Innovation Driving Industrial Dynamics. Between Incentives and Knowledge

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1. Introduction

This paper is about the co-evolution of technologies and markets. Being our concern the understanding of their impact upon the advancement of industries, these two aspects can not be easily decoupled, nor independently treated.

Classical economics recognized precisely in the link between technological evolution and market forces the trigger of industrial revolution and the consequent tumultuous process of economic growth: «In turning from the smaller instruments in frequent use to the larger and more important machines, the economy arising from the increase of velocity becomes more striking» (Babbage, 1832, pp. 4-36).

However, Adam Smith explained that the use of «more important machines» is limited by the extent of the market. He described the combined effect both of innovation, which creates new markets, and of new markets setting incentive for innovation. Karl Marx as well highlighted the role of machineries as the main source of productivity increases, but also the low wages as a possible reason for demand shortage.

Despite the awareness among the classics, the analysis of the co-evolution of technologies and markets as the main determinants of industrial dynamics has been abandoned in traditional neoclassical theory.

A certain extension of this approach is to be found only in the search for economic magnitudes and effects which are responsible for both the direction and the kind of technological progress. The so-called demand-pull approaches look, on the one hand, at the demand side of the economy and consider product innovations as initiated from there. On the other hand, the

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change in relative prices is considered to be responsible for certain factor-saving directions technological progress is taking.

Conversely, the role of technology has been completely removed from the realm of the discipline: technological progress has been treated as an exogenous variable and therefore banned to the extra-economic sphere. Neoclassical economics is characterized by the assumption of an only reactive behaviour of actors as it is used for all kinds of exogenous shocks (preferences changes, relative factor price changes, income changes, etc.). The economic processing of technological changes does not signify anything but simply follows the market forces where the economic development is pushed by an exogenous technology shock.

Within this analytical frame, regardless whether technological-push or demand-pull approaches are considered, characteristic for both is that actors only react to economic changes. New technological know-how is considered a pure public good that each economic actor can appropriate at no costs and which is – external to the economic sphere – generated (invention) and adapted for economic purposes (innovation). Consequently, neither innovative activities nor the existence of spillover effects constitute a certain additional economic problem.

In this paper we review and discuss contributions, which, on the contrary, considered innovation both as a key factor of advancement and as an endogenous dimension of any economic system. The paper consists of two major blocks.

Section 2 discusses the evolution of technology and markets from the firm's perspective. Respective approaches therein take into account that firms or actors consciously and actively invest resources in order to achieve new technological know-how usable for economic purposes. Consequently, technological progress becomes an endogenous phenomenon, i.e. it is based on economically motivated decisions of firms and other actors. Compared to approaches with exogenous technological change these models perform much better in analyzing the importance of technological progress. The sources of new ideas are found on the technology side; hence this approach is called technology push.

Section 3 highlights the role of the demand side in shaping competitive conditions and technological trajectories. Hence demand is considered a pulling factor telling the firms where and by which intensity to innovate. Consequently this approach is labelled demand pull.

Within each of the two sections, we proceed symmetrically. Indeed, both technology push and demand pull contributions are neither monolithic, nor homogenous since a second divide intersects both streams of literature. There first exists a flow of literature both coherent with mainstream economics and focused on the monetary incentive of firm to innovate. On the firms' side, this is translated into the analysis of the impact of markets and institutions upon the rewards of innovation. On the demand side, this framework looks at the pure incentive effects related to demand changes and results in the analysis of market size as the main pull mechanism.

A second approach departs from mainstream economics, sacrifices the analytical tractability of the issues, and highlights the role of the knowledge embedded in the innovation processes. The focus is thus on the learning process within firms as necessary precondition to innovation. The demand side here is conceived as a flow of information from users and consumers to producers out of which innovations become generated.

The organization of the paper will mimic the historical structure of the literature. Specifically, it shows how these approaches emerged, the critiques they confronted with and, eventually, their refinement. The last section discusses major challenges ahead in the field of economics of innovation.

2. Supply and Innovation

Why do firms engage in innovative activities and invest into R&D? How are those activities related to a firm's environment in general and to market/industry structure and dynamics in particular?

Firms will engage in innovative activities if they see an economic or technological opportunity. Analytical approaches have taken into account these two aspects quite differently. The differences first accrue to the assumptions on the behaviour of the economic actors to be able to identify or anticipate those opportunities. Secondly, there are differences in the balance by which the problem of economic chances and of technological opportunities are taken into account.

On this basis we can distinguish roughly two main camps; a first one based on neoclassical thinking assumes perfectly rational agents whose only problem to tackle is to design optimal R&D projects. In this approach technological opportunities are always there and have only to be exploited or as Dasgupta - Stiglitz (1980a, p. 272, fn. 1) put it: «It is as though Mother Nature has a patent on all techniques of production [...] and that society has to pay x to purchase the right to use the technique of production [...]».

In this sense, the intensity and direction of innovative activities entirely depend on the economic incentives offered, being mainly the profit to be gained. And these profits are in turn dependent on the competitive situation a firm faces and partly intertwined with the conditions for appropriating innovation rents and hence technological spillovers.

The other camp renders innovative agents boundedly rational in the sense that they neither have all information at hand nor are well equipped to solve each problem (Simon, 1955). In this sense, agents need to explore technological opportunities for innovative success and require respective knowledge and competences. Their availability governs the intensity and direction of innovative activities. The way how actors acquire and build up these competencies and transform them into competitiveness are at the core of the analysis. Market conditions providing the financial resources for appropriate investments are crucial; technological spillovers are considered more a device for learning than a source of profit diminishing imitation. Summing up, we can distinguish between an incentive based theory and a knowledge based one. The following paragraphs will discuss both in details.

2.1. *Innovation and economic incentives*

2.1.1. *The origins: Schumpeter and first IO analyses*

When addressing innovation activities of firms in Industrial Organization (IO), the Neo-Schumpeter-Hypotheses are an obvious point of departure. Schumpeter, in *Capitalism, Socialism and Democracy* (1942), postulated that large firms are the main driver of innovations and technological change (Schumpeter Mark II). By contrast, in Schumpeter's alternative approach, formulated earlier in *The Theory of Economic Development* (1912), entrepreneurs and therefore small firms are considered the engine of innovative change (Schumpeter Mark I). This Schumpeterian controversy led to the two Neo-Schumpeter hypotheses. The first concentrates on the firm and suggests that large firms are more innovative than small firms. The second one argues on the basis of industry or market structure claiming that innovation activities are more intense in more concentrated sectors. Finally these hypotheses have been taken up by industrial economics from the 1960s onward and were discussed first within the Structure-Conduct-Performance Approach of IO.

The seminal work by Arrow (1962) is to be considered the first approach looking at the relationship between the benefits accruing to innovative activities and the R&D costs. His analysis looks at the economic incentives of the actors to engage in R&D activities under alternative market structures. To make that analysis as simple as possible he compares a monopoly and a situation of perfect competition where innovative activities do not alter the respective market structure. Arrow showed that the differential profit in the case of perfect competition is always larger than the one in the monopoly. The reason is to be seen in a lower profit in the case of the monopoly: the profit after innovation partly replaces the profit before innovation. In case of perfect competition this replacement does not apply and the full amount of innovation rents is gained. Consequently, the economic incentives for innovative activities are higher in perfect competition than in the monopoly situation so that one should expect more intense innovation in the former case. Hence, within this IO framework Arrow challenged the Schumpeter hypotheses.

Besides the criticism of Demsetz (1969) who identifies the non-comparability of the situations of monopoly and perfect competition in the Arrow approach, other criticism refers to the purely static character of the analysis as well as to the neglect (*i*) of the interdependence of market structure and innovative activities (Reinganum, 1989; Gilbert - Newberry, 1982), (*ii*) of oligopolistic competition (by focusing only on monopoly and perfect competition) (Dagupta - Stiglitz, 1980a), and (*iii*) of technological interdependencies among innovators and (potential) imitators (Levin - Reiss, 1984).

2.1.2. *The economics of R&D and New Industrial Economics*

The latter three issues have been taken up by the approach of New Industrial Economics by addressing the issues of the incentive to innovate, the bidirectional influence of the market structure and the role of technological spillovers. The analyses are mainly of a game-theoretic type where strategic choices of profit maximizing firms refer not only to quantity or to price but also to R&D expenditures. Integrating this issue into an equilibrium oriented modelling approach allows for welfare analysis by investigating the private and the social gains from innovative activities.

The models developed can be distinguished by the way (*i*) R&D expenditures affect innovation and (*ii*) market competition and market structure are taken into account. Regarding the effect of R&D expenditures, three alternative lines of research have been taken: in a first one the level of R&D is positively related to the economic reward (e.g. Dasgupta - Stiglitz, 1980a; Levin - Reiss, 1984); a second approach relates the level of R&D to the likelihood of becoming successful (e.g. Sah - Stiglitz, 1987); and a third line suggests a negative relation between the level of R&D and the time to introduce a new product or new process (e.g. Dasgupta - Stiglitz, 1980b; Kamien - Schwartz, 1980). As modelling devices, non-tournament models assume either a non-monopolistic or endogenous market structure whereas in tournament models (as well as in contest models) innovation competition allows only for one winner and thus leads always to a monopoly.

Contest models: A core issue in understanding innovation incentives is the relationship between the appropriability of innovation rents and the rate of technical progress. That is addressed in so-called contest models. Here firms announce R&D expenditures allowing them to create an innovation which then is protected by a patent and allows earning economic rents. These models show that an announcement is the lower, the lower is the degree of patent protection; hence the incentive to engage in R&D is reduced (Witt, 1987). That type of modelling can be criticized along two lines: first, as they are deterministic (e.g. Barzel, 1968; Scherer, 1967; Dasgupta - Stiglitz, 1980b; Gilbert - Newberry, 1982; Katz - Shapiro, 1985) they can be interpreted as auction models, where competing firms make offers and only the winner of the auction will then manage R&D activities (e.g. Dasgupta - Stiglitz, 1980b). It is quite obvious that this pattern is not a race; the competitive aspect here refers to a potential competition – which might be quite tough (Reinganum, 1989, p. 855). Secondly, the appropriability conditions for innovation rents depend not only on the public good character of know-how but also on the market structure after innovation. These two aspects have been taken up by two lines of modelling, non-tournament models and patent races.

Non-Tournament models: Dasgupta - Stiglitz criticised Arrow (1962) and suggested a model in which R&D competition and innovation are modelled as a non-tournament (Dasgupta - Stiglitz, 1980a). Many competing firms, producing a homogenous output, spend R&D in order to generate technologically equivalent and perfectly protected improvements of their respective production technologies leading to lower unit costs. The incentive to spend R&D activities does not depend on possible imitative activities of competitors but only on the market structure and the features of the applied technology. Consequently, given a technology, innovation revenues are determined by the economic interdependence of the firms. Within a competitive surrounding allowing for market entry innovation revenue will be zero in market equilibrium.

Provided these assumptions a number of relationships between market size and R&D decisions can be deduced. Generally valid results cannot be found in this model but only solutions dependent on certain parameters of demand and unit cost elasticities. In most cases, however, the rate of progress is larger in markets with a higher degree of monopoly. Schumpeter's argument of a positive relationship between market power and innovation rate seems to be here validated.

Technological spillovers are discussed in Levin - Reis (1984), Spence (1984) and d'Aspremont - Jacquemin (1988) who enhance the Dasgupta - Stiglitz framework. Levin - Reiss (1984) and Spence (1984) show that spillover effects generally lead to a reduction of individual R&D expenditures and therefore have a negative incentive effect on R&D, with the exception of complementary R&D projects. Despite the incentive reducing effect, spillovers reduce inefficiencies due to R&D duplication and enhance welfare. D'Aspremont - Jacquemin (1988) show this to take place when the intensity of spillover effects is high.

Tournament models or patent races: Non-tournament models attempt to explain how R&D levels and rates of technological progress are influenced by market forces. However, these models do not discuss any strategic behaviours, implemented by actors to defend their technologically or economic leading positions. In addition, patterns such as creative destruction (Reinganum, 1985) and success-breeds-success (Dasgupta, 1986) are not taken into account. On the contrary, tournament or patent race models do that.

In these models technological competition is interpreted as a race for a certain patent. The firm first to introduce an innovation enjoys patent protection and the resulting temporary monopoly. Investing in R&D activities is meant to increase the probability to be successful earlier than competitors. For the losers the R&D expenditures spent are lost. The level of investments depends on two effects which impinge upon the expected rewards: the profit motive and the competitive threat. The former consists of the difference between the profit before and after successful innovation. The latter ensues by comparing the profit in case of a successful innovation and the profit in case the competitor wins. Both differences should be positive for an innovative engagement to be considered worth to be pursued.

The interplay of these two effects generates asymmetric incentive structures for the incumbent monopolist and other firms willing to enter the market. Reinganum (1985) shows that, in the case of a drastic innovation, the incumbent and the potential entrant face the same competitive threat whereas the incumbent's profit motive is much smaller (as the current monopoly profit is competed). Hence, the follower has a higher incentive to engage in R&D which increases its success probability and the monopoly position consequently is more likely to change from the incumbent to the entrant, the case of creative destruction. In case of a non-drastic innovation, however, the incumbent is investing more in R&D because it has a higher competitive threat. Thus, she will have a higher probability of success and of keeping her monopoly position. Taking into account technological spillovers between the firms does reinforce the tendency for creative destruction and weaken the continuation of monopoly position.

Extending the analysis and allowing for success-breeds-success pattern – as opposed to leapfrogging pattern – requires a dynamic model with a sequence of several patent races as in Reinganum (1985). For drastic innovations the respective patent races in the sequence are independent from each other so that the sequential character of the model is not essential and static solutions apply. For non-drastic innovations, however, this independency does not hold any more and to win a certain patent race now is not only worthwhile for profit reasons but also for gaining strategic advantages for future races.

Drawing on stochastic models only in a few cases they are analytically solvable and simulation techniques as in Beath *et al.* (1988) have to be applied. In setups where spillover effects among firms are restrained backward firms are not able to compete for the same stage within the innovation sequence as the leading firms. However, they approach step by step the position of the leading firms. These models are of the catch-up type. Beath *et al.* (1988) combine the R&D decision with Bertrand and Cournot behaviour on the market. Their simulation analyses show that Bertrand behaviour tends to reinforce dominance and thus the catch-up type. Contrariwise, Cournot behaviour rather sustains leap-frogging.

2.2. *Innovation and the generation of new knowledge*

2.2.1. *Empirics first: the Neo-Schumpeter Hypotheses revisited and other regularities*

We now leave the realm of the incentives based theory to move towards a more empirically-grounded and knowledge-based approach to industrial dynamics. IO research addresses the Neo-Schumpeter Hypotheses mainly from a theoretical point of view. Accompanying empirical work on the validation of these hypotheses provides rather weak evidence for the hypothesis that large size or concentrated markets lead to higher innovative activities. Instead, other industry or technology specific factors show larger explanatory power. The inclusion of other variables such as technological opportunity and conditions of appropriability leads to a drastic reduction of the significance of the coefficients for concentration. Especially in the context of the Neo-Schumpeterian hypotheses, the variance of R&D intensity is barely explained by the concentration variable whereas the firm and the industry (fixed-effects) variables explains 32% and 16% of total variability (Scott, 1984). In other studies, 4% of variance is explained by concentration, whereas more than 50% is explained by variables representing demand, opportunities and appropriability (Levin et al., 1985). Consequently, technological characteristics, demand side characteristics (e.g. product diversification), as well as aspects of strategic interaction (e.g. intensity of price competition) show higher validity than the factors central to the hypotheses tested. In addition, a causality problem is involved in interpreting these empirical findings, as it is not clear whether innovative activities determine structural variables or the other way round. As a consequence, the application of a dynamic view on industrial innovative activities promises to have a closer look at the changing and complex causality relationships.

Moreover, other empirical works highlight facts (often already labelled as stylized facts) related to the dynamics of entry and exit (Geroski, 1995; Audretsch, 1995; Doms et al., 1995; Malerba - Orsenigo, 1997; Klepper - Simons, 2005; Cantner et. al., 2009a and 2009b), to market turbulences, to the persistency in firm performance differences (Mueller, 1977; Auerswald, 2010; Caves - Barton, 1990; Cantner - Krüger, 2004), to size distribution of firms, to patterns of firms' growth (Simon, 1955; Ijiri - Simon, 1977; Bottazzi - Secchi, 2006; Cefis et al., 2007), and to a long term perspective just as in the industry life cycle discussion.

These various dimensions of the dynamics of industries lead us to conclude that structural characteristics used traditionally, such as firm size and age, the intensity of competition (market concentration) and barriers to entry (scale economies etc.), are able to explain the dynamics of firms and of industries only partially. As these rather incentive based factors seem not able to fully account for industry dynamics, an alternative line of research has emerged – the knowledge based approach –, focusing on the knowledge and capabilities of actors and firms as well as on the search and learning processes involved in building them up. Within that, an approach directly addressing four characteristics of technology and technological change, opportunities, appropriability conditions, cumulativeness of change, and the specific nature of knowledge is known with the acronym OACK.

OACK serves as a basis for investigating industrial dynamics and industrial evolution by looking at innovative activities and market structure as complex and mutually dependent phenomena. OACK claims that the ways agents bring about new ideas and economize are considerably different (or heterogeneous); the degree of those differences depends on the four OACK features of technology. It further claims that these various ways compete among one another in markets where the degree of competition depends on the degree of heterogeneity of innovative activities and successes. The heterogeneity across firms in innovation implies both the presence of idiosyncratic capabilities (absorptive, technological, etc.) and that firms not only do different things but, and most importantly, when they do the same thing, they know how to do it in different ways. This focus on the underlying capabilities for innovation activities requires behavioural foundations and their embeddedness in the technological environment prevailing in an industry. In the following we discuss how the OACK approach has been useful to classify innovative activities.

2.2.2. *Innovative patterns and their classification in the OACK approach*

Understanding innovative activities requires opening up the black box (Rosenberg, 1982) of how actors acquire and apply the knowledge used for creating new combinations. A first step is to briefly address a rather general pattern of the innovation process in modern manufacturing as suggested by Dosi (1988):

(*i*) Endogeneity of innovative activities
(*ii*) Uncertainty
(*iii*) Partial dependence on and contacts to science
(*iv*) Learning-by-doing, learning-by-using, learning-by-innovating, learning-by-inventing
(*v*) Cumulativeness

Features (*i*) and (*ii*) point to the fact that economic actors (primarily firms) are engaged in innovation and by that they are confronted with strong and therefore non-calculable uncertainty (Knight, 1921; Arrow, 1991). This implies that designing R&D projects in an optimal way is impossible and the search for new ideas is a trial-and-error process. Hence, an understanding of the economic agent different to the homo oeconomicus is required. Drawing back on Simon (1955) the concept of bounded rationality is applied, that questions the assumption of ubiquitous information (substantial rationality) available to agents, as well as the assumption of unbounded capabilities (procedural rationality) to use this information. The resulting notion of bounded rationality seems to be especially relevant for actors being engaged in innovative (and also imitative) activities. The act of creating something new, as an experimental activity, is necessarily linked to imperfect information and imperfect abilities to use it.

The notion of bounded rationality entered the theory of the firm with Cyert - March (1963) as stable behavioural traits. Nelson - Winter (1982) developed it to the concept of routines, a form of adaptive control with a more flexible behaviour. Routines are behavioural devices which show certain stability over time as they are based on often idiosyncratic knowledge and competences. They will be changed, however, if their reward does not meet an aspirated level. A further strategic dimension of routines has been developed within the dynamic capability view of the firm (DCV) as introduced by Teece et al. (1997) drawing on the resource based view of the firm (e.g. Penrose, 1957; Wernerfeld, 1984). A firm's more or less unique knowledge and competencies are just seen as a major resource (characterized as being valuable, rare, imperfectly tradable, and non-substitutable) contributing to her competitiveness. Since these resources are not given but rather developed and implemented over time, they have been labelled dynamic capabilities, in order to stress their role in long term strategic planning. Other firms have to incur non-negligible costs (also to build up respective absorptive capacities (Cohen - Levinthal, 1989)), if able at all, in order to copy or to imitate knowledge and competences these capabilities represent.

Features (*iii*) to (*v*) fit into the dimension of the OACK approach by indicating how innovative actors act in this trial-and-error process. They gather information and they accumulate knowledge by learning in order to build up dynamic capabilities. The latter in turn enables them to both explore new opportunities and to exploit existing ones (Rosenberg - Nelson, 1994; Zucker *et al.*, 1998; Mowery et al., 2004). To the degree learning relates to the accumulation of own experience, actors are heterogeneous in terms of their technological (as well as economic) knowledge. As an important consequence of this heterogeneity, the traditional conception of knowledge as a quasi-public good (Arrow, 1962) has to be reconsidered. Knowledge seems to have a tacit component (Polanyi, 1967) and, therefore, is not transferable at all (Cowan *et al.*, 2000) or only at a certain price as a latent public good (Nelson, 1991). These features increase the appropriability of knowledge and reduce the importance of patent protection, otherwise prominent in traditional approaches. Because of this stickiness of knowledge the social dimension of learning assumes a central role and it becomes crucial the way to extract knowledge from other sources such as science or competitors.

Based on the elements of the OACK approach and combining them with the general pattern of innovation in manufacturing, several classifications have been suggested in order to broadly classify emerging patterns. Two of them, by Pavitt (1984) and by Malerba - Orsenigo (1995; 1997), received considerable attention.

The Pavitt classification distinguishes sectors by their specific organization of innovation activities and the specific features of technological change. In the end, four different classes are identified: science based industries; supplier dominated industries; production oriented industries with specialized suppliers and scale intensive sectors. This classification accounts for a first nice relationship between the way firms organize their activities to create/use new know-how and the structural dimensions of the sector they work in.

The classification by Malerba - Orsenigo is oriented towards the pattern of innovation activities and combines them with the pattern of learning in firms. This exercise led to two classes of sectors, so-called regimes. A first class contains sectors belonging to an entrepreneurial regime with a larger number of predominantly small firms, low market concentration and market turbulence, easy market entry and exit, and low stability in the ranking of innovators (Schumpeter Mark I). These features are related to high technological opportunities, weak conditions of appropriability and a low degree of cumulativeness of technological knowledge. Consequently, market competition is intense and always fed by new ideas from within and from outside (entering firms) the market.

The sectors of the second class belong to a routinized regime. Large firms are more frequent, which operate in more concentrated markets with low turbulence in market shares, a high stability in the ranking of innovators and a low rate of market entry. The appropriability conditions for new knowledge are considerably high and knowledge is highly cumulative. Hence, here we may observe a considerably low intensity of competition among firms which pursue innovation activities in a rather routinized way, continuously building up competitive advantage in a success-breeds-success manner.

This difference in the organization of innovative activities across industries may be related to a fundamental distinction between Schumpeter Mark I and Schumpeter Mark II models. Schumpeter Mark I is characterized by creative destruction (with technological ease of entry and a major role played by entrepreneurs and new firms in innovative activities). By contrast, Schumpeter Mark II is characterized by creative accumulation (with the prevalence of large established firms and the presence of relevant barriers to the entry for new innovators).

In a dynamic fashion, technological regimes and Schumpeterian patterns of innovation change over time. According to an industry life cycle view, the Schumpeter Mark I pattern of innovative activities may turn into a Schumpeter Mark II pattern (Klepper, 1996), but in the presence of a major technological discontinuity, a Schumpeter Mark II pattern may be replaced by a Schumpeter Mark I. These transitions quite naturally lead us to an understanding of the dynamics and the evolution of industries. If we consider herein the role of both technology and knowledge, the dynamic features of system also need a revision, an issue to which we turn next.

2.3. *Industrial dynamics*

Industry dynamics refers to an approach which looks at the change of industries over time (Malerba - Orsenigo, 1996) where innovative activities are a major driver of the dynamics.

2.3.1. *Basic dynamic mechanisms and patterns*

Combining the elements of the OACK approach with the behavioural foundations of innovative activities suggests that «different agents (firms) know how to do different things in different ways (domains, levels of performance, etc.)» (Malerba - Orsenigo, 2000, p. 295). Consequently, the heterogeneity of firms in a sector or market can be related to differences in knowledge and competences built up over time. Those differences contribute to differential competitiveness and consequently to differential success.

In this sense, the knowledge and competence specificities of firms are the major determinant of the industrial structure and its evolution over time. Two kinds of mechanisms driving that dynamics of industries have been here identified: (*i*) mechanisms leading to the advance of knowledge and the generation of innovations and (*ii*) mainly market based mechanism of selecting between different new combinations. We discuss these two mechanisms in turn look at their interdependencies in the next section.

First, the cumulativeness of knowledge due to a firm specific process of learning leads to a specific, path-dependent development of a firm's competencies: this specificity generates differences in firms' performances and path dependency makes it difficult for followers to catch up to the leaders. Such kind of dynamics, labelled success-breeds-success, has been described by Almarin Philips in the 1960s for the airplane industry (Philips, 1971). Success-breeds-success can be mitigated when agents can learn from others or imitate them. This implies that a backward firm may be able to catch-up to the knowledge or innovation leader (Verspagen, 1992; Cantwell, 1993). A complete catching-up or even an overtaking may be constrained either by imperfect transferability of knowledge due to tacitness (Polany, 1967) or by lacking absorptive capacities (Cohen - Levinthal, 1989) by the lagging firm.

Second, firm heterogeneity caused by differential innovative success requires an understanding of market competition different from the allocative conception in neoclassical economics. Markets in this context are seen as a platform upon which competition among heterogeneous agents or better heterogeneous products takes place. With respect to innovation activities, different ideas and the different knowledge stocks and competencies behind them are in competition (Metcalfe, 1994; Nelson - Winter, 1982).

In this context, markets serve a twofold purpose. First, they are a selective mechanism and they work efficiently if, step by step, worse performing ideas are selected out and better ideas are able to survive. The second aspect refers to Hayek's notion of competition as a discovery process (von Hayek, 1968), which allows firms to learn more about the viability of their new ideas. This leads to a more complete picture as the success of the market or failure of a firm provides information about the comparative evaluation of the product or new idea. This information can be used to adjust and design further innovation activities. In this sense, the search and learning mechanism from above is nicely combined with the mechanism of selective competition.

2.3.2. *The concert of mechanisms*

In the view of the empirical findings presented above and the literature on the behavioural foundations of innovative agents, there have been various attempts to analyze formally these phenomena. We briefly mention those that look at dynamics and at innovation. A first group of models attempts to reconcile the empirical regularities with the equilibrium approaches of industrial organization (e.g. Jovanovich, 1982; Ericson - Pakes, 1995; Sutton, 1998) thereby leaving out heterogeneity of actors or learning processes.

A second group of models deviates from equilibrium analysis and takes a more evolutionary or Neo-Schumpeterian perspective. The modeling exercises have analytical solutions only when the set-up is rather simple. However, more complicated relationships and the representation of heterogeneous agents with idiosyncratic paths of development often require simulation techniques to identify characteristic patterns of development. This group contains models in the evolutionary tradition of Nelson and Winter (Nelson - Winter, 1982; Dosi et al., 1995), industry life cycle models (Klepper, 1996, 2002; Klepper - Simons, 2000), history friendly models (Malerba et al., 1999; Malerba - Orsenigo, 2002), and more macro level models, by linking innovation and industry evolution to structural change and changing sectoral composition of the economy (Metcalfe, 1998; Foster - Potts, 2004; Dosi, 2001; Saviotti, 1996).

Innovation-Market feedbacks. In general these models are based on the feedback effects between market competition and innovation activities (e.g. Mazzuccato - Semmler, 1998; Cantner, 2009; Klepper, 1996, 2000). In view of medium term dynamics, depending on the relationship between market success and innovative activities, one can distinguish a reinforcing interaction leading to success-breeds-success dynamics and monopolistic pattern, on the one hand, and retarding relationships allowing for turbulence in market shares and a continuous leapfrogging in technological leadership on the other. These results quite nicely resemble empirical regularities such as persistent technological or economic performance differences in the former case and market turbulences with high entry and exit rates in the latter case. Technological spillovers affect such pattern by smoothening turbulences and slowing down the tendency towards monopolization whereas strong conditions of appropriability reinforce those dynamics.

Industry Life Cycle Features. Recent work on the ILC shows how, for specific markets or sectors, quite narrowly defined (e.g. automobiles, tires, laser, TV, penicillin), the mechanisms present in the previous sections interact and shape the pattern of industrial dynamics over a longer period of time. The life cycle starts with an entrepreneurial phase. The high intensity of competition over time may lead to the establishment of a technological standard or dominant design. This process is often accompanied by a sharp shakeout of firms which do not successfully help to establish that standard or fail to adapt to it. Moreover, this standard serves as a major barrier to further entry. The industry under consideration then develops into a phase of a routinized regime with less intense competition and stability of market shares.

This development is accompanied and driven by a change in the major orientation of innovation activities. The process of standardization usually exhausts this phase of product competition and innovation activities become more process oriented. The long-run pattern of the ILC suggests a succession of industrial structures. Among the main driving forces behind this development are the knowledge and competences of firms in that sector. Klepper - Simmons (2000; 2005) as well as Cantner et al. (2007; 2009a; 2009b) look at the importance of various knowledge components for ILC development. They distinguish between knowledge acquired by firms before they entered an industry, while being active in that industry, and knowledge related to innovative activities. In addition, and related to knowledge accumulation in the industry, the time of entry is considered. Pre-entry experience, early entrance (and thus high post-entry experience) and degree of innovativeness turned out to be the most important factors for firms' survival. Looking at the relative importance of those knowledge categories for survival it turns out that the disadvantage of lower accumulated knowledge because of a late date of entry can be compensated by innovation knowledge.

The systemic view. Another dimension of firm heterogeneity based differences in knowledge and competencies is the deliberate exchange of technological know-how (Allen, 1983). Especially in the case of complex technologies, which are based on a larger number of knowledge components and competencies, the exchange of know-how and the cooperation of firms in developing innovations are necessary and important. This cooperative element of innovative activities is at the core of so-called sectoral systems of innovation (Malerba, 2004) such as the automobile sector or the pharmaceutical industry. Large and small firms cooperate and a specific division of labour is agreed upon. This obviously shapes the structure of an industry, often with large core firms and small satellite firms.

3. Demand and industrial dynamics

In the previous section, we discussed the evolution of technology and markets from a firm's perspective. The ability of firms to strategically respond to external stimuli as well as their attempt to change the competitive environment is the pivotal force shaping the dynamics of industries and economies. In this section we deal with the complementary role of users and consumers both in designing markets and in pulling innovations.

The role of demand in innovation processes has been explicitly discussed already by Adam Smith: the extent of a market limits the division of labour, which in Adam Smith's view has been considered the main trigger of increasing returns leading to new products and process innovations. Indeed

> [...] this great increase of the quantity of work which, in consequence of the division of labour, the same number of people are capable of performing, is owing to three different circumstances; [...] and lastly, to the invention of a great number of machines which facilitate and abridge labour, and enable one man to do the work of many (Smith, 1776, ch. 1, p. 7).

However, the division of labour is limited by the extent of the market because

> [...] when the market is very small, no person can have any encouragement to dedicate himself entirely to one employment, for want of the power to exchange all that surplus part of the produce of his own labour, which is over and above his own consumption, for such parts of the produce of other men's labour as he has occasion for (ibid., ch. 3 p.1)

The role of the increasing returns in the economic process has been analyzed (Young, 1928), although mainly in heterodox approaches to economics of innovation (Dosi, 1988). By contrast, the explicit tie connecting market size and innovation made by Adam Smith has been rarely further discussed. A notable exception is the work by the sociologist of invention Gilfillan (1935a; 1935b), who not only revisited the idea of Adam Smith, but also suggested an additional role played by the demand side in the innovation process.

On the one side, he surmised that the pace of technology should be faster in those sectors where the number of potential adopters, and thus firms' incentives to innovate, are higher. Secondly, based on a vast qualitative analysis on the shipping industry, he suggested that demand not only provides incentives, but also draws attention to new needs to be addressed by the supply side. In his words, «there exists a technological lag, a chronic tendency of technology to lag behind demand» (ibid., p. 1) and, thus, only users and consumers can reveal firms the route to go to satisfy their needs.

These two mechanisms linking demand and innovation, that is demand as incentive and demand as source of information, can be tracked down in the literature along two distinct but similar paths: at first, they have been flourishing both in the academia and among policy makers, but they eventually run into diminishing returns when facing incontestable empirical rejections and theoretical critics. In the first stage, these solid critiques they are confronted with jeopardised the idea of demand as a determinant of innovation, but they ultimately forced to a sound refinement of the theory. The next paragraphs follow these two streams of literature. Note that the incentive mechanism is consistent with a mainstream approach considering also technological choice as driven by market incentives. On the contrary, the information mechanism strongly departs from neoclassic economics, which, by considering information as a quasi-public good reproducible at zero marginal cost, does not regard information flows as a relevant problem.

3.1. *Demand as incentive device*

Schmookler (1962; 1966) empirically tests the demand pull hypothesis, i.e. technological change is pulled by the existence or emergence of new markets because human needs precede technological solutions. He looked at the innovation activity in the railway industry, captured by the numbers of patents, and compared it with the evolution over time of different economic indicators such as stock prices and gross capital formation. He showed that peaks in innovative activities lagged behind those capturing the economic performance. Building upon the assumption that the economic performance proxies demand as total expenditure he deduced that «the influence [upon innovation] of the latter [unfolding economic needs] has been substantial» (Schmookler, 1962, p. 20).

Contemporaneously, Arrow revealed the mechanism underneath this incentive effect (Arrow, 1962). In the attempt of illustrating the impact of market structure on the propensity to innovate, which we have shown in the previous section, he analytically stated that incentives to innovate are equal to the increase in the mark-up per unit produced by an innovation times the units sold in the market. The simplicity and the analytical tractability of this proposition makes the use of this concept widespread not only in the economic analysis of innovation and technological change (among other Kennedy, 1964; Drandakis - Phelps, 1965; Samuelson, 1965; Hayami - Ruttan, 1970; Acemoglu - Linn, 2005), but also in new growth theories (Aghion - Howitt, 1992; Grossman - Helpman, 1991; Romer, 1986; Romer, 1990).

Arrow and Schmookler's approaches, despite the clarity of the reasoning and their results, run into diminishing returns when confronted with undeniable empirical rejections. Scherer (1982) reruns Schmookler analysis on a larger dataset and rejected the demand pull hypothesis when he used data for the manufacturing sector as a whole. On the contrary, when including in the analysis only capital goods industries, Schmookler results appear to be valid. Schmookler hypothesis seems to work only in industries with large firms, facing a stable homogenous demand, and mainly engaged in incremental product innovations or process innovation.

In sum, the demand pull hypothesis has an explicatory power of innovation, but the range of its applicability has been reduced. Specifically, the main result is that the concept can not be applied without explicitly reference to the structure of the industry and the joint evolution of the technology side.

Schmookler's approach also fails in understanding the dynamic nature of the phenomenon. In Adam Smith's view, the size of the market not only enables innovation, but endogenously generates a further stage where innovation itself expands demand: for instance, that might occur by allowing lower price or by introducing new products. A further critic in this direction has been made by Kleinknecht - Verspagen (1990), which clearly address the problem of endogeneity in technological change: first they correct the spurious relationship of innovation and the level of investment by controlling for potential latent variables such as the size of sector. Secondly, they test for reverse causality and find evidence of a co-evolution of demand and technology. With a rich dataset at the firm level, also Crespi - Pianta (2007) find evidence of an impact of demand, also when carefully controlling for possible source of endogeneity. Similarly, Mazzanti - Zoboli (2005) do not reject the presence of a demand pull effect in environmental innovation.

Similarly to Schmookler's, Arrow's approach underwent heavy empirical falsification of the mechanism he described. The main result of new growth theory is the prediction of growth with scale effects: if Arrow's incentive mechanism acts as a multiplier, an increase in the market size creates larger incentives and, thus, permanently stimulates growth. Jones (1995a) empirically rejects the hypothesis of growth with scale effect on a sample of OECD countries. In sum, not only the early Schmookler analysis suffers from severe statistical flaws, which when corrected, lead to a reduced magnitude of the demand pull effect, but also the theoretical paradigm underneath fails to be proven robust to empirical falsification.

Young (1998) suggests a possible refinement of the concept, which can explain the lack of scale effect without dismissing the role of demand. He retrieves the «principle of equivalent solutions» (Gilfillan, 1935), which states that different innovations fulfilling the same need might coexist: if an economy is large enough and consumers exhibit heterogeneous preferences, firms can find it profitable to investigate alternative solutions to the same technological problem. On the one hand, this dynamic increases variety provided on the market and, thus, might result in higher welfare for users and consumers. On the other hand, it divides the available amount of resources in different streams of R&D (one for each equivalent solution), reduces the speed of technological improvement and, as effect, hinders growth. Young (1998) develops a growth model where rents provided by an increase in the size of the market can be dissipated by developing more than one solution, with the purpose of satisfying an heterogeneous market.

Similarly, Acemoglu - Linn (2005) formalize the same idea and test it empirically in the pharmaceutical market. Foellmi - Zweimueller (2005) focus on consumers' heterogeneity in terms of income: the more skewed the income distribution, the less homogeneous is final demand, and the weaker are the incentives to invention. Ultimately, a large market increases the overall incentive for innovation, but consumers' heterogeneity can simultaneously trigger an increase in the variety of alternative solutions and hinder growth. Any empirical study focusing on the relationship between market size and innovation should necessarily take into account the mutual crowding out effect of various equivalent solutions.

3.2. *Demand as source of knowledge*

As Gillfillan suggested, demand can be interpreted not only as the size of the market providing incentives to invention, but also as a useful source of information to direct research towards the actual needs of potential buyers. The underling hypothesis behind the mechanism is that needs are anticipated in the market, not created by technology. Once again, together with incentives also knowledge is considered as a driving mechanism of the innovative process. His approach has been widely analyzed since the 1960s.

Myer - Marquis (1969) discuss the results of a survey investigating the economic and technological background of 567 innovations in five different industries. They conclude that in about 75% of the innovations demand factors were prominent and they set an empirical milestone in innovation studies. Indeed, an upsurge of empirical evidence followed their studies: Isenson (1969), Rothwell *et al.* (1974), Freeman (1968), Berger (1975), Boyden (1976), Lionetta (1977), and Gilpin (1975) examine the role of demand in anticipating technology and always reckoned the tendency of technology to lag behind human needs: «What is important is what consumers or producers need or want rather than the availability of technological options» (Gilpin, 1975, p. 65).

This paradigm was accepted until the end of the 1970s, when two disruptive articles by Mowery - Rosenberg (1979) and Dosi (1982) tackled its underlying assumptions. They explain that the theoretical flaw of those studies was the incapability of distinguishing between demand from the «limitless set of human needs» (Dosi, 1982, p.150). For this reason, demand-led studies could simply capture that successfully realized innovations obviously meet some needs but they could not explain the «why of certain technological developments instead of others and of a certain timing instead of other» (ibid.).

This critique is substantial because it hits those studies at their core assumption. Since then, innovation studies have been mostly focusing on the technology side (Freeman, 1994). However, as this paragraph shows, the few scholars still engaged in this research agenda managed to overcome this critique by refining the conceptualization of the demand side.

Those authors tried to leave a vague idea of demand by focussing on consumers with very well defined needs. Teubal (1979) for instance suggests that the influence of demand upon innovation depends on «need determinateness, the extent to which preferences are specified (or need satisfaction is expressed) in terms of product classes, functions and features» (Teubal, 1979, cited in Clark, 1985, p. 244).

Von Hippel (1976) introduced the concept of lead users, that is those users familiar with problems and conditions which the rest of the market will face in the future. An innovator can gain useful insights about users' needs only from those kind of users. The stream of literature linked with lead user has been flourishing in managerial literature (Foxall, 1987; von Hippel - Finkelstein, 1979; Parkinson, 1982; Shaw, 1985; Spital, 1978; Voss, 1985; Urban - von Hippel, 1988; Herstatt - von Hippel, 1991; Knodler, 1993; Morrison *et al.*, 2000; Franke - Shah, 2001)

Malerba *et al.* (2003) develop a model where a group of users exhibits selective preferences for an innovation because they have diverse needs from the rest of the market. Those experimental users allow the creation of a niche market which acts as an incubator for the new technology. In diffusion studies a similar idea has been put forward. A new product or process can be introduced in the market only if there exists a minimal threshold of pioneers, that is users with explicit and stringent needs to be fulfilled (Rogers, 1995).

Also Windrum and Frenken (Windrum - Frenken, 2003; Windrum, 2005) highlight that users with diverse preferences can drive innovation cycles in mature industries. Specifically, they show that in some industries, such as camera and computer industries, the presence of market niches can pull innovation with the purpose of satisfying peculiar market niches. On the same line, Christensen (1997) and Adner - Levinthal (2002) suggest that a disruptive technology can emerge when markets realize that a product can be used in a different way by users with peculiar needs. They conceive a product as a bundle of characteristics and suggest that, if some characteristics are improved instead of others, the final destination of a good can be altered.

All of these studies share the view that not all users and consumers can provide firms with useful information but only sophisticated consumers, that is consumers able to specify their needs with a high accuracy (Guerzoni, 2007; 2010). In other words, what really matters in the information flow from market to firms is not the limitless set of human desires, but a small sub-sample of demand consisting of users with well defined needs.

Summing up, the literature about demand and innovation can be divided in two streams. On the one hand, demand can be conceived as the market size and acts as an incentive upon firms in order to pull innovation. On the other hand, demand can provide firms with useful information to direct R&D. Critics to these studies forced both streams to be refined over time: demand might well play a role as incentive, but it should be controlled for its heterogeneity. The role of demand as source of information is also undeniable, but only those consumers well aware of their preferences are able to serve this purpose.

4. Duality as a research heuristic and its limitation

In the early age of economics, innovation has been considered as an endogenous factor of growth and development and, therefore, widely analyzed. Overtime the role of innovation was almost dismissed from the realm of economic studies.

This paper tracks down the efforts of scholars of economics of innovation to keep the co-evolution of technology and markets as the key units of analysis to explain the development of industries.

This literature consists of two complementary building blocks. On the one side, the issue can be tackled by highlighting the role of firms and entrepreneurs, which actively shape the competitive environment and react to change by introducing product, process, and organizational innovations. On the other side, the focus can be set on the demand side, which not only provides incentives, but also relevant information to direct R&D efforts along the right path. This dichotomy is known in the literature as the «technology push vs. demand pull debate» (Freeman, 1994).

A second large divide emerges from the literature. On the one side a stream of literature reduces the problem of innovation as simply a matter of rewards to innovating. Incentives play clearly a role in defining opportunities and constrains, but they are only one side of the coin. The other side considers innovation the end result of a complex process of learning which simultaneously takes place both in the firms and in the consumers. Innovation itself should be conceptualized as the process of matching available technological opportunities with well defined needs.

As depicted in Figure 1, the literature can be thus summarized in four simplified patterns driving innovation and industrial dynamic. This research heuristic of focussing and emphasizing a particular aspect of the phenomenon consists of building ideal types. In the word of Weber

> An ideal type is formed by the one-sided accentuation of one or more points of view and by the synthesis of a great many diffuse, discrete, more or less present and occasionally absent concrete individual phenomena, which are arranged according to those onesidedly emphasized viewpoints into a unified analytical construct (Weber, 1997, p. 90).

Weber stressed the heuristic nature of this process and clearly highlighted that an ideal type does not claim any empirical validity. However, the risk of both bridling the theory in the heuristic and overlooking connection is always present (Freyer, 1930).

For this reason, in our paper we keep this separation for illustrative purpose only: indeed once we acknowledged that technology and market coevolve, any clear-cut distinction is not possible as well as any supremacy of one effect upon the other. Further challenges for the issue rely precisely in improving the understanding of this process by looking at the interaction of the

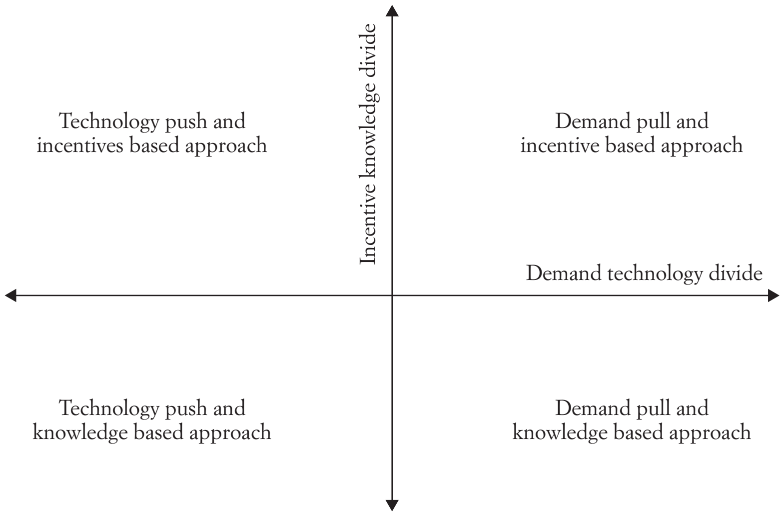

FIG. 1. The intersection of the two divides.

two divides. First, both users' and firms' impact upon innovation should be simultaneously taken into account because of the relevant feedbacks among different actors in the system. Recent studies are showing a path to go by taking into account the complexity of the approach. For instance Frenken *et al.* (1999), Castaldi et al. (2006) make use of the product characteristics approach to show possible trade-offs emerging between consumers needs and technical constraints. Valente (2003) captures the strategic interaction of firms and consumer in the evolution of competitive markets. Crespi - Pianta (2007) look at the dynamics of consumption and investment at the sectoral level and let demand pull and technology push effect interact together. On the other, Cantner *et al.* (2009c) couple this interaction by applying the evolutionary concept of the replicator dynamics and Cantner - Plotnikova (2009) address the relationship between product diversification, market niches and core technological competencies of firms in the pharmaceutical and biotech sector.

Secondly and for analogous reasons, the big divide between incentive-based and knowledge-based approaches has to be fulfilled. Indeed the degree of availability of knowledge, on the one hand, heavily impinges upon the distribution of expected profit. On the other hand, this is partly endogenous determine by firms incentives to invest in codification, knowledge transfer and absorptive capabilities. The pioneer paper in this field is Cohen - Levinthal (1989) where it is shown that incentives to innovate depend also by the need of developing in house absorptive capabilities. Guerzoni (2010), on the other hand, analytically models the impact of both market size and users' sophistication on firms' organization of production and on the consequent pattern of innovation. Fontana - Guerzoni (2008) test that the propensity to innovate in product or process innovation precisely depends on both the size of the market and the information from consumers, which reduce uncertainty.

The challenge ahead is twofold: further improvements in this area not only require fine analytical skills in order to cope with this complexity, but also data at the micro level both about firms and consumers decision.

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Summary: Innovation Driving Industrial Dynamics. Between Incentives and Knowledge (J.E.L. codes B0, L1, L2, O3)

The aim of the paper is to critically review contributions on the role of innovation upon industrial dynamics and the evolution of sectors. Two theoretical and interpretative divides stream along the literature; on the one hand, there is the well known divide «technology push vs. demand pull». The technology push literature assumes that, being the set of possible human needs limitless, users cannot provide information for firms, which ultimately make their decision based upon technological opportunities and bottlenecks. Conversely, demand pull theories suggest that there is tendency of new technology to lag behind the revelation of human needs.

On the other hand, both technology push and demand pull contributions are not monolithic, neither homogenous since a second divide intersects both streams of literature. Indeed there exists a flow of literature both coherent with mainstream economics and focused on the monetary incentives of firms to innovate. On the technology side, this is translated into the analysis of the impact of markets and institutions upon the rewards of innovation. On the demand side, this framework results in the analysis of the market size as the main pull mechanism.

A second approach departs from mainstream economics, sacrifices the analytical tractability of the issues, and highlights the role of the knowledge embedded in the innovation processes. The focus is thus on the learning process within and between firms as necessary conditions to innovation. The demand side here is conceived as a flow of information from users and consumers to producers.

The organization of the paper will mimic the historical structure of the literature. Specifically, it shows how these approaches emerged, the critiques they are confronted with and, eventually, their refinement. Finally, the paper discusses the recent attempts to overcome both divides in order to have an increasingly coherent theory of innovation and evolution of industries.