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

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The aim of this paper is an investigation on the role of demand upon innovation. Despite the decades-long debate on demand and innovation, theory still lacks an 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 the main outcome, the paper explores the underlying mechanisms of demand-pull theories and proposes a theoretical taxonomy of industries.

Keywords: innovation; demand

JEL Classification: O31; O33; L15

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, an analytical formulation is still lacking. This paper attempts to partially 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.

Section 2 puts forward a framework explaining the way demand 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). 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 demand, conceived as market size and consumers' sophistication play an important role in determining both the optimal organization of production and, consequently, innovative behavior at the firm level.

In Section 3, the paper presents a model exploring this mechanism. It first analyzes 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 characterized by an idiosyncratic blend of size of demand and consumers' sophistication

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and, as a result, by a distinctive pattern of production and innovation. Conclusions suggest a few remarks about the limits of the model and new lines of research.

2. Standardization and variety

The trade-off between standardization and variety is a crucial choice for firms' strategies (David 1994; David and Rothwell 1996; Weitzman 1992): 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 characterized 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.

Piore and Sabel (1984) highlighted that 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 labor in simple steps and the consequent substitution of labor 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 (Piore and Sabel 1984, 19).

These two modes of production involve different innovative efforts at the 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 model in the next section discloses the link between demand 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 both 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.

The model relies on a peculiar characterization of the demand rooted in the literature. Guerzoni (2007) suggests that, overall, the literature can be organized in two streams. One suggests that firms direct their R&D efforts towards the most profitable markets (Schmookler 1962, 1966); the second indicates in consumers a crucial source of ideas (Berger 1975; Boyden 1976; Freeman 1968; Isenson 1969; Langrish et al. 1972; Lionetta 1977; Myers and Marquis 1969; National Science Foundation 1959; Rothwell et al. 1974). Over the decades, both approaches have been refined. The size of the market matters, but it should be controlled for its heterogeneity (Young 1998). Concerning the second stream of literature, generic consumers' needs do not provide any useful information to firms, but only sophisticated consumers can provide feedbacks with adequate accuracy (Adner and Levinthal 2001; von Hippel 1986; Malerba et al. 2003; Teubal 1979).

The concepts of heterogeneity and sophistication are not unrelated. Guerzoni (2007) formalized the concept of sophistication, explored the link among sophistication and heterogeneity, and proved the former to be a necessary condition for observing a heterogeneous structure of consumers' preferences. The analytical proof relies on the intuition that processes of choice are conceived as a hierarchic sequence of steps where an agent specifies at each step with an increasing accuracy his preferences (Tversky 1972; Tversky and Sattath 1979). We define sophistication the extent of this accuracy. If agents have heterogeneous preferences, their diversity is revealed with growing precision at each step of the decision process. Thus, sophistication is pre-condition to disclosure heterogeneity.

This is relevant to the aim of this paper because it allows reducing the complexity of the demand side by modeling heterogeneity as a function of sophistication. On this basis, demand is defined as the blend of market size and consumers' sophistication. In sum, this peculiar mix of market size and users' sophistication contributes 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 upon firm production and innovative choices.

3. The model

3.1. Foreword

The model presented below is a model with vertical innovation generated in a competitive sector in the spirit of Aghion and Howitt's (1992) model of creative destruction. 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 (Acemoglu and Linn 2005; Thompson and Klepper 2003; Malerba et al. 2003). 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 (Neumann, Gross, and Munter 2001; Sutton 1998) use a continuum set of technologies; on the contrary, this work follows Elberfeld and Götz'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 (2007) 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.

3.2.   *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

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

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:

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

where d is an indictor 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 $1/\varepsilon$. Due to the additivity of Poisson processes,

the flow of product innovation at each time t is given by:

$$Q_{j,t} = \varepsilon w_{j,t} \tag{3}$$

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 $1/\varepsilon w_{j,t}$. 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 until a new invention is made in the market. 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:

$$P_t = \delta z_t \tag{4}$$

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 $(\partial \Pr(\alpha)/\partial \alpha) > 0$ $\Pr(1) = 1$ 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.

3.3. The model: preliminary results

We first state five lemmata, used a stepping stones to prove the central propositions of the model introduced in the next paragraph. Proofs are in the Appendix.

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 $\bar{c}$.*

LEMMA 2 *Expected profits for a firm producing the top quality in a submarket are*:

$$\pi_j(t) = \Pr(\alpha)(q^* - \bar{q})\frac{M}{N(\alpha)} \tag{5}$$

LEMMA 3 *Expected profits for firms producing with lower marginal cost are*:

$$\pi(t) = [1 - \Pr(\alpha)](\bar{c} - c^*)M \tag{6}$$

LEMMA 4 *In equilibrium, in each period, R&D efforts are*:

$$w_{j,t} = \max \left\{ \frac{\varepsilon[\Pr(\alpha)(q_j{}^* - \bar{q})(M/N(\alpha))] - r}{\varepsilon}; 0 \right\} \tag{7}$$

$$z_t = \max \left\{ \frac{\delta[[1 - \Pr(\alpha)](\bar{c} - c^*)M] - r}{\delta}; 0 \right\}, \tag{8}$$

where r is the discount factor.

LEMMA 5 *In equilibrium, at each time the flow of product and process innovation is*:

$$Q_j(t) = \varepsilon \left[\Pr(\alpha)[q_j{}^* - \bar{q}] \frac{M}{N(\alpha)} \right] - r \tag{9}$$

$$P(t) = \delta[[1 - \Pr(\alpha)](\bar{c} - c^*)M] - r \tag{10}$$

3.4. The model: results

PROPOSITION 1 *An increase in market size has always a positive impact on both product and process innovation.*

Proof

$$\frac{\partial Q_j}{\partial M} = \varepsilon \frac{\{\Pr(\alpha)[q_j{}^* - \bar{q}]\}}{N(\alpha)} > 0 \tag{11}$$

$$\frac{\partial P}{\partial M} = \delta[1 - \Pr(\alpha)](\bar{c} - c^*) > 0 \tag{12}$$

∎

PROPOSITION 2 *An increase in consumers' sophistication has a negative impact on process innovation and an uncertain one on product innovation.*

Proof

$$\frac{\partial P}{\partial \alpha} = -\delta(\bar{c} - c^*)M < 0 \tag{13}$$

$$\frac{\partial Q_j}{\partial \alpha} = \frac{\varepsilon(q_j{}^* - \bar{q})(\partial \Pr(\alpha)/\partial \alpha)MN(\alpha) - \varepsilon(q_j{}^* - \bar{q})\Pr(\alpha)M(\partial N(\alpha)/\partial \alpha)}{N^2(\alpha)} \overset{>}{\underset{<}{}} 0 \tag{14}$$

∎

PROPOSITION 3 *The impact of sophistication on product innovation depends on the α elasticities of* $\Pr(\alpha)$ *and* $N(\alpha)$.

Proof Note that for (14) the sign of the derivate depends on the elasticities of $\Pr(\alpha)$ and $N(\alpha)$ with respect to α. Indeed $(\partial Q_j / \partial \alpha) \geq 0$ if $(\partial \Pr(\alpha)/\partial \alpha)N(\alpha) - \Pr(\alpha)(\partial N(\alpha)/\partial \alpha) \geq 0$. Multiplying both sides of the equation times α and rearranging we obtain:

$$\frac{\partial Q_j}{\partial \alpha} \geq 0 \text{ if } \frac{\partial \Pr(\alpha)}{\partial \alpha} \frac{\alpha}{\Pr(\alpha)} \geq \frac{\partial N(\alpha)}{\partial \alpha} \frac{\alpha}{N(\alpha)}, \tag{15}$$

that is:

$$\frac{\partial Q_j}{\partial \alpha} \geq 0 \text{ if } \varepsilon_{\Pr(\alpha),\alpha} \geq \varepsilon_{N(\alpha),\alpha} \tag{16}$$

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

PROPOSITION 4 *A necessary condition to observe at least one firm introducing a product innovation is*:

$$M > \frac{(1+r)\,N(\alpha)}{\varepsilon \Pr(\alpha)\,(q_j^* - \bar{q})} \tag{17}$$

Proof Directly from (9). ∎

PROPOSITION 5 *A necessary condition to observe at least one firm introducing a product innovation is*:

$$M > \frac{(1+r)}{\delta[1 - \Pr(\alpha)]\,(\bar{c} - c^*)} \tag{18}$$

Proof Directly from (10). ∎

3.5. *The model: comments*

These propositions highlight the importance of two dimensions of demand in shaping firms innovative behavior: 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 (11) and (12)). It is consistent with the empirical literature on the issue and avoids the criticisms on innovation and market size put forward by Scherer (1982), Mowery and Rosenberg (1979), and Dosi (1982) because it defines clearly and analytically the concept of demand, the effect on market structure is explicitly modeled, and takes into account technology conditions as control variables as well.

The effect of an increase in the degree of sophistication (Equations (13) and (14)), on the contrary, is more controversial: it is negative in case of process innovation and it is uncertain for product innovation. The result that sophistication might have a negative effect and thus mitigate or even counterbalance the positive impact of the increase in market size is not an obvious one and deserves some further comments. In the case of process innovation this result depends on the effect of competition: sophisticated consumers need *ad hoc* products produced by niche players, which became more successful than the mass-producer. However, they have to focus on quality improvements rather than on efficiency gains, thus favoring product innovations in detriment of process innovations.

Concerning product innovation only, the effect of an increase in sophistication is more complex. 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 (14)). 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 (14)). This tension can be analyzed in terms of elasticity (Equation (16)): 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' production choices: the interplay of size and sophistication identifies four patterns of demand. Figures 1 and 2 represent Propositions 4 and 5, 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
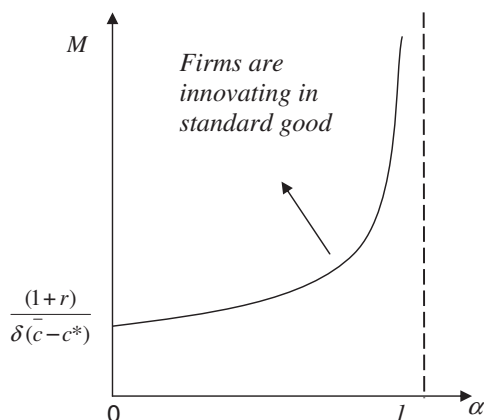

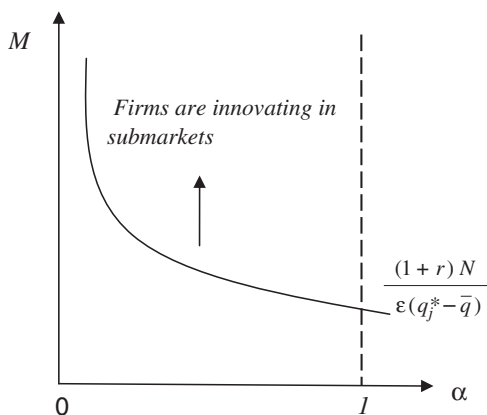Figure 1.   Proposition 4 explained.

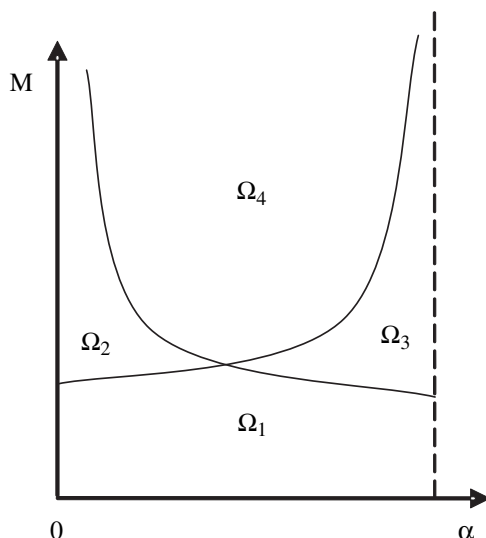
Figure 2.   Proposition 5 explained.

Figure 3.   Joint representation of Propositions 4 and 5.

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 4 is a qualitative resume – and not an isomorphic representation – of the firms' innovative behavior 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 hypotheses, 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
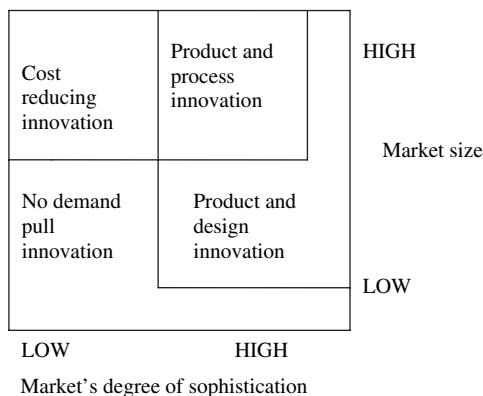

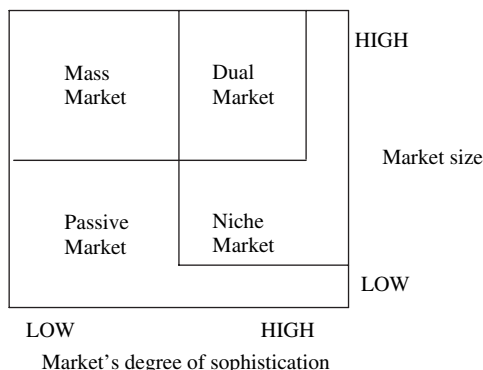Figure 4.   Innovation and patterns of demand.

Figure 5.   The patterns of demand.

personal computers, raw materials or for producers' goods were 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 then 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 feedback 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 a 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, Clark, and Kantrow 1983) and the empirical story of the industrial dualism in the automobile industry. Some authors (Davis 1987; Pine 1993) 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. However, despite the attempt by large firms to improve flexibility, mass customization has not been put to work yet.

4.   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 always has 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 investigating *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 (Malerba and Orsenigo 1995; Pavitt 1984). This model provided a theoretical basis to introduce a demand-based taxonomy and calls for empirical analysis.

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Appendix

Proof of Lemma 1 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

$$q^* - p = \bar{q} - \bar{c}, \tag{A1}$$

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 favor of firms producing the quality good:

$$p(q^*, t) = q^* - \bar{q} + \bar{c} \tag{A2}$$

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 form the utility function, they would sell the same quantity but at a lower price and, thus, they would not maximize their profits. If $p > \bar{c}$ they would face competition from non-innovative firms. ∎

Proof of Lemma 2 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. ∎

Proof of Lemma 3 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. ∎

Proof of Lemma 4 We first prove (7). Firms aiming at introducing product innovation, choose $w_{j,t}$ in order to maximize the flow of expected profit over time:

$$E(\pi_{j,t}) = \varepsilon w_{j,t} W_{t+1} - w_{j,t}, \tag{A3}$$

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:

$$\text{if } w_{j,t} > 0 \longrightarrow \varepsilon W_{t+1} = 1$$

or

$$\text{if } w_{j,t} = 0 \longrightarrow \varepsilon W_{t+1} \leq 1 \tag{A4}$$

Kuhn–Tucker conditions explain that if investments in R&D are positive, expected profits (A3) 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:

$$W(t+1) = \int_{t+1}^{\infty} e^{-(r + \varepsilon w_{j,t+1})t} \pi_{t+1} \, \mathrm{d}t = \frac{\pi_{t+1}}{r + \varepsilon w_{j,t+1}} \tag{A5}$$

Equation (A5) involves that, the expected value of introducing the next innovation is equal to the discounted value of profits over an interval with length $1/\varepsilon w_{j,t}$. 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 (A5) illustrates that the incumbent owning the best quality does not invest in R&D: 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 (A5) can be re-arranged as:

$$rW_{t+1} = \pi_{t+1} - \varepsilon w_{j,t+1} W_{t+1} \tag{A6}$$

The flow value of owning the next best technology is equal to the monopolist profits in the submarket S_j minus the probability of loosing all the value because a new innovation is introduced. In equilibrium, both Kuhn–Tucker conditions and (A6) should be fulfilled. Thus, substituting (A4) and (5) in (A6) we obtain (7).

Mutatis mutandis, the proof holds also for R&D investment in process innovation (Equation (8)).
∎

Proof of Lemma 5   Consider the case when R&D investments are positive. Substituting (7) in (3) and (8) in (4) and re-arranging, we obtain (9) and (10). ∎

Please note that we do not discuss the impact of the number of firms upon innovativeness. Dasgupta and Stiglitz (1980) and Loury (1979) suggest a negative a negative correlation between number of firms and investment in R&D. However, Lee and Wilde (1980) show exactly the opposite case with different assumptions. Sutton (1998) suggests, as solution of this dilemma, to look at the relationship between fixed costs and marginal costs. We did not want to enter this debate because the market structure is not the issue of this paper and, for this reason, the number of firms does not enter in the equation: we address the impact of demand upon firms' trade-off between product innovation and process innovation. The number of firms affects symmetrically this trade-off. This holds even in the case of free entry where expected profits are zero, but still incentives for the two types of innovations are different.