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Working Paper

The impact of market size and users' sophistication on innovation: the patterns of demand and the technology life cycle

Jena Economic Research Papers, No. 2007,046

Provided in Cooperation with:

Max Planck Institute of Economics

Suggested Citation: Guerzoni, Marco (2007) : The impact of market size and users' sophistication on innovation: the patterns of demand and the technology life cycle, Jena Economic Research Papers, No. 2007,046, Friedrich Schiller University Jena and Max Planck Institute of Economics, Jena

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JENA ECONOMIC RESEARCH PAPERS



2007 – 046

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by

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www.jenecon.de

ISSN 1864-7057

The JENA ECONOMIC RESEARCH PAPERS is a joint publication of the Friedrich-Schiller-University and the Max Planck Institute of Economics, Jena, Germany. For editorial correspondence please contact m.pasche@wiwi.uni-jena.de.

Impressum:

Friedrich-Schiller-University Jena
Carl-Zeiß-Str. 3
D-07743 Jena
www.uni-jena.de

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The impact of market size and users' sophistication on innovation: the patterns of demand and the technology life cycle

Marco Guerzoni*

Abstract

The aim of this paper is an investigation on the role of demand in industrial dynamics. Despite the decades-long debate on demand and innovation, theory still lacks a comprehensive analytical formulation. This paper proposes a model where demand is conceived as a peculiar blend of two conditions, market size, and users' sophistication. These conditions drive firms' incentives to innovate. As main outcome, the paper proposes both a theoretical taxonomy of sectors and an original explanation of technological life cycle.

Key words: Innovation, demand, industry life cycle

JEL classification: O31, O33, L15

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1. Introduction

The aim of the paper is an investigation on the role of demand upon innovation. Despite the decades-long debate on the issue, a comprehensive analytical formulation is still lacking. This paper attempts to fill this gap by proposing a model where demand, conceived as a peculiar blend of two conditions, market size and users' sophistication, drives incentives to innovate. These two conditions have been always considered crucial to the understanding of the influence of demand upon innovation and section 2 resumes the debate and the main conclusions so far achieved by the literature.

Section 3 puts forward a framework explaining the way these two dimensions might pull innovation: the evolution of various industries suggested that there exists a tension between the manufacture of a standardized good and the introduction of specific varieties (Piore and Sabel 1984, Guerzoni 2004). Firms can combine these two tasks together only to certain extent because they require two alternative organizations of production. This section advocates the idea that market size and consumers' sophistication play an important role in determining both the optimal organization of production and, consequently, innovative behaviour at the firm level.

In section 4, the paper presents a model exploring this mechanism. It first analyses the impact of these dimensions on the innovative output. Secondly, it shows that their interplay can be used to group sectors according to the patterns of demand they are facing. Each pattern is characterised by an idiosyncratic blend of size of demand and consumers' sophistication and, as a result, by a distinctive pattern of production and innovation. Finally, this paper explores the dynamic properties of the model with a numerical simulation and discusses the relation between this work and standard literature on industry life

cycle. The conclusions suggest a few remarks about the limits of the model and new lines of research.

2. Previous literature

Concerning the influence of demand upon innovation, two streams of literature can be identified. They root in the seminal works by Schmookler (1962, 1966) and Myers and Marquis (1969). Schmookler conceived demand as the size of the market: in his view, if an improvement either in the production techniques or in the product quality ensures a higher mark-up, demand acts as a multiplier on the increased gain per unit and, therefore, grants higher profits. Being innovation an economic activity driven by market incentives, a large demand pulls innovation because it grants a high stream of expected profits. Schmookler empirically tested this hypothesis on a dataset of selected sectors and provided evidence supporting his theory. However, relatively recent studies (Scherer 1982, Kleinknecht and Verspagen 1990) highlighted that the size of the market is a good proxy for the expected demand only for large and established industries and for process and incremental product innovations because they have little impact on the market structure. In other cases, innovation might impinge upon the market structure by augmenting firms' market shares, by cannibalizing existing products, and by modifying the size of the market itself. Analytical models of patent race (for a review Reinganum 1981) and of endogenous market structure (among others Sutton 1998, Jovanovich and Rob 1987 and Klepper 1996) have deeply analysed this issue.

The analytical conceptualization of Schmookler's approach roots in the path-breaking article by Arrow (1962). Arrow's mechanism, linking the size of the market with incentives to invest, is the core assumption of various economic models ranging from models of innovation and market structure, of biased

technical change, to new growth theories (among others Dasgupta and Stiglitz 1980, Samuelson 1965, Romer 1986). Precisely new growth theories pinpointed the most interesting development for the subject matter of this paper. One of their main result has been that larger economies should grow faster for different reasons, among which the high level of incentives provided by the market size. However, Jones (1995a) empirically falsified this result. As explanation, he suggested that the reason might lie in the lack of inter-temporal spillovers and in the resulting decrease of productivity of the R&D sector, the engine of growth (Jones 1995b).

Young (1998) added a complementary argument, which focuses on the demand side. He proposed that, when an economy is large, there might be an attempt to develop different solutions for the same problem. On the one hand, such an event increases variety in the economy, but, on the other hand, it spreads R&D efforts among different projects. The outcome of this process is both a reduction of available resources for developing each single solution and an increased number of competitors in the market. At the firm level, this occurrence leads to both a reduced amount of expected profits and, thus, a lack of incentives to innovate. At the aggregate level, this might hinder growth.

This latter motivation is demand led because the survival of different solutions requires some degree of heterogeneity on the demand side. Otherwise, only the most efficient solution for the economy would survive on the market. In sum, the size of the market does impinge upon incentives to invention, but both the effect of innovation on market structure as suggested by Scherer (1982) and Kleinknecht and Verspagen (1990) and the heterogeneity on the demand side should be taken into account.

A second group of studies conceived demand as a source of information rather than as an incentive (Myers and Marquis 1969, Langrish et Al. 1972, Ienson

1969, National Science Foundation 1959, Rothwell and Freeman 1972, Freeman 1968, Berger 1975, Boyden 1976, Lionetta 1977). The main outcome of these qualitative studies has been the empirical evidence that firms perceive demand as the most important source of ideas. The drawback of this approach is the vagueness of the concept of demand they used. As explained by Mowery and Rosenberg (1979), and Dosi (1982), in order “to conclude that it is demand that drives innovation, market must clearly be distinguished from the potentially **limitless set** of human needs” (Dosi 1982 p. 150, bold added). Otherwise, the necessary outcome is the “incapability of defining the why and when of certain technological developments instead of others and of a certain timing instead of other” (ibid.).

The concept of lead user, as introduced by Von Hippel, precisely deals with this critique. Lead users are “consumers whose present strong needs will become general in a marketplace months or years in the future” (von Hippel 1986, p.792). Similarly, Teubal (1979) 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 also cited in Clark 1985 p.244). Recently, Malerba et al. (2003) and Adner and Levinthal (2001) have focused on the role of consumers with diverse preferences as a source of innovation. These studies overcame the Mowery-Rosenberg-Dosi critique because they considered demand no longer as the potentially limitless set of human needs, but rather a precise set of specific needs identified by sophisticated consumers.

Overall, the literature can be organized in two streams. One suggests that firms direct their R&D efforts towards the largest and, thus, most profitable markets; the second indicates in consumers a crucial source of ideas. Over the decades, both approaches have been refined. The size of the market matters, but it should be controlled for its heterogeneity. A heterogeneous market might call

for a variety of equivalent solutions and spreads R&D efforts and profits across different submarkets. Thus, market's size effect results to be empirically more significant for process and incremental product innovation where the market is likely to respond homogeneously. Concerning the second stream of literature, generic consumers' needs do not provide any useful information to firms. Only sophisticated consumers, i.e. those consumers who are well aware of their needs, can provide feedbacks with adequate accuracy. Empirical evidence showed that this is especially true for radical product improvements.

Guerzoni (2007) formally proved that sophistication is a necessary condition for observing a heterogeneous structure of consumers' preferences. This is relevant to the aim of this paper because it allows reducing the complexity of a conceptualization of the demand side by modelling heterogeneity as a function of sophistication. On this basis, demand is defined as both the blend of market size and consumers' sophistication.

The next section puts forward the second building block of the paper. It discusses the tension between standardization and variety, and shows how the optimal location choices in this trade-off are driven also by the relevant dimensions of demand.

3. Standardization and variety

The trade-off between standardization and variety is a crucial source of industrial dynamics (David 1994, David and Rothwell 1996, Weitzman 1992). On the one hand, many benefits derive from standardization such as a greater predictability of the outcome, faster learning economies due to simplification and routinisation, scale economies, easier production of complementary assets and components' interfaces, and network externalities. In other words, standardization, by creating order and, consequently, by reducing uncertainty,

allows an efficient systematization of the production processes. Moreover standardization does not impinge on quality as often is believed: “the alleged sacrifice of quality to quantity is a myth” (Rae 1965, p.53). In contrast, standardization leads to higher accuracy standards.

The other side of the story is that a real trade-off exists between standardization and variety: “the consumer gets lower costs but at the expense of variety” (ibid.). Variety might be desirable for many reasons: there can be a taste for variety in the consumers because, as David (1994) emphasised, “consumers may have demand for intrinsic novelty as means for combating the malaise of boredom”. Secondly, they can have a preference for variety as a way to seek distinction (Swann 2001), or variety can better fit their preferences (Lancaster 1990 for a review).

Moreover, the economy as a whole might take advantage from variety. First, Saviotti and Pyka (2003) warn against the risk of a low production of variety. He explains that, if a system produces the same amount of output with a decreasing amount of input (notably labour) due to the productive gains from standardization, it might be not sustainable in the long run: indeed the creation of variety both via new products and via new machineries is considered as a necessary condition to overcome technological unemployment. Secondly, David (1994) admonishes against the possibility of a lock-in: a standardized product can generate important network effects and, therefore, erect high entry barriers, which hinder the diffusion of new products.

Firms have to face the same trade-off as well: the production of a standardized good allows a quick exploitation of learning economies, a higher predictability, and a reduction of costs of gathering information. However, competition in markets for standardized goods is tough, price based, and characterised by small mark-ups. On the contrary, the production of variety increases the quality

perceived by consumers, their willingness to pay and firms' market power. Conversely, it requires information about consumers' requirements and *ad hoc* technologies, and increases the uncertainty of future profits.

As many studies highlighted (Piore and Sabel 1984), firms can combine mass production with the creation of specific varieties only to a certain extent. In markets, where we observe heterogeneous consumers, large producers do introduce some degree of product differentiation, but those competitors supplying a changing variety of oddments are typically niche players.

This event occurs because the strategic choice between the manufacture of a standardized good or, conversely, the generation of a specific variety has a deep impact on a firm organization of production. The production of a standardized good requires high mechanical accuracy achievable only by both the division of labour in simple steps and the consequent substitution of labour with machinery. The production of variety, on the contrary, is closer to the idea of craft production because it requires the development of new ideas that, obviously, cannot be performed by a machine. Thus, in the latter case, machineries are conceived as an extension of workers' skills, rather than a substitute, and they are introduced to augment workers' ability of producing variety (Piore and Sabel 1984, p.19).

These two modes of production involve different innovative efforts at firm level. Standardization requires innovations improving the mechanization in the process of production, for instance by increasing the exactness of coordination and the degree of interchangeability among components. On the other hand, the creation of variety requires innovation in product design, marketing, and customer care: the objective of creating a new variety is how to better satisfy consumers' preferences, the goal of standardization is cost reduction (*ibid.*).

The purpose of the paper is precisely to disclose the link between demand, as a blend of market size and consumers' sophistication, and the optimal location in the trade-off between standardization and variety. For a firm, standardization means a high break-even point and requires consumers with a low degree of sophistication because homogeneity and low taste for variety are necessary conditions to accept a "*one-fits-all*" product design. The creation of variety, on the contrary, leads to high costs in gathering information for producing the specific variety users are looking for. For this reason, it requires consumers to be sophisticated, able to specify their needs and wants, and willing to pay for their satisfaction.

In sum, the peculiar mix of market size and users' sophistication contribute to the definition of the optimal location in the standardization-variety trade-off and, thus, of the mode of production. Each mode of production leads to a peculiar pattern of innovation. The following paragraphs analytically define the two dimensions of demand and explore the outcome of their interaction.

4. The model

4.1 Foreword

The model presented below is a model with vertical innovation generated in a competitive sector in the spirit of Aghion and Howitt's model of creative destruction (Aghion and Howitt 1992). The model draws mainly from two pieces of literature. On the one side, it draws a peculiar schematization of demand from recent works in industrial dynamics. The model conceives demand as a set of different submarkets, where each submarket requires a peculiar version of the good, as it has recently been done in the literature (Klepper and Thompson 2003, Malerba et Al. 2003, and Acemoglu and Linn 2005). It departs from this tradition because it adds the dimension of

sophistication, makes the number of submarkets endogenous with respect to this dimension, and takes into account both product and process innovation.

On the other side, this model builds upon the literature on the mechanisms explaining technology choices. The main studies (Sutton 1998 and Neumann et al. 2001) use a continuum set of technologies; on the contrary, this work follows Elberfeld and Goetz's (2002) assumption according to which the choice among technologies is a binary one. In their model, a firm can adopt a technology with small fixed and high marginal costs or, conversely, an alternative technology characterized by high fixed and low marginal costs. In the model presented here, the choice is between a technology producing at a lower cost a standard version of the product purchased by all consumers and a second one producing a good dedicated to a specific submarket, but with a higher quality. Goyal and Netessine (2003) make the same assumption.

Building on this tradition, in this model there is the pioneering attempt to take into account the degree of users' sophistication. As previously shown, sophistication can be defined as the degree of consumers' awareness of their needs. This awareness has two implications: first, it is positively correlated with consumers' ability to communicate their needs to firms. For this reason, the probability of producing a successful innovation in the model is a function of consumers' sophistication. Secondly, as discussed above, sophistication impinges also on the level of heterogeneity, captured in the model by the number of submarkets. For this reason, also the number of submarkets will depend on the degree of sophistication.

4.2 The model: structure

Consider an economy constituted by consumers and firms. The demand side is characterized by a set of M consumers, each indexed with m , and a parameter

α with $\alpha \in [0,1]$. Consumers are infinitely living and time is continuous. M defines the size the market, whilst α captures the degree of consumers' sophistication. α plays two roles: first, it impinges upon the quality of information flowing from consumers to firms: the higher α is, the easier it will be for a firm to introduce of a successful product innovation.

Secondly, α captures the idea that sophistication impinges on the structure of demand as well. Consider the M individuals partitioned in N submarkets of equal size, where S_j is the generic submarket. Assume that the number of submarkets is a proxy for demand heterogeneity. As discussed before, the degree of heterogeneity depends on users' sophistication. Thus, the greater α is, the higher is the number of submarkets. At the one extreme ($\alpha = 1$), each single consumer represents a submarket; when α is equal to 0, on the contrary, there is only one submarket including all of the consumers. This is the case of homogenous demand. Thus

$$(1) \quad N = f(\alpha) \text{ with } \frac{\partial f(\alpha)}{\partial \alpha} > 0, f(1) = M, f(0) = 1$$

In each period consumers face the decision of buying a good of a standard quality, \bar{q} , or a top quality, q_j^* , good. Standard quality goods are horizontally homogenous and they match consumers' preferences in each submarket. Top quality goods, on the contrary, fit only the submarket S_j they are developed for. This hypothesis captures the empirical evidence that vertical product improvements are intrinsically associated with a fine-tuning on the preferences of a specific market segment.

In each period, consumers buy one unit of the good if it confers a positive utility U . If more than one good is available, they buy the one granting the highest utility according to the following utility function:

$$(2) \quad U_{m,t}(p_t, q_t) = dq_t - p_t \quad \text{with } d = \begin{cases} 0 & \text{if } q_t = q_j^* \text{ and } m \notin S_j \\ 1 & \text{otherwise} \end{cases}$$

where d is an indicator variable suggesting that a top quality good confers a positive utility only to those consumers who are part of the submarket the good is developed for. Since consumers decisions are not the focus of this model, assume that q is large enough to grant always a positive utility.

Concerning the supply side, firms can produce a good of a standard quality \bar{q} incurring in standard marginal costs \bar{c} . In each period, firms can engage in either product or process R&D. The former improves product quality from \bar{q} to q_j^* , the latter reduces marginal cost from \bar{c} to c^* . Each time a firm introduces a product (process) innovation, assume that the former best practice became the standard quality (production cost). Firms have constant average costs and, thus, in equilibrium the number of firms operating in the economy will be indefinite. Competition for innovation takes the form of a patent race: the first to invent receives monopolist profits until the next innovation is introduced (Reinganum 1985).

Product innovations occur randomly following a Poisson arrival rate of ε for each monetary unit invested in product R&D. Thus, average waiting time for the next product innovation, if a monetary unit is invested, is $\frac{1}{\varepsilon}$. Due to the additivity of Poisson processes, the flow of product innovation at each time t is given by:

$$(3) \quad Q_{j,t} = \varepsilon w_{j,t}$$

where ε can be also interpreted as a proxy for the technology opportunities and $w_{j,t}$ is the investment in product R&D at time t , by a firm operating in the submarket S_j . Thus, average waiting time for the next product innovation in submarket j is $\frac{1}{\varepsilon w_{j,t}}$. If the economy is at time t , we define $t+1$ the time when

the next innovation occurs. Because competition for innovation is structured as a patent race, the average waiting time for next innovation does not depend on the aggregate investment, but on the investment of the single firm. In equilibrium, an indefinite number firms will be investing the same amount of resources. However, only the first firm to invent will have positive returns for its investment. This is a standard assumption in the literature of patent race without technological spillovers.

In this model, all the submarkets are of equal size; thus, there is no reason why a firm should prefer a submarket instead of another one. Consequently, we assume that firms randomly choose the submarket where they operate.

Similarly, the flow of process innovation at each time t is:

$$(4) \quad P_t = \delta z_t$$

being δ the Poisson arrival rate (and proxy for the technological opportunities) and z_t the investment in process R&D.

A firm engaged in product innovation, once an innovation is being introduced, has a positive probability, function of α , that the innovation is successful in the market. Define this probability $Pr(\alpha)$ and assume $\frac{\partial Pr(\alpha)}{\partial \alpha} > 0$ $Pr(1)=1$ and $Pr(0)=0$. This captures the idea, that the more

sophisticated are consumers, the easier they can provide firms with useful knowledge on the direction of inventive activity.

Price and R&D investments are the strategic variables. First, firms make their R&D investment decisions. Thereafter, price competition takes place among three type of firms: an indefinite number of non innovating firms producing quality \bar{q} with cost \bar{c} , one firm in each submarket producing a q_j^* quality good with probability $Pr(\alpha)$, at cost \bar{c} , and one firm producing standard quality at cost of production c^* . At each time, firms compete on prices given technological conditions and decide R&D investments that will impinge upon the expected arrival time of the next innovation.

4.3 The model: results

Lemma 1

At each point in time the firm producing the top quality good in each submarket sets the price $(q^* - \bar{q} + \bar{c})$ and the firm producing at marginal cost c^* sets the price \bar{c} .

Proof

The proof shows first that $p = (q^* - \bar{q} + \bar{c})$ is the best price strategy for firms producing the high quality good, when standard firms sell at price \bar{c} . Secondly, the proof shows that, given this price, the firm innovating in process technology sets the price \bar{c} .

Assume that firms with the best production technology set the price \bar{c} . Thus, the limit price to exclude them from the market should satisfy

$$(5) \quad q^* - p = \bar{q} - \bar{c} ,$$

that is the price that makes consumers indifferent between buying the high quality good and the low quality good. Assuming that consumers break the tie in favour of firms producing the quality good:

$$(6) \quad p(q^*, t) = q^* - \bar{q} + \bar{c}$$

We assume that $p(q^*, t)$ is always non negative. It is then straightforward to prove that \bar{c} is the optimal price set by firms with the best process technology. If $p < \bar{c}$, due to the inelasticity of the demand curve deriving from the utility function, they would sell the same quantity but at a lower price and, thus, they would not maximise their profits. If $p > \bar{c}$ they would face competition from non-innovative firms.

Lemma 2

Expected profits for a firm producing the top quality in a submarket are:

$$(7) \quad \pi_j(t) = \Pr(\alpha)(q^* - \bar{q}) \frac{M}{N(\alpha)}$$

Proof

It descends necessarily from lemma 1. $M/N(\alpha)$ is the potential market faced by a product innovator under the assumption that consumers are evenly distributed across submarkets. $\Pr(\alpha)$ is the probability that a product innovation meets consumers' needs, and $(q^* - \bar{q})$ is the mark-up.

Lemma 3

Expected profits for firms producing with lower marginal cost are:

$$(8) \quad \pi(t) = [1 - \Pr(\alpha)](\bar{c} - c^*)M$$

Proof

The firm with the best process technology serves all the market not covered by quality product producers, $[1 - \Pr(\alpha)]M$, and $(\bar{c} - c^*)$ is the mark-up per unit.

Proposition 1

In equilibrium, in each period, R&D efforts are:

$$(9) \quad w_{j,t} = \max \left\{ \frac{\varepsilon \left[\Pr(\alpha)(q_j^* - \bar{q}) \frac{M}{N(\alpha)} \right] - r}{\varepsilon}; 0 \right\}$$

$$(10) \quad z_t = \max \left\{ \frac{\delta [1 - \Pr(\alpha)](\bar{c} - c^*)M}{\delta} - r; 0 \right\},$$

where r is the discount factor.

Proof

We first prove (9). Firms aiming at introducing product innovation, choose $w_{j,t}$ in order to maximize the flow of expected profit over time:

$$(11) \quad E(\pi_{j_t}) = \varepsilon w_{j,t} W_{t+1} - w_{j,t},$$

where W_{t+1} is the value of introducing the next innovation weighted with the probability that this event occurs. Free entry in the R&D to introduce product innovation ensures zero profits conditions. From Kuhn-Tucker conditions:

$$\begin{aligned}
 & \text{if } w_{j,t} > 0 \rightarrow \varepsilon W_{t+1} = 1 \\
 (12) \quad & \text{or} \\
 & \text{if } w_{j,t} = 0 \rightarrow \varepsilon W_{t+1} \leq 1
 \end{aligned}$$

Kuhn-Tucker conditions explain that if investments in R&D are positive, expected profits (11) should be zero ($\varepsilon W_{t+1} = 1$). On the contrary, with $\varepsilon W_{t+1} \leq 1$ expected profits are non-positive and firms do not carry R&D. Second order conditions are necessarily fulfilled due to the linearity of the function. Deriving the optimal flow of R&D investments requires to make W_{t+1} explicit:

$$(13) \quad W(t+1) = \int_{t+1}^{\infty} e^{-(r+\varepsilon w_{j,t+1})t} \pi_{t+1} dt = \frac{\pi_{t+1}}{r + \varepsilon w_{j,t+1}}$$

Equation (13) involves that, the expected value of introducing the next innovation is equal to the discounted value of profits over an interval with length $\frac{1}{\varepsilon w_{j,t}}$. The denominator is also known as obsolescence adjusted interest

rate and shows that the greater the amount of resources devoted to R&D in the sector, the shorter the period of monopolist profit and, thus, the smaller the incentives to invention. Moreover, equation (13) illustrates that the incumbent owning the best quality does not invest in R&D: the value of investment is not W_{t+1} , but the strictly smaller $W_{t+1} - W_t$, that is the value of introducing an innovation corrected with the loss of value due to the cannibalization of its own monopolistic position. Equation (13) can be re-arranged as:

$$(14) \quad rW_{t+1} = \pi_{t+1} - \varepsilon w_{j,t+1} W_{t+1}$$

The flow value of owning the next best technology is equal to the monopolist profits in the submarket S_j minus the probability of losing all the value

because a new innovation is introduced. In equilibrium, both Kuhn-Tucker conditions and (14) should be fulfilled. Thus, substituting (12) and (7) in (14) we obtain (9).

Mutatis mutandis, the proof holds also for R&D investment in process innovation (equation 10).

Proposition 2

In Equilibrium, at each time the flow of product and process innovation is:

$$(15) \quad Q_j(t) = \varepsilon \left[\Pr(\alpha) [q_j^* - \bar{q}] \frac{M}{N(\alpha)} \right] - r$$

$$(16) \quad P(t) = \delta [1 - \Pr(\alpha)] (\bar{c} - c^*) M - r$$

Proof.

Consider the case when R&D investments are positive. Substituting (3) in (9) and (4) in (10) and re-arranging, we obtain (15) and (16).

Corollary 1

An increase in market size has always a positive impact on both product and process innovation.

Proof:

$$(17) \quad \frac{\partial Q_j}{\partial M} = \varepsilon \frac{\{\Pr(\alpha) [q_j^* - \bar{q}]\}}{N(\alpha)} > 0$$

$$(18) \quad \frac{\partial P}{\partial M} = \delta [1 - \Pr(\alpha)] (\bar{c} - c^*) > 0$$

Corollary 2

An increase in consumers' sophistication has a negative impact on process innovation and an uncertain one on product innovation.

Proof

$$(19) \quad \frac{\partial P}{\partial \alpha} = -\delta(\bar{c} - c^*)M < 0$$

$$(20) \quad \frac{\partial Q_j}{\partial \alpha} = \frac{\varepsilon(q_j^* - \bar{q}) \frac{\partial \Pr(\alpha)}{\partial \alpha} MN(\alpha) - \varepsilon(q_j^* - \bar{q}) \Pr(\alpha) M \frac{\partial N(\alpha)}{\partial \alpha}}{N^2(\alpha)} \begin{matrix} > \\ < \end{matrix} 0$$

Note that for (20) the sign of the derivate depends on the elasticities of $\Pr(\alpha)$ and $N(\alpha)$ with respect to α . Indeed $\frac{\partial Q_j}{\partial \alpha} \geq 0$ if $\frac{\partial \Pr(\alpha)}{\partial \alpha} N(\alpha) - \Pr(\alpha) \frac{\partial N(\alpha)}{\partial \alpha} \geq 0$.

Multiplying both sides of the equation times α and rearranging we obtain:

$$(21) \quad \frac{\partial Q_j}{\partial \alpha} \geq 0 \text{ if } \frac{\partial \Pr(\alpha)}{\partial \alpha} \frac{\alpha}{\Pr(\alpha)} \geq \frac{\partial N(\alpha)}{\partial \alpha} \frac{\alpha}{N(\alpha)},$$

that is:

$$(22) \quad \frac{\partial Q_j}{\partial \alpha} \geq 0 \text{ if } \varepsilon_{\Pr(\alpha), \alpha} \geq \varepsilon_{N(\alpha), \alpha}$$

where $\varepsilon_{\Pr(\alpha), \alpha}$ and $\varepsilon_{N(\alpha), \alpha}$ are the α -elasticities of respectively $\Pr(\alpha)$ and $N(\alpha)$.

Corollary 3

A necessary condition to observe at least one firm introducing a product innovation is:

$$(23) \quad M > \frac{(1+r)N(\alpha)}{\varepsilon \Pr(\alpha)(q_j^* - q)}$$

Proof

Directly from (15).

Corollary 4

A necessary condition to observe at least one firm introducing a product innovation is:

$$(24) \quad M > \frac{(1+r)}{\delta[1 - \Pr(\alpha)](\bar{c} - c^*)}$$

Proof.

Directly from (16).

4.4 The model: comments

This model highlights the importance of two dimensions of demand in shaping firms innovative behaviour: market size and consumers' degree of sophistication.

First, the model shows that market size has a positive impact on both process and product innovation (equations 17 and 18). It is consistent with the empirical literature on the issue and avoids the criticisms put forward by Scherer, Mowery and Rosenberg, and Dosi because it defines clearly and analytically the concept of demand, the effect on market structure is explicitly modelled, and takes into account technology conditions as control variables as well.

The effect of an increase in the degree of sophistication (equations 19 and 20), on the contrary, is more controversial: it is negative in case of process innovation and it is uncertain for product innovation. On the one hand, a rise in

sophistication increases the number of submarkets and, thus, by reducing market size for that specific product, lowers potential profits (the second term in equation 19). On the other hand, it reduces uncertainty and increases expected profits by augmenting the probability that firms introduce an innovation matching consumers' preferences (first term in equation 19). This tension can be analysed in terms of elasticity (equation 22): an increase in sophistication has a positive impact on the number of product innovations if the probability of introducing a successful innovation is more sensitive to variation of sophistication than the number of submarkets. Which effect is going to prevail is an empirical question.

Secondly, the model suggests that demand acts upon innovation by influencing firms' innovation choices: the interplay of size and sophistication identifies four patterns of demand. Figure 1 and 2 represent corollaries 3 and 4, and Figure 3 illustrates their joint meaning. Under given technological conditions, captured by ε and δ , figure 3 pinpoints four zones. In a small market with low sophistication, zone Ω_1 , firms are not innovating; a large market with low sophistication, zone Ω_2 , shows process innovation; small markets with high sophistication, zone Ω_3 , show at least one product innovation; and in a large market with high sophistication, zone Ω_4 , there are both product and process innovations.

Graphs show other properties of the outcome. First a minimum size of the market is required for both process and product innovation to be profitable. In case of product innovation the required critical mass decreases when the sophistication increases. On the contrary, concerning process innovation, the critical mass tends to infinite when sophistication is large.

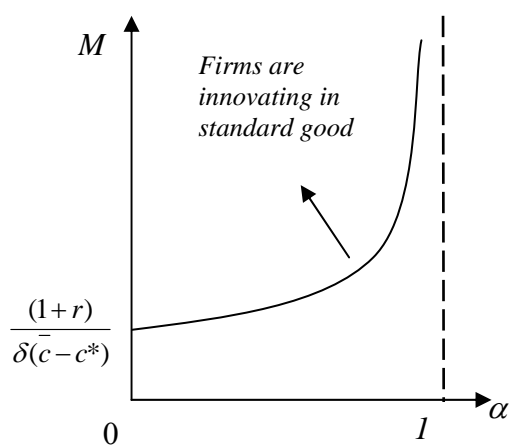


Figure 1: corollary 4 explained

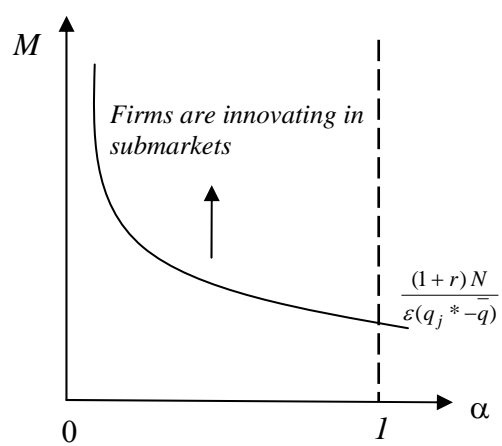


Figure 2: corollary 3 explained

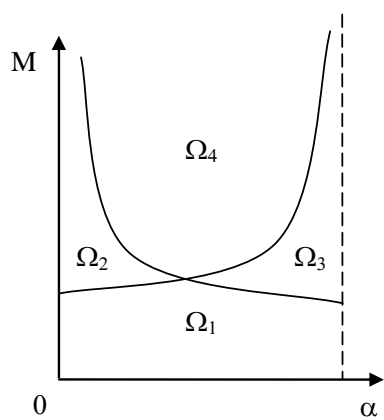


Figure 3: joint representation of proposition 6 and 7.

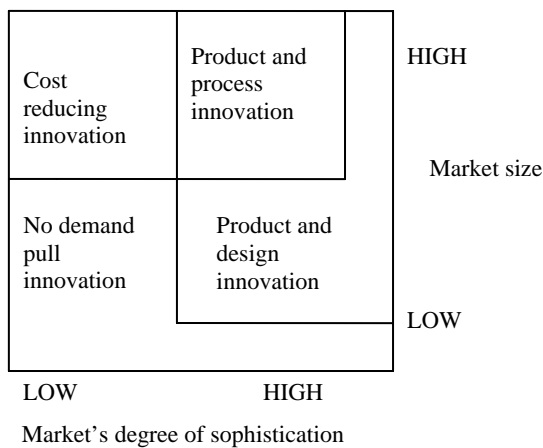


Figure 4: Innovation and patterns of demand.

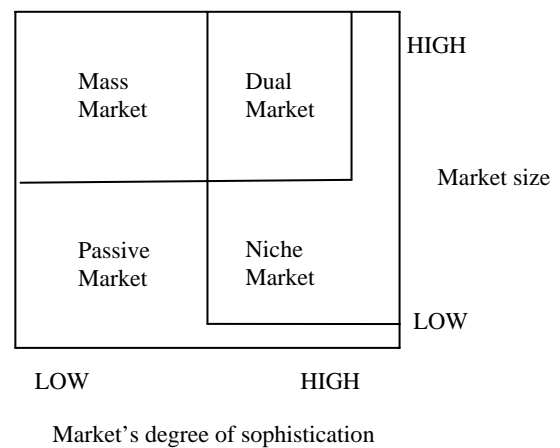


Figure 5: the patterns of demand.

Figure 4 is a qualitative resume – and not an isomorphic representation – of the firms' innovative behaviour in the economy and, on this premise, figure 5 suggests a taxonomy of markets: there exist *passive markets* where demand does not pull innovation at all. The small size of the market and the low users' sophistication do not make investments in innovation a profitable activity. Both product and process innovations, if any, are due to a "technology push"; as in the Schumpeterian hypothesis, innovation results from an act of will made by the entrepreneur or from the efficiency of R&D laboratories.

In *mass markets*, all of the requirements for the production of a standard good are fulfilled, that is firms find it profitable to invest in process R&D and produce a standard good. These markets could be mainly mass markets for consumers' goods and commodities, but they can also represent a market for standardized producers' goods, like for instance Personal Computers, raw materials or for producers' goods where user-producer interactions do not matter very much. Because of the low degree of sophistication, it is more profitable for firms to seek cost reducing process innovation and exploit the size

of the market rather than following differentiation strategies. New radical innovations, if any, are due to technological breakthroughs, rather than to demand stimuli. These markets fit very well the “demand pull” empirical evidence found by Schmookler.

In *niche markets* innovation is oriented toward the generation of variety. The small size of the market does not allow for considerable investments in process technologies because the number of units of output is not large enough to sink high fixed costs. On the other hand, users are well aware of their needs and often help producers in the design process, by giving valuable feedbacks or even by suggesting innovative solutions. For this reason, the likelihood of producing a marketable innovation specific for a niche is very high. Mechanisms at work in this pattern explain the empirical evidence about sectors where user-producer interactions *à la* Lundvall are a central feature. In the real world, in these markets radical product innovations are likely to occur because, despite the small size of the market, users’ awareness of needs reduces the uncertainty of the potential demand, by providing the firm with useful knowledge.

A large size of the market coupled with a high degree of consumers’ sophistication leads to a *dual market structure*. On the one hand, there are firms producing a standard product; on the other hand, firms supply variety of oddments in niche markets. The latter introduce product innovation for sophisticated users whilst standard firms focus on process innovation and sell a standardized product to submarkets not reached yet by dedicated versions of the good. This pattern of demand fits with literature on industry de-maturity (Abernathy 1983) and the empirical story of the industrial dualism in the automobile industry. Some authors (Pine 1993, Davies 1987) forecast the advent of the mass-customization, i.e. a mode of production where the same technology could mass-produce all of the different versions of a good and, thus,

finally overcome the trade-off between standardization and variety. So far, mass customization has not been put to work, but it could be observed an attempt by large firms to improve the flexibility of the process technology in terms of both quantity and variety.

4.5 The patterns of demand and the industry life cycle

A property of the model is that neither past nor future has an influence on the research efforts at a given time. Only the two relevant demand parameters, size and sophistication, and the control variables for technologies opportunities, ε and δ , determine R&D levels. This property implies that, at each point in time, optimal investments crucially depend on M and α . By varying these parameters over time, it is possible to depict the evolution of demand patterns and, thus, the resulting dynamics in firms' innovative behaviour.

The most popular story summarizing industrial dynamics over time is the industry life cycle. Over time an industry observes a progressive shift from design to cost competition and from product to process innovation due to a progressive depletion of technological opportunities (Abernathy and Utterback 1978; Klepper 1996). However, industry life cycle can be explained also as the result of an evolving path through the four patterns of demand described above.

For instance, consider the story of the evolution of variety generation in the automobile industry, which is often taken as paradigmatic for the industry life cycle. When the innovation of the horseless carriage was first introduced, neither producers nor users knew how to develop the concept of a car. As time went by, the limited number of users became more sophisticated and, thus, aware of their needs: a car should not have been an expensive and craft-produced toy for rich dandies, as many early producers thought, but, on the

contrary, a transport tool for farmers in the uneven roads of the wide American countryside (Wik 1972). Henry Ford, because of his frequent contacts with early users, understood that there was a wide potential market for this product, if cheap and solid. For this reason, Henry Ford aimed to produce a car for the multitude, which was cheap enough to be bought by both farmers and workers and solid enough to be driven on the countryside roads. He achieved this goal both by introducing design and process innovation and by producing a standardized product on the assembly line: "the consumer [got] lower costs but at the expense of variety" (Womack et Al. 1990 p.13). Thus, the shift of the pattern of demand occurred from a passive market into a niche market and, with Ford, into a mass market. Consequently, the type of innovation moved from an innovation in the product design to cost reducing process innovations. Over time, consumers learned how the product car could satisfy other various needs for transport, entertainment, and status seeking. The increased degree of sophistication of the market allowed firms to divide the market in segments and submarkets and to avoid price competition by producing differentiated products. Demand evolved from a mass market into a dual market. In this market, there is a core of large companies producing a standardized good and many small industries producing dedicated specialty components.

Similarly, Knodler (1993) tells the story of the technological improvement in the U.S. steel industry. Around 1860, about 200.000 tons of steel were sold in the U.S. market and produced with craft steel making techniques such as the crucible steel and cementation steel, suitable for the small and sophisticated cutlery producers. A new demand coming from the rail industry increased in only 10 years the market for steel up to 1.600.000 tons: the pattern of demand shifted from a niche market to a mass market. This shift pulled the introduction of cost reducing process technologies such as the invention of the Bessemer steel process. Time went by, demand was large and major improvements had been made in the process of steel production and iron extraction. Gradually,

when new steel users such as the Pennsylvania Railroad and automakers entered the market, demand began to require more and more sophisticated products. The result has been a new shift from a mass market to a much more segmented market where even users themselves are both producing steel and investing in R&D (Knodler 1993, Meyer 2005). Figure 6 and 7 show the evolution of the sectors through the different patterns of demand.

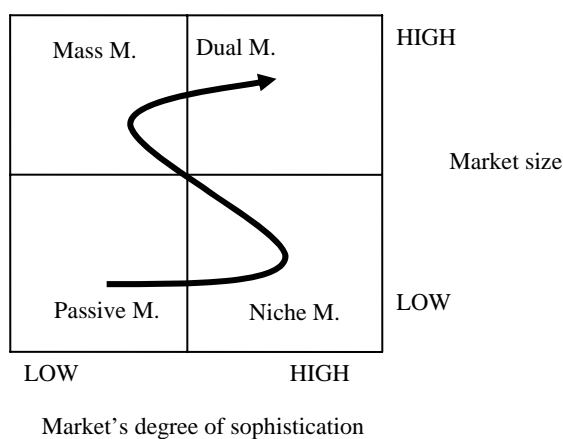


Figure 6: evolution path of pattern of demand in the US automobile industry

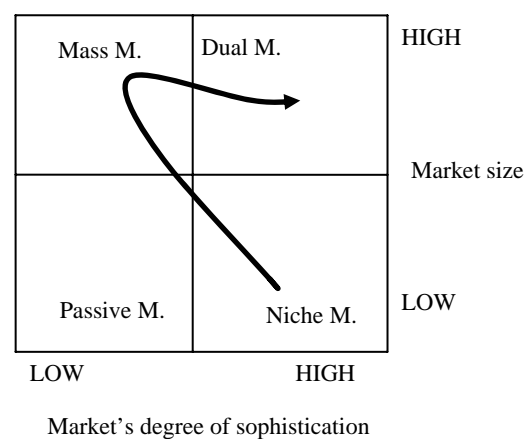


Figure 7: evolution path of pattern of demand in the steel industry

In term of the model, keeping everything equal, the demand conditions leading to a product life cycle such the one depicted in Figure 6 could be summarize as follows:

- b. A small initial size of the market.
- c. An increasing size of the market.
- d. A small initial degree of sophistication.
- e. A degree of sophistication is initially increasing, then decreasing, and increasing again.

Assume that the degree of sophistication at time t , (α_t), can be proxied by the ratio of sophisticated consumer (S_t) and the size of the market (M_t). Under this assumption, condition 4 can be re-written as

$$\text{d. (bis) } \exists \bar{t}, \bar{t}^{\text{=}} \text{ with } \bar{t} < \bar{t}^{\text{=}} \left\{ \begin{array}{l} \forall t < \bar{t} \rightarrow \dot{M} < \dot{S} \\ \forall \bar{t} < t < \bar{t}^{\text{=}} \rightarrow \dot{M} > \dot{S} \\ \forall t > \bar{t}^{\text{=}} \rightarrow \dot{M} < \dot{S} \end{array} \right.$$

Where t is the time and \dot{M} and \dot{S} the growth rate of M and S . This formulation, comparing the increase of the size of the market with the increase of the sophisticated consumer, shows that industry life cycle is only one of the possible history, although a very plausible one. The plausibility derives from the fact that the diffusion of a product often follows a logistic curve that is a function with a small positive derivative both at early and late stage of the diffusion and a high growth in between (fig. 8).

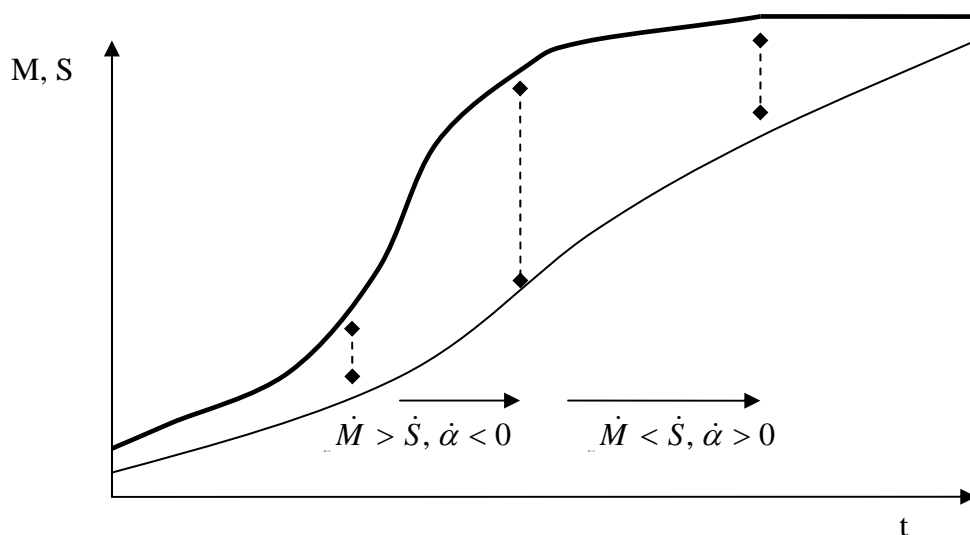


Figure 8

The following paragraphs show the results of a numerical simulation that reproduces this evolution path of demand.

The purpose of the exercise is purely a methodological one because an analysis of consumption is beyond the purpose of this paper. However, it shows further applications of the model as, for instance, the replication of an historical dynamics within a market, the implementation of counterfactual analysis, and the prediction of future scenarios.

The simulation has been run assuming that a market for a product grows along an S-shaped curve. A common solution for modelling the diffusion path is the assumption that market growth is positively correlated with the size of the market in each time and the number of potential adopters:

$$(25) \quad \dot{M}_t = k_1 M_t (\bar{M} - M_t)$$

where k_1 is a parameter and \bar{M} the number of whole market. Thus, $(\bar{M} - M_t)$ is the number of potential adopters. Equation 25, being a Bernoulli's equation, has the following logistic function as integral:

$$(26) \quad M_t = \bar{M} \left[\bar{M} k_2 e^{-k_1 \bar{M} t} + 1 \right]^{-1} \quad \text{with} \quad M(0) \leq \bar{M} \quad \text{and} \quad \text{with initial condition}$$

$$k_2 = \frac{1}{M_t} - \frac{1}{\bar{M}} \quad \forall t$$

The numerical simulation assumes a linear growth for the evolution of the number sophisticated users S .

$$(27) \quad \dot{S}_t = c_2$$

The integral is:

$$(28) \quad S_t = \bar{S} + c_2 t \text{ with } \bar{S} < M(0) \quad \bar{S} \text{ and } c_2 | S_t < M_t$$

The model considers the degree of sophistication as the percentage of sophisticated users:

$$(29) \quad \alpha_t = \frac{S_t}{M_t}$$

Equations (26) and (29) describe the evolution of the two relevant parameters and, thus, the evolution of the industries over different patterns of demand. Given these conditions, equations (15) and (16) determine the flow of both process and product innovations.

The following tables depict the outcome of a model parameterization that replicates dynamics in the steel industry.

Figure 9: demand dynamics

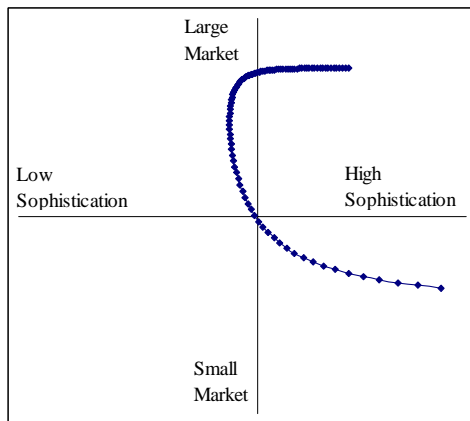
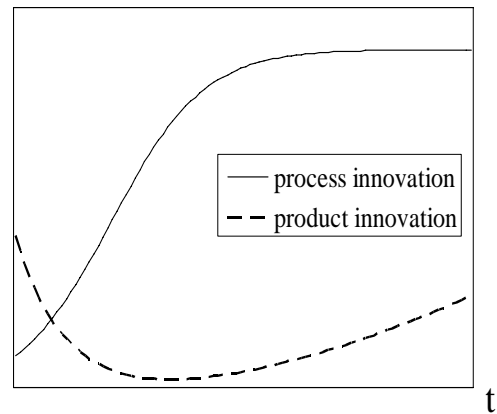


Figure 10: innovation dynamics



Parameter	Values
\bar{M}	10
Mmax	100
\bar{S}	1
c1	0.09
k1	0.001
c2	99
k2	0.06
ε	0.015
δ	0.009
\bar{q}	0.8
q*	1
C	0.2
c*	1
G	0.01
R	0.05

$$\begin{aligned}
 P(\alpha) &= \alpha \\
 N(\alpha) &= M^\alpha \\
 M(t) &= \bar{M} \left[\bar{M} k_2 e^{-k_1 \bar{M} t} + 1 \right]^{-1} \\
 S(t) &= \bar{S} + c_2 t
 \end{aligned}$$

Figure 11 and 12: parameterization and dynamic equations

Figure 9 describes the evolution of demand and Figure 10 portrays the number of product and process innovations over time. When demand is nothing more than a niche market, process innovations are rare, while there are various product innovations. As demand moves toward a mass market, the number of process innovations steadily increases, whilst product innovations disappear. In product life cycle theory, this event corresponds to the appearance of a dominant design. Finally, when the sector reaches a de-maturity stage, i.e. a large market but very sophisticated, we observe the coexistence of both process and product innovations. As a result, this model replicates the standard life cycle of an industry.

Although this is a plausible story, because it mainly derives from the reasonable assumption of an S-shape diffusion curve, it is still a special case. Thus, this model analytically reduces the product life cycle theory to a special case of a more complex framework where diffusion and learning, by coevolving together, shape firms' production decisions and innovative output at the aggregate level. Undeniably, by

varying the assumptions on the evolution of both market size and consumers' sophistication, it is possible to generate alternative outcomes such as bifurcations in the technological trajectories or the non-existence of a dominant design, which have been recently observed in many sectors (Windrum 2003, Windrum and Frenken 2003).

These considerations hold under peculiar assumptions on technology, captured by ε and δ . It is straightforward that if technology because of its rigidities does not allow an easy generation of variety, firms will rather focus on standardization despite market requirements and the other way round.

5. Conclusions

The aim of this paper was to improve our understanding of the influence of demand upon innovation. Literature explains that demand, in order to pull innovation, might either grant a stream of expected profits or provide firms with relevant knowledge about needs and wants. A decade-long debate on demand-pull theories has shown that, in order to capture the incentives effect, the size of the market should be controlled for its heterogeneity and effects on market structure should be considered as well. Moreover, for a better comprehension of the role of users in providing knowledge, a model requires a precise definition of needs and wants. Borrowing the original result from previous work (Guerzoni 2007), i.e. that the degree of sophistication explains both consumers' awareness of their need and market heterogeneity, the model is based on a conceptualization of demand as a peculiar blend of market size and consumers' sophistication.

The model roots in an original mechanism. Demand does not directly pull innovation, but it plays a crucial role in determining the optimal location of firms in the trade-off between standardization and variety. This strategic choice impinges powerfully on the organization of production and, consequently, on the patterns of innovation. The model shows first that these effects have a different impact on the aggregate industry innovative output, as suggested in the literature. Specifically, the

market size has always a positive effect on R&D investments, while the effect of consumers' sophistication is uncertain.

Secondly, the interplay of demand dimensions can be used to group sectors according to four patterns of demand. Innovation processes are complex and, therefore, the search for mechanisms holding across all industries and over time is often meaningless. For this reason, among scholars of economics of innovation, the attempt of grouping empirical evidence in taxonomies and investigate *similia similibus* is well established. There exist taxonomies of sectors and industries based on technology and firms' micro-characteristics; among those, the Pavitt's taxonomy and the Schumpeterian regimes of innovation are well known (Pavitt 1984, Malerba and Orsenigo 1995). This model provided a theoretical basis to introduce a demand based taxonomy and calls for empirical analysis.

Finally, the model was able to replicate the outcome of the Product Life Cycle (PLC) theories. PLC is a powerful concept, well established in the literature; however, economists of innovation are increasingly dissatisfied with this approach because it does not take account many empirical cases, such as bifurcations in the technological trajectories, non-existence of a dominant design, and the existence of a phase of dematurity at the end of the life cycle. The model replicated the PLC only as a specific case and alternative assumptions on market growth and consumer' sophistication lead to different outcomes. Nevertheless, this paper does not suggest that only the demand side matters. Indeed, these results hold only under the *ceteris paribus* condition on the technology side. The aim of the paper was not to add a new contribution on the "demand pull" vs. "technology push" debate, but to explore the mechanism on the demand side. Generally, whether *ceteris paribus* hold or not and, thus, whether technological or demand factors prevail is an empirical question.

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