their individual assessment of that innovation's efficiency or returns

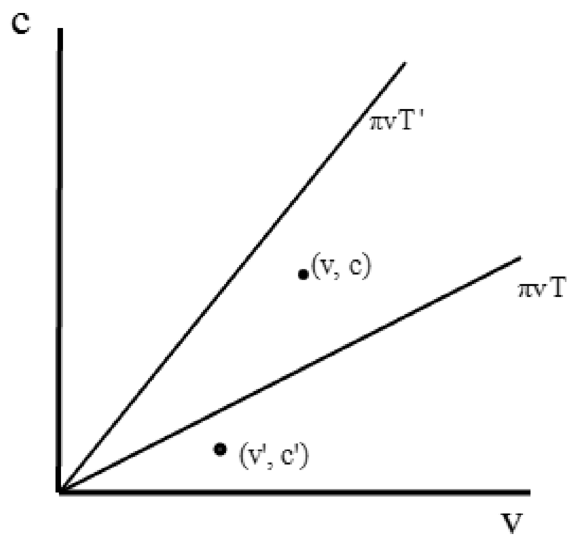
⇓

Internal Influence

Bandwagon Effects Hypothesis The sheer number of banks adopting an innovation causes a bandwagon pressure prompting other banks to adopt		**Rational-Efficiency Hypothesis** Banks adopt (reject) innovations based on their updated individual assessment of the innovation's efficiency and returns due to endogenous factors.
Institutional bandwagon	**Competitive bandwagon**	**Updated information**
• Bandwagon pressures on non-adopting banks arising from the threat of lost legitimacy and lost stockholders support.	• Bandwagon pressures on non-adopting banks arising from the threat of lost competitive advantage.	• Information flow from adopting banks to nonadopting banks prompting the latter to update their assessment of the innovation's efficiency and returns. • Returns to innovation increase (decrease) with increases in the number of adopters due to positive (negative) externalities. • Adoption costs decline (increase) with increases in the number of adopters due to the fixed cost nature of new market development (increase in the level of promotional activities).

FIG. 1. Theoretical Background of Diffusion Models

Appendix 3 Ideas, innovations and length of protection (Scotchmer p. 99)



Appendix 4 Effectiveness of appropriability mechanism for product innovations

Selected industries	Sample Size	Secrecy	Patents	Other Legal	Lead time	Complementary sales service	Complementary manufacturing
food	89	58,54	18,26	21,18	53,37	39,83	51,18
Petroleum	15	62	33,33	6,33	48,67	40,33	35,67
Basic Chemicals	35	48	38,86	11,57	38,29	45,86	44,71
Drugs	49	53,57	50,2	20,82	50,1	33,37	49,39
Machine Tools	10	61,5	36	9	61	43	34,5
Computers	25	44,2	41	27,2	61,4	40,2	38
Electrical equipment	22	39,09	34,55	15	33,41	32,27	31,82
Semiconductors and related	18	60	26,67	22,5	53,33	42,22	47,5
Medical equipment	67	50,97	54,7	29,03	58,06	52,31	49,25
Autoparts	30	50,83	44,36	15,65	64,35	44,84	53,06
All	1118	51	34,83	20,71	52,76	42,74	45,61

Source : Cohen, Nelson and Walsh (2000), table 1

Appendix 5 Persson and Norback's (2007) game tree

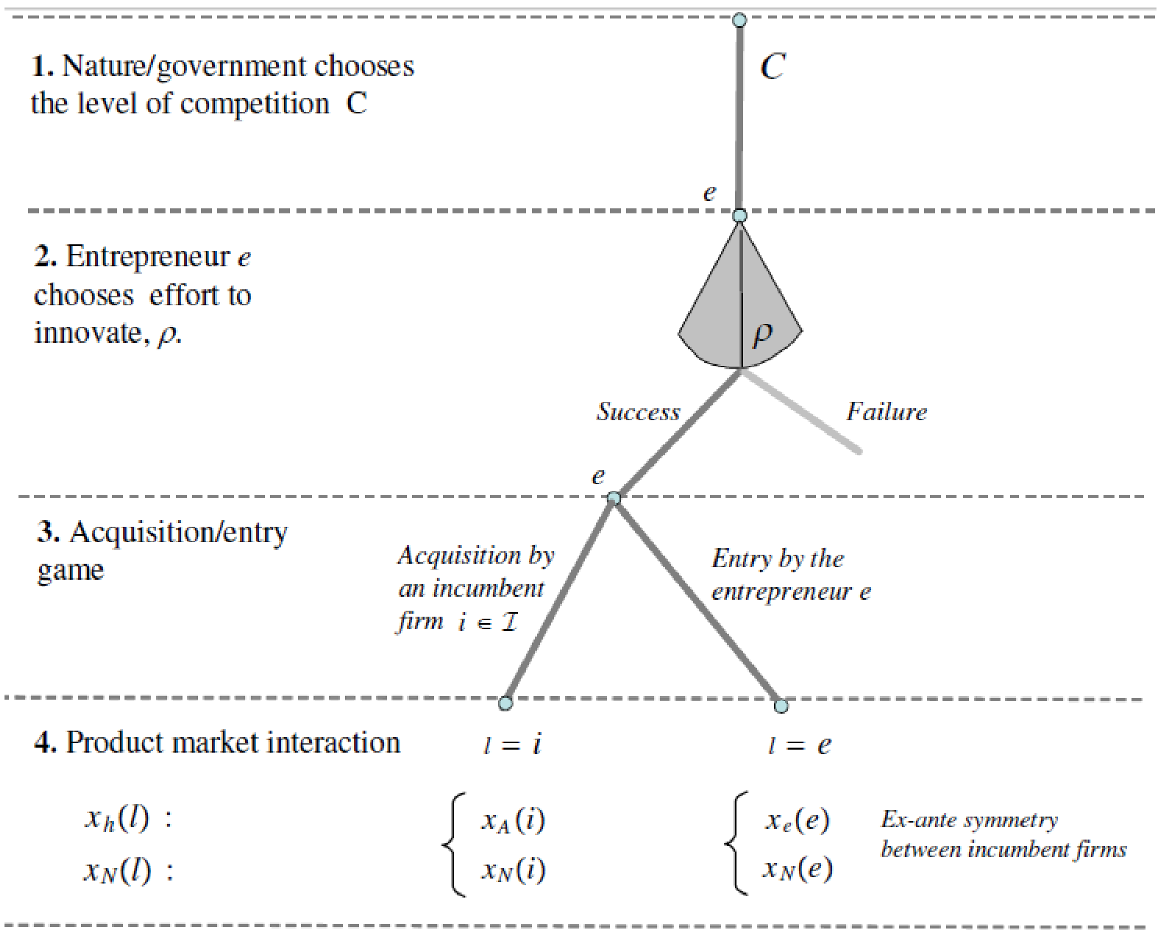


Figure 2.1: The sequence of the game.

Persson, Norback (2007)