Knowledge cumulability and path dependence in innovation persistence[1]

Francesco Crespi
Dipartimento di Economia, Università Roma Tre
BRICK (Bureau of Research on Innovation Complexity and Knowledge), Collegio Carlo Alberto

Giuseppe Scellato
Dipartimento di Ingegneria Gestionale e della Produzione, Politecnico di Torino
BRICK (Bureau of Research on Innovation Complexity and Knowledge), Collegio Carlo Alberto

(Revised version, March 2014)

1. Introduction

The theoretical and empirical assessment of the determinants of firm-level innovation persistence in time has important implications for our understanding of knowledge production processes, long-run industry dynamics, as well as for the evaluation of the expected impacts of specific policy tools to sustain innovative activities. The theme of innovation persistence in recent years has attracted the interest of scholars along different research perspectives, ranging from the economics of knowledge, to the economics of organization and the economics of innovation (Malerba et al. 1997; Cefis and Orsenigo, 2001; Peters, 2009; Antonelli et al., 2012; Clausen and Pohjola, 2013). Indeed, the theoretical reasoning about firm-level persistence of innovation activities is deeply rooted in the Schumpeterian view of industry dynamics. In the Schumpeter Mark I regime, technological change follows a process of creative destruction in which innovation creates just temporary monopoly power, with new and innovative firms replacing exiting firms. On the contrary, according to the Schumpeter Mark II regime, technological change is the outcome of a gradual process of technological accumulation. In particular, the cumulativeness of knowledge and its tacit component contribute to generate entry barriers, economies of scale and 'success breeds success' dynamics, leading to higher persistence of innovation (Malerba and Orsenigo, 1995).

As will be discussed later in this chapter, the sources of persistence have been subsequently addressed along different perspectives, going beyond explanations that refer just to sectoral or technological regimes. In so doing, the study of firm-level innovation persistence over time has proven to be a good viewpoint to observe and interpret patterns of data that have implications for diverse areas of enquiry. First, the enquiry on the sources of innovation persistence clearly contributes to our understanding of the presence of persistent heterogeneity in firms'

[1] This paper is part of the research project 'Policy Incentives for the Creation of Knowledge: Methods and Evidence' (PICK-ME), funded by the European Union D.G. Research with the Grant number 266959 within the context Cooperation Program / Theme 8 / Socio-economic Sciences and Humanities (SSH).

performances, in line with the legacy of studies building on the seminal contributions by Nelson (1991) and Dosi and Malerba (1996). Secondly, the topic of innovation persistence is strictly related to the literature that has addressed the complex relationship between market structures and innovation (Sutton, 1998, Gilbert 2006, Aghion et al. 2005). Third, the presence of persistent innovation patterns at the firm level can be interpreted as the result of the capability of firms to exploit dynamic capabilities to sustain competitive advantage as highlighted by management studies (Teece, 2007). In this context, the role of knowledge cumulativeness and the relevance of strategic decisions to leverage internal and external knowledge emerge as crucial in shaping path dependent dynamics of innovation persistence (Antonelli et al., 2013b). Once again, this finding points to the centrality of the notion of path dependence in economic theory (David, 1997; Colombelli and von Tunzelmann, 2011). Finally, the investigation of the drivers of persistent innovation can be relevant for innovation policy studies, under the hypothesis that different types of policy instruments have diverse likelihood to induce long lasting effects on firms' innovation incentives.

Recent contributions have highlighted how the correct identification of the types of *non-ergodic* processes through which firms persistently innovate is a nontrivial task and empirical results vary significantly according to the indicators adopted to measure innovation outcomes along time. However, there have been significant advancements in the empirical tools for the study of persistency. Such methods include the use of dynamic panel data models that allow to properly account for firm-specific unobservable heterogeneity and hence allowing the identification of true state persistence, depurating the data from spurious effect (Peters, 2009; Raymond at el. 2010). Moreover, transition probability matrixes have been widely adopted to provide descriptive evidence on the dynamics of innovation persistence and its path dependent character (Antonelli et al. 2013a).

The recognition that innovation is a highly differentiated phenomenon that is associated with diverse strategies of firms and characterised by remarkable industry and country specificities, has led researchers to try to use an array of different innovation indicators. In this respect, the availability of survey data (e.g. the European Community Innovation Surveys –CIS) has opened up a great opportunity for detailed investigations of the variety of innovation processes. These sources of data have provided researchers with new information on the innovative efforts (including but not limited to R&D investment) of firms and the diverse strategies that lead to the introduction of new products, new processes and new organisational behaviours (Archibugi and Pianta, 1996).

Available firm-level evidence suggests that the actual degree of innovation persistence varies according to the indicator adopted (Duguet and Monjon 2004): while the works that have used patents as indicators suggest that persistence is weak, exhibiting strong values only in the case of top patentees, empirical analyses based on survey data found stronger evidence of innovation persistence, particularly for product innovation. Furthermore, the complementarities among different types of innovation activities (i.e. product or process innovation) appear to be crucial in shaping different patterns of persistence (Clausen and Pohjola 2013; Antonelli et al. 2012), including the case of organizational innovation (Le Bas et al. 2011, Latham and Le Bas, 2006).

The objective of this chapter is to provide a critical overview of both the extant evidence on innovation persistence and the underlying theoretical frameworks that can provide guidance on the identification of the actual determinants of such persistence. In particular, the paper shows that the largest part of the empirical contributions reviewed provides evidence in favour of the presence of path dependent persistency patterns in innovation efforts at the firm level. Such an evidence is interpreted within a theoretical framework based on the two fundamental concepts

of internal and external knowledge cumulability and dynamic capabilities, which allow us to interpret the path dependent character of innovation persistence. The overall evidence on innovation persistence and the analysis on how such persistence is related to knowledge properties is discussed in terms of implications for innovation and technology policies[2].
The reminder of the chapter is organized as it follows. Section two discusses the main theoretical explanations for innovation persistence. In section three we discuss the specific link between innovation persistence, knowledge cumulativeness and path dependence. Section four is dedicated to a review of recent econometric studies on the topic. Finally, in section five we draw the main conclusions and policy implications, and highlight areas of research in this specific field that seem to deserve further investigations.

2. The standard economics of innovation persistence

The seminal contribution by Arrow (1962) addressed the incentives to innovate of a monopolist. Because of the presence of a "replacement effect", a monopolist gains less from innovating than does a competitive firm which converts a formerly competitive market into a monopoly through innovation. This approach based on the "replacement effect" would predict limited persistence in innovation. Gilbert and Newberry (1982) have studied a more specific case: a monopoly threatened by a potential entrant. In this case it is possible to demonstrate, under very general assumptions, that, because entry will reduce its profit, the monopolist's incentives to remain a monopolist is greater than the entrant's incentive to become a duopolist. There is clearly an asymmetric effect between the incumbent whose new innovation will destroy rents generated from prior innovations and the prospective entrant. Since these early works many scholars have contributed to our understanding of the sources of observed persistence by integrating the incentive based approach. In particular, the literature has traditionally shed attention upon two main factors that might explain the capability of firms to maintain high innovation rates along time: the role of sunk-costs and barriers to entry and exit in the innovation activity; the presence of a virtuous process linking firm technological success, superior economic performance and larger amounts of financial resources to be invested in R&D activities. Below we briefly summarise the key elements of such theoretical frameworks.

2.1 The role of sunk costs and entry barriers

The generation of technological knowledge is an activity characterized by significant indivisibility and learning (Stiglitz, 1987) and the production of new knowledge deriving from R&D efforts is affected by substantial sunk costs (Máñez et al., 2009). R&D related assets are typically non-redeployable, their economic returns are defined in the long term and they require smooth investment plans. Such characteristics contribute to generate exit barriers and make technological innovation a systematic component of the firm strategy, once the firm has incurred the non recoverable R&D start-up costs. Sutton (1991) has extensively analysed the concept of endogenous sunk costs, including R&D and advertisement, as an explanatory factor behind the evidence of many manufacturing industries becoming dominated by a few firms as

[2] The analysis of the implications in terms of firms' economic performances is left outside from the discussion as it is beyond the scope of the chapter.

they grow to a large size. The peculiar aspect of Sutton's approach (1991, 1998) refers to the distinction between exogenous sunk costs (traditional fixed costs related to the production technology) and endogenous sunk costs, which are the results of an intentional decision of incumbents to increase their price-cost margin and whose size does not depend on the level of production. In presence of endogenous sunk cost, even in the case of an expansion in the demand, there would be a lower bound in industry concentration and the number of active firms might also get smaller. Hence, the endogenous sunk costs are likely to induce persistency in innovation.

2.2 The 'success-breeds-success' effect and financial constraints

According to the Schumpeterian Mark II model firms able to introduce an innovation at time t can be able to earn profits above the norm for a long period of time. Such, quasi-rents generated by an early innovation can be partly used to fund further R&D expenditures. High levels of R&D expenditures consequently increase the opportunity to generate further innovations and simultaneously keeping high levels of profit and high rates of introduction of innovations. In this respect the 'success breeds success' hypothesis asserts that innovation feeds profitability, which later funds innovation activities (Flaig and Stadler, 1994; Latham and Le Bas, 2006). Successful innovation activities have a positive impact on the conditions for follow on innovations by providing the firm with higher permanent market power, by reducing financial constraints as well as by broadening the space of available technological opportunities. There is a large and consistent evidence on financial constraints to innovation investments (Hall and Lerner, 2009) which has highlighted how the limited capability to access external financial sources significantly bound the innovation potential especially of small firms. Financing constraints are more likely to occur for innovative firms because their investments returns are uncertain, they have little collateral to secure firms' borrowing and their capital, which is mostly intangible, is also difficult to be redeployed in alternative settings (Himmelberg and Petersen, 1994; Scellato, 2007). In particular, the presence of liquidity constraints on capital investments due to capital market imperfections, tend to delay the initial start of in-house research and development activities for product enhancement (Carpenter and Petersen, 2002). The fact that firms have to rely mostly on internal resources to finance R&D projects generates an additional factor inducing the emergence of innovation persistency patterns.

3. Knowledge cumulability and path dependence in the persistence of innovation

The notion of path dependence provides a comprehensive framework for the analysis of dynamic processes and indeed offers the analytical tools to understand why early innovators are likely to experience rates of introduction of innovation persistently above the average (David, 1997; Antonelli, 1997). The existence of persistence phenomena related to the introduction of innovations can be in fact hardly reconciled with the neoclassical paradigm where innovation is a "manna from heaven", equally distributed among firms and in space. On the contrary, this evidence suggests that innovation exhibits the typical dynamic traits of a non-ergodic process in which history is important as it affects the likelihood of the different possible states in which the process may end up (David, 2007). However, a non-ergodic process may be either *past dependent*, when the features of the process are fully and exhaustively defined at its onset, or *path*

dependent when irreversibility affects its dynamics and yet small, contingent events along the process may change its key characteristics, such as path, speed and destination (David, 1997; Antonelli, 2006).
In this respect, innovation persistence would be *past dependent*, and consequently fully determined by the introduction of the first innovation, if firms built long-lasting innovating capabilities after the introduction of the first innovation. This result would be consistent with the resource-based theory of the firm, which explains innovation persistence as the result of intrinsic characteristics of the firm. In this interpretative framework, innovation capabilities are time-invariant endowments that display their effects. Firms are able to learn but innovation persistence is fully driven by the initial allocation of innovation capabilities.
On the contrary, as it will be discussed in the next section, there is evidence that not only initial conditions are relevant for explaining persistence processes but contingent events significantly affect the dynamics of the process. This suggests that innovation persistence is a *path-dependent* process as opposed to a *past dependent* one, in which the probability of introducing an innovation at time t is influenced by previous innovative activities but the transition probability might change over time because of the effects of internal and external contingent events.
In our view the role of path dependence in innovation persistence can be framed by integrating the different theoretical ingredients stemming from the economics of knowledge and the economics of organization.

3.1 The role of knowledge cumulability

In the last decades, the economics of knowledge has made important steps forward in the analysis of the characteristics of knowledge as an economic good (Antonelli and Colombelli, 2013). In particular, on the one hand, the knowledge generation function approach allowed economists to fully appreciate the need to explicitly consider knowledge as the output of a dedicated activity and take into account the variety of inputs, complementary to R&D expenditures, that make possible the generation of new knowledge (Nelson, 1982). On the other hand, knowledge has been recognized to be at the same time an input in the generation of new knowledge and in the production of other goods (David, 1993).
In this context, building on the arrovian analysis of knowledge as an economic good (Arrow,1962 and 1969; Nelson, 1959) the process of knowledge generation can be understood as a recombinant process where existing bits of knowledge enter as inputs in the generation of new ideas (Weitzman,1996, 1998; Antonelli et al., 2012). This approach shed new light on the role of knowledge indivisibility and hence, non-exhaustibility, cumulability and complementarity (Antonelli and Colombelli, 2013) in the generation of new knowledge. In so doing the path dependent character of the knowledge generation process could be fully appreciated. At each point in time the generation of new technological knowledge is the result of a process of search, identification and use of bits of knowledge previously generated and stored in the stock of competence and knowledge accumulated in the past (Scotchmer, 1991). Therefore, the current levels of research efforts of each organization determine the rate and direction of innovative activities but only within a context that is shaped by knowledge accumulated in the past both inside and outside the organization (Antonelli, 2011).

The fundamental role of the stock of knowledge as an input into the generation of new knowledge allows the understanding of its non-ergodic character and, hence, to correctly interpret persistence phenomena in innovation activities. Firms that have been able to start generating new technological knowledge can rely upon their own output to generate new

additional knowledge at lower costs. Moreover, since learning, together with research activities, is a major source of new knowledge, dynamic increasing returns are likely to characterize the performance of innovation activities: the larger is the cumulated size of innovation activities carried on and the larger are the positive effects on costs. In this respect, Stiglitz (1987) has added an important dynamic element with the notion of learning to learn: firms that have started to learn about the generation of new knowledge enjoy distinctive dynamic increasing returns as they are better able to learn in the subsequent attempts to generate new knowledge. By innovating, the firm explores a process of learning and discovers new ideas by recombining (re-arranging) old ones (Weitzman, 1996). Moreover, the accumulation of knowledge and the creation of routines to valorise and exploit it within the same organization eventually lead to the creation of *dynamic capabilities* that, as it will be discussed, may favour the systematic reliance upon innovation as a competitive tool (Teece et al. 1997).

3.2 The role of external knowledge

A large number of empirical studies confirm the pervasive role of technological spillover in favouring the economic performances of clustered firms in terms of output, employment and innovation. The subsequent literature has interpreted these empirical findings as reliable clues to assessing the positive effects of knowledge externalities on the rate of introduction of technological changes by firms that are able to use external knowledge as an input in their own innovation processes (Acs, Anselin, and Varga 2002; Fritsch and Franke 2004).
In this respect, the recombinant approach enables to appreciate the central role of two important inputs into the generation of new technological knowledge such as the knowledge base of each firm as qualified by stock of knowledge that each firm possess, and the knowledge that are external but complementary to the research activities undertaken by each firm (Antonelli, 2011). The access to high quality pool of external knowledge, in fact, may alter the current amount of knowledge that each firm is able to generate. At each point in time, no single agent in fact possesses all the necessary bits of knowledge to be used as inputs in the knowledge generation process. On the contrary, agents need to access the variety of knowledge items that are available at the system level. Hence, the search of external knowledge is necessary and its acquisition is the result of an intentional activity. The access to external knowledge is in fact possible only if dedicated resources are devoted to search, identify and eventually recombine the external elements of knowledge with the internal ones. This implies that current research efforts are a necessary investment to access, learn and absorb the stock of existing external knowledge generated by third parties.
Following this approach, external factors add to internal ones and shape the context in which the persistence of innovation occurs. The external conditions, namely the quality of local pools of knowledge and the strength of the Schumpeterian rivalry, together with the internal conditions, in particular the level of dynamic capabilities, exert a specific and localized effect on the persistent introduction of innovations. Because externalities are internal to the local system in which firms are embedded, the changing conditions exert a path-dependent effect on the sequence of innovations (Antonelli et al., 2013a). As internal factors, external factors are contingent because the structure of the system in which external knowledge is generated tends to change as a result of the introduction of innovations. At each point in time, the networks of interactions and the types of transactions on factor and product markets change. Yet, at each point in time, the architecture of the system and the market exert a strong effect on the ability of firms to access and use external knowledge and to rely on it for the introduction of further innovations as a competitive tool.

3.3 The role of dynamic capabilities

As discussed so far, knowledge cumulability, related to knowledge indivisibility and knowledge non-exhaustibility, plays a central role in path dependent innovation persistence. The introduction of further innovations is easier for firms that can command a larger internal knowledge base and have access and capability to use larger knowledge bases from other agents operating in the external environment (Antonelli, 2008 and 2011; Colombelli and von Tunzelmann, 2011). For this reason, the effects of internal and external knowledge cumulability are typically path-dependent. Knowledge accumulated in the past exerts a strong influence in the future generation of new knowledge. Internal and external knowledge cumulability affect the dynamics of economic processes because the knowledge base that each firm can access and use internally and externally shapes the probability of the generation of new knowledge. Such effects can change over time because the rates of accumulation and the conditions of access are not fixed.

Past knowledge, however, is not a single, deterministic factor: management strategies appear to be crucial in shaping the amount of knowledge that each firm is able to generate at each point in time and in sustaining persistent innovative activities through R&D investment choices and other decisions related to the acquisition of specific pieces of external knowledge (Antonelli et al., 2013a). In this respect, the economics of organization has shown that repeated interactions between the accumulation of knowledge and the creation of routines to valorize and exploit it within the same organization eventually lead to the creation of dynamic capabilities that favour the systematic reliance upon innovation as a competitive tool (Nelson and Winter 1982; Rothaermel and Hess 2007; Verona and Ravasi, 2003). Dynamic capabilities are defined as 'the subset of competence/capabilities which allow the firm to create new products and processes, and respond to changing market circumstances' (Teece et al., 1997: 510). 'If an enterprise possesses resources/competences but lacks dynamic capabilities, it has a chance to make a competitive return (and possibly even a supra-competitive return) for a short period; but it cannot sustain supra-competitive returns for the long term except due to chance' (Teece, 2007: 1344). In particular, only firms able to leveraging their dynamic capabilities can innovate persistently over a long period of time.

This framework emphasizes that the past displays a relevant impact on current and future performances. However, the dynamic capabilities approach recognizes that the business enterprise is shaped but not necessarily trapped by its past. Management can make big differences through investment choice and other decisions. The generation of new knowledge and the introduction of innovations are in fact the conditional results of a creative and localised reaction that occurs when firms face unexpected events in both factor and product markets (Antonelli, 2008 and 2011). The positive loop between accumulation of knowledge, generation of dynamic capabilities and continuous innovation performance is clearly sustained by the contingent generation of extra profits that can feed the process. Hence, managers can act creatively and strategically for shaping firms' paths. It remains possible to get portions of space – within a corridor constraint by path dependent dynamics – in which creative solutions could be implemented through managers decisions (Antonelli 2011; Vergne and Durand, 2011; Le Bas and Scellato, 2013).

We still have limited empirical evidence but the few available contributions that have tried to link innovation persistence, dynamic capability and strategic approaches seem to suggest that indeed, in addition to industry specificities and technological regimes, firm-level innovation strategies do matter. Firm heterogeneity in the form of strategic differences across firms

constitutes a key driving force behind a firm's probability to innovate over time (Pohjola et al. 2012). In this perspective firms focusing their strategy on acquisition, assimilation and exploitation of externally available knowledge are able to continuously renew their knowledge stock and strengthen their dynamic capabilities. Hence, managers can deal with, and even take benefit from, path dependence if they are able to select the appropriate self-reinforcing mechanisms along the capability paths that emerge from the firm–environment interaction (Vergne and Durand, 2011). Management strategies appear to be crucial to sustain superior innovation performance over time through investment choices and other decisions related to the leveraging of dynamic capabilities and the exploitation of strategic assets. Managerial contingencies in fact affect the non-ergodic dynamics of innovation persistence (Clausen et al. 2013; Antonelli et al., 2013b).

The recognition of the relevance of internal and external knowledge cumulability in the generation of innovations allows us to appreciate how dynamic capabilities co-evolve with firm innovation persistence in a path dependent way (Le Bas and Scellato, 2013). There is co-evolution as a very general form of adaptation when the strategic actions taken by firms have a certain impact on their environment and subsequently on their future evolution as well. The access conditions to the local pools of knowledge that engender externalities at the firm level are clearly endogenous to the system as they are emergent properties of a system that is itself exposed to changes at both macro and the meso levels. For the same reason, it can be argued that the internal characteristics that affect innovation persistence are subject to a time variability which shapes the dynamics of the process in a step-wise manner. Hence, persistence is path dependent rather than past dependent: knowledge cumulability shapes the process together with a number of contingent and localized conditions that exert significant effects on the non-ergodic dynamics of the process and change its path, its speed and its duration (David, 1997 and 2007; Antonelli, 2008; Antontelli et al., 2013b). This implies that innovation persistence can no longer be regarded as the result of an intrinsic capability of the firm that behaves as an endowment, given once and lasting forever; rather, it should be regarded as the conditional result of a systemic and interactive process that keeps changing over time.

3. Empirical evidence on innovation persistence

The different frameworks that have been summarized in the previous paragraphs provide complementary and self-reinforcing rather than competing hypotheses about the source of persistency. The concept of endogenous sunk costs is clearly correlated to the generation of internal competencies through the investment in learning. The effects of knowledge accumulation and the 'success breeds success' hypothesis interplay giving rise to a virtuous circle in which profits fund R&D and other technology activities and, a time period later, they enable the learning process to continue (Le Bas and Scellato, 2013). In this respect, the assessment of the prevailing factors is likely to depend on industry and technology contingent conditions. In this section we review a selection of available econometric evidence on innovation persistence in which we highlight the relevance of the different theoretical frameworks.

The empirical analysis of the persistence of innovation activities at the firm level is a relatively recent undertaking in the economic literature. In the special issue of the International Journal

of Industrial Organization dedicated to the economics of path dependence, Malerba, Orsenigo and Petretto (1997) pave the way to this new area of investigation. Currently available evidence can be grouped into a subset of studies that build upon the analysis of large samples of patents and a subset of empirical studies that make use of data from innovation surveys repeated along time. In the following paragraphs we provide a review of the most relevant econometric studies, highlighting their specific contributions to our understanding of the relative importance of the different potential drivers of the analyzed phenomenon. In table 1 we show a synopsis of the reviewed articles. The review builds on the introductory article by Le Bas and Scellato (2013) for a recent special issue on the theme of innovation persistence.

3.1 Empirical studies based on patent data

Malerba et al. (1997) tested the evidence provided by the OTAF-SPRU data base for five European countries (Germany, France, UK, Italy and Sweden) for the period 1969-1986 for 33 technological categories. The econometric evidence confirms the existence of persistence patterns in innovative activities, with the contemporaneous presence of serial innovators and persistent non innovative firms.. The paper does not investigate the determinants and the features of the persistency but rather analyses its effects. It shows in fact that the persistence of the innovative activity plays an important role in explaining the concentration of technological activity, that is the share of patents granted to the firms, the stability of the ranking of innovators and their innovative intensity. Geroski, Van Reenen and Walters (1997) study the innovative history of UK firms in the period 1969-1988 using patent records and the introduction of 'major' innovations. The empirical analysis is based upon the estimate of a proportional hazard model to capture the drivers of the duration of innovation spells. Results seem to indicate that "success only follows really major success, and then for only a limited period of time". Indeed patent data seem to suggests that just a minority of firms is persistently innovative. The somehow weak persistence of patenting activity is confirmed by Cefis and Orsenigo (2001) who apply a transition probability matrix approach to analyze the persistence of innovative activity in the years 1978-1993 for a samples of about 1400 manufacturing firms in each country, respectively in Germany, Italy, Japan, US and France. The results show that on average innovative activities are characterized by a weak persistency. More specifically, both low-innovators and top-innovators tend to remain in their classes. Much of the persistence in innovation activities however seems to be determined by the 'economic' persistency of the firms themselves. This study provides original evidence about inter-sectoral differences that confirm the importance of technology-specific factors. A subsequent study by Cefis (2003) focuses on 577 UK patenting firms in the period 1978-1991. Also in this case the transition probability matrix shows little persistence in general and it is characterized by a strong threshold effect. Only great innovators, in other words, have a stronger probability to keep innovating. Cefis and Ciccarelli (2005) contribute the literature on the persistence of innovation by exploring the persistence of the effects of innovation rather than the persistence of innovation *per se* and its causes. Their paper investigates the effects of innovative activity on profitability using a panel of 267 UK firms in the period 1988-1992. The innovativeness of firms is measured by means of patent statistics. The econometric model tests with both a Bayesian approach and classical estimation methods the hypothesis that past innovations exert a short and long term positive effect upon the profits of firms. The results of the Bayesian approach confirm that the impact of innovation on profits is cumulative and long lasting. This work provides a tangential contribution to the identification of persistence of innovation, as it confirms that because past innovations have a long lasting effect on profitability, innovation at

time t can be positively influenced by past innovation via the greater availability of financial resources. The approach by Alfranca, Rama and von Tunzelmann (2002) is quite original in this context. They study the persistence of innovation in a specific sector with a focus on a well-identified group of firms. They analyze 16,698 patents granted in the United States from 1977 to 1994 to 103 global firms in the food and beverage industry. They test whether patent time series are trend stationary or difference stationary to detect how large the autoregressive parameter is and how enduring is the impact of past innovation on current ones in these companies. Their results show that the 17 years patent series are not consistent with the random walk model. The evidence confirms that global firms, both of very large and smaller size, in this industry, exhibit a stable pattern of technological accumulation in which "success breeds success". Latham and Le Bas (2006) make an important contribution to the field with a systematic investigation of the persistence on innovation based upon the analysis of French and US patents. Their results confirm that the persistence of innovation takes place, but only and mainly in a limited time span. They test the hypothesis that size and profitability exert a major positive effect on the spell of innovation activities: the larger are the firms and the larger their profitability and the longer the time spell over which firms are able to sustain a sequence of innovations. The work coordinated by Latham and Le Bas expands further the investigation with the analysis of the persistence of innovation among individual inventors, as distinct from firms. The persistence of innovation is stronger among individuals than among firms. This result provides strong evidence about the important role of 'serial inventors': creative individuals that are characterized by high levels of productivity and are able to generate a persistent flow of inventions through time.

3.2. Empirical studies based on survey data

The use of survey data allows differentiating the analysis of persistence as captured by different input and output indicators of innovation activities, including R&D activities, product and process innovations, organizational innovations. The joint use of such indicators makes it possible to account for the effects of complementarities between different types of innovation and for the interrelations between innovation inputs and outputs. Indeed, the rich information on firm level characteristics, deriving from survey data can improve our understanding of the actual determinants of persistence and to identify the relevance of true state persistence in innovation activities and eventually qualify it as past or path dependent.

Peters (2009) provides strong evidence in favour of persistence of innovation activities both in terms of innovations inputs, in terms of R&D activities, and innovation outputs as measured by the number of innovation introduced by German manufacturing and service firms in the years 1994-2002. The research exploits the Manheim Innovation Panel. A firm is defined as an innovator when it exhibits positive innovation expenditures and has introduced a new product or a new production process. The results of the empirical investigation confirm that firms experience high levels of persistence in undertaking innovation activities: almost half of the difference across firms in the propensity to innovate between previous innovators and non-innovators in the German manufacturing industry can be explained by the state dependence, i.e. whether the firm was already involved in innovation activities tat time t-1. The persistence of innovative activities is explained by the levels of human skills, support of public funding, financial liquidity and size. Notably, the author pointed out the importance of unobserved heterogeneity, which explains a considerable amount of variation of the dependent variables. Raymond et al. (2010) find contrasting evidence. They study the persistence of innovation in

Dutch manufacturing firms using firm data from three Community Innovation Surveys (CIS), in the years 1994-2000. The innovations that each firm claims to have introduced in each period of observation is the unit of analysis. They test the hypothesis of persistence with a maximum likelihood dynamic panel data tobit model accounting for individual effects and handling the initial conditions problem. Their findings suggest that there is no evidence of true persistence in achieving technological product or process innovations. At each point in time however the shares of sales stemming from innovative products, introduced in the past have a (small) effect on the current shares of sales of innovative products. Roper and Hewitt-Dundas (2008) use innovation survey data and show that in the case of 3604 plants covered by the Irish Innovative Panel in the period 1991-2002 both product and process innovations are strongly persistent. In this case the size and ownership of plants matters: large plants that are part of multinational companies are more able to sustain the innovation process through time than smaller ones locally owned. The persistence in the introduction of product innovations is associated to strategic variables, while the persistence in the introduction of process innovations is associated to market pressure. Antonelli et al. (2012) show an empirical analysis based on a sample of 451 Italian manufacturing companies observed during the years 1998–2006. Results highlight the relevance of innovation persistence. The highest level of persistence is found for R&D-based innovation activities, witnessing the actual presence of significant entry and exit barriers to innovation activities. Moreover, they obtain more robust evidence of persistence for product innovation than for process innovation, once complementarity effects between the two types of innovation are accounted for. This research outcome can be explained by the closer link between product innovation, R&D activities and knowledge cumulability with respect to process innovation (Crespi and Pianta, 2008). The levels of R&D intensity, as measured by the two indicators R&D expenditures per employee and the share of internal R&D over total, as well as the level of fixed capital investment enhance the probability of subsequent innovation outcomes. Such result confirms the idea that R&D investment activity is associated with the presence of sunk costs that might motivate the continuous undertaking of innovation activities

Triguero et al. (2013) examine the relationship between firm-specific characteristics, technological regimes and persistence measured by innovative spells. The results are based on a sample of Spanish manufacturing firms over a period of 19 years (1990 to 2008) and show that high technological opportunities, patents, cumulativeness of learning based on previous experience and accumulated R&D, as well as the use of knowledge provided by universities, enhance persistence in innovative activity. The analyses are based on discrete-time duration models controlling for some of the existing problems in the continuous-time duration models used in previous studies. Using the same data source, Triguero and Corcoles (2013) apply a dynamic random effect panel model and find that R&D (input) and innovation (output) are highly persistent at the firm level. Among external/environmental factors, market dynamism affects R&D and innovation. Regarding firm specific characteristics, size and outsourcing also have a positive impact on both processes. Past innovative behaviour is shown to be more decisive in explaining the current state of R&D and innovation activities than external factors or firm-level heterogeneity. The crucial role of external factors in innovation persistence, as measured by total factor productivity (TFP), is further analysed by Antonelli et al. (2013a) who showed that the external conditions, namely the quality of local knowledge pools and the strength of the Schumpeterian rivalry, along with the internal conditions exert a specific and localised effect upon the persistent introduction of innovations.

Hecker and Ganter (2013) examine the persistence of technological and organizational innovation for a sample of German firms over the time span from 2002 to 2008, using a

balanced panel data from the fourth, fifth and sixth wave of the German Community Innovation Survey. Results confirm also for this dataset a significant persistency effect for technological innovation (product and process) while results are mixed in the case of organisational innovation. Clausen and Pohjola (2013) focus the innovation persistence analysis on comparing breakthrough product innovation (product innovations that are new and previously unknown to the market) and incremental innovation (innovations that are new to the firm but not new to the market). They use a panel database created by merging four waves Community Innovation Survey (CIS) and R&D survey data collected by Statistics Norway between 1997 and 2006. They find that previous innovation output persistency effects tend to override the effect of R&D in generating new innovation output. The authors interpret this as evidence of knowledge accumulation effect through innovation output over that of R&D investments. The positive and significant effect on persistence of the share of internal R&D expenditures supports this interpretation: knowledge accumulated internally within the firm has an effect over time. Interestingly, such pattern is present only in the case of radical innovations, suggesting that breakthrough product innovation is driven not just by past investment but also by 'dynamic learning effects'. Clausen et al. (2012) address the role of innovation strategies as a source of persistent innovation. Their results support the idea that the differences in innovation strategies across firms are an important determinant of the firms' probability to repeatedly innovate. In particular, they identify five innovation strategies that capture the main differences of the innovation activities. The authors employ two dependent variables: product innovation and process innovation. Their database contains information about all enterprises which have participated in at least one of the R&D surveys conducted by Statistics Norway since 1993. The results confirm the general finding in the literature that innovation is persistent at the firm level. Moreover, the find that firm heterogeneity - in the form of initial strategic differences - constitutes a relevant drivers firms' probability to keep innovating over time. The econometric results seem to suggest that the effects of innovation strategies are, in many cases, larger than the "pure" effect of lagged innovation.

Martínez-Ros and Labeaga (2009) use the Spanish database ESEE and find evidence in favor of persistence in product and process innovation. The authors highlight the importance of complementarity between product and process innovation as a determinants of subsequent innovation activities. Le Bas and Poussig (2013) use two waves of the Community Innovation Survey (2002–2004, 2006–2008) conducted in Luxembourg and show that complex innovators (i.e. those performing jointly product and process innovation) are more inclined to remain persistent innovators than single innovators. Within the group of single innovators pure product innovators have an advantage over pure process innovators.

Haned et al. (2013) analyse the impact of organizational innovation on the patterns of technological innovation persistence, using firm-level data from three waves of French Community Innovation Surveys. Their results indicate a positive effect of organizational innovation on the dynamics of technological innovation, according to various measures of organizational change that captures their degree of continuity and diversity. Such effect is more substantial for complex innovators, that is, those companies that innovate in both products and processes. In particular, the evidence suggests that the more organisational practices are implemented by the firm, the higher the probability that it will remain an innovator (although this pattern does not apply to pure process innovators). Lhuillery (2013) provides an analysis of the influence of marketing activities on innovation success and in particular on persistent innovation success, using three waves of the French CIS innovation survey covering the period 2002-2008. Results seem to indicate that innovation in marketing does not positively influence persistent innovation success in low-tech industries. The impact of innovation in marketing is

found to be more complex in high-tech industries: innovation marketing positively influences persistent innovation success for incremental innovation but negatively influences it for radical innovation. Such evidence is in line with existing literature which, for the most part, associates incremental innovation success with marketing and radical innovation success with R&D resources. Frenz and Prevezer (2013) analyse the link between technological regimes and persistence in innovation at the firm level using a balanced panel of around 4,000 firms that responded to the latest three waves of the UK version of the CIS. Key explanatory variables include measures of appropriability, cumulativeness, technological opportunity and closeness to the science base. They find strong persistence in innovation in the short run; less so, and only with respect to new-to-market product innovation, in the longer run. The extent to which firms exchange knowledge with other companies, the intensity of R&D investments, as well as their size matters in explaining innovation persistence. The authors claim that their results suggest the presence of a pattern of technological accumulation at the level of the firm rather than at the industry level (measured by the average share of new- to-market sales within the industry). High levels of technological opportunity increase the chance of persistent product innovation among the services firms. Deschryvere (2014) analyses the role of persistence of innovation output on the relationship between R&D investment and growth in SMEs. The analysis is based on an unbalanced firm-level panel of 516 firms containing 1998–2008 data from the R&D surveys and the Business Register of Statistics Finland and the Community Innovation Survey (CIS). The empirical analysis of the relationship between innovation and firm performance is performed through vector autoregression models. Results indicate that only continuous innovators have positive associations, albeit small, between R&D growth and sales growth. The correlation between sales growth and subsequent R&D growth is not always stronger for continuous innovators than for occasional innovators, particularly in the case of process innovators. Suarez (2014) discusses the concept of innovation persistence in the context of unstable economic environments. The author studies the innovative behavior of Argentinean firms using data from national innovation surveys in three distinct macroeconomic environments: the 1998–2001 economic crisis, the 2002–2004 recovery period, and the 2005–2006 growth phase. Results suggest that persistence is conditioned by firm's ability to respond to changes in the environment. The instability of the environment induced sporadic short-term innovations, with limited impact on the firms' capabilities and resources. Actual innovation persistence is observed only among firms that changed together with the environment.

The largest part of the empirical contributions reviewed seems to provide evidence in favour of the presence of persistency patterns in innovation efforts at the firm level, due to true state dependence and not driven just by firm-specific time variant unobservable factors. Still, the results also show relevant nuances that can provide further hints about the economic determinants and implication of persistence.

The early papers that have used patent-based indicators to account for persistency have found indeed a rather limited evidence of persistence. In this regard, however, it has to be remarked that patent application intensity, especially for smaller firms, might reflect to some extent the appropriation strategies adopted to secure the outcomes of innovation investments rather than the intensity of underlying innovation effort. At the same time, survey-based studies are forced to adopt a dichotomic approach given the structure of available data (whether a firm has performed or not a certain type of innovation in a certain time period) and this in turn represent a clear limitation of this second class of analyses.

However, this class of studies has provided important insights to qualify the patterns of innovation persistence, with relevant implications for the theory of the economics of

knowledge. Independently of the sectors and country analysed product innovation appears to be more persistent in time than process innovation. Different studies have explicitly investigated the complementarities between the two macro typologies of innovation highlighting that, also for the firms performing both of them, it is product innovation that drives the persistency dynamic. Moreover, radical product innovation (related to the introduction of products new to the market and not only new to the company) shows a more persistent impact on subsequent innovation persistence. Results turn to be more mixed in the case of organisational innovation and marketing-related innovation. Such type of innovation activities are indeed more sporadic, although some studies have revealed that organisational change can have an impact on the persistency of product innovation under specific circumstances. As predicted by the sunk-cost approach, expenditures in research and development, and particularly the share of internal R&D costs, show substantial persistence even after accounting for firm-specific characteristics. Finally, interesting evidence pertains the presence of an export premium: companies exporting a relevant share of their turnover tend to show a higher innovation persistence.

5. Conclusions

The reviewed empirical evidence provides key lessons on the nature of innovation activities with relevant implications regarding the theory of the firm and the relevance of the notion of path dependence in economic thinking.

The largest part of the empirical contributions reviewed in this chapter seems to provide evidence in favour of the presence of persistency patterns in innovation effort at the firm level. Such evidence confirmed the presence of true state dependence in innovative activities as the detected persistence effects showed to be robust when controlling for firm-specific time variant unobservable factors. Moreover, the contemporaneous significant influence on current innovation performance exerted by past innovative efforts and different, internal and external, contingent factors confirms the path dependent character of the identified persistence. In particular, the introduction of radically new products, which requires the development and exploitation of specific skills, seems to be more likely to induce and support subsequent persistent innovation patterns. This can be attributed to the presence of technological learning processes that eventually generate new knowledge for the innovating company. Organisational change results in increased subsequent innovation capabilities only when knowledge accumulation has already reached a significant threshold. The exporting companies have higher learning opportunities that in turn have a positive impact on firms' capabilities and innovation persistence.

The results originating from the analysis of the drivers of innovation persistence appear to be fully coherent with a theoretical framework based on the two fundamental concepts of knowledge cumulability and dynamic capabilities which allow us to fully interpret the path dependent character of innovation persistence. In this context, dynamic capabilities follows a sort of co-evolution with the intensity of firms innovation persistence in a systemic and interactive process that keeps changing over time.

The overall evidence on innovation persistence and its links with knowledge properties has also relevant implications for innovation and technology policies.

First, the recognition that innovation persistence is a path dependent rather than past dependent process implies that there is room for public intervention as firms initial conditions

can be modified along the process through properly designed policy instruments. Second, the identification of persistence in innovative activities suggests that public policies can produce long lasting effects on firms innovation performances if they are able to induce firms to shifting towards more innovative patterns. In this context cumulative process of learning of both benefiting companies and public authorities can lead to virtuous processes able to increase the overall effectiveness of policy interventions (Antonelli and Crespi, 2012, 2013). Third, the reviewed empirical evidence provides clear indications on the different potential of alternative policy instruments in inducing persistent effect on innovation performances. In particular, public efforts to sustain the introduction of product rather than process innovations or radical innovations rather than incremental ones, appear to be more effective in producing long lasting effects on firms' innovation activities. In addition, as knowledge cumulability has been found to be central in explaining innovation persistence, it is possible to conclude that when the target of public policies is centered on economic sectors characterized by high knowledge cumulability the potential long term impact of policy instruments can be maximized (Antonelli and Crespi, 2012). Moreover, the interpretation of the evidence on financial constraints to innovation investments and on the role of sunk R&D costs in innovation persistence seem to suggest the importance of policy tools addressing the financial support of the start-up phases of firm's R&D infrastructures. Finally, some empirical analyses of innovation persistence patterns have also showed the positive impact of external factors. The learning opportunities stemming from the access to localised and qualified pools of knowledge are likely to exert a positive impact on the generation of dynamic capabilities within firms. In this perspective, policies aiming at enhancing R&D networking and knowledge exchange can have a long lasting.

Despite the large number of contributions produced on the analysis of innovation persistence, extant empirical results leave unanswered some relevant questions. First, while we have convincing evidence of a link between firm-level knowledge cumulativeness and innovation performance, it has not yet been deeply investigated the relationship between specific properties of firms' knowledge bases, such as the degree coherence and variety, and their capability to continuously innovate through the exploitation of dynamic capabilities. Second, the study of innovation persistence under different technological regimes would deserve further analyses. Third, in terms of managerial implications the literature has clearly stated how individuals are decisive to the formation of dynamic capabilities (Rothaermel and Hess 2007).

This calls for further specific analyses of the role of highly talented individuals, such as serial inventors, within organizations. Fourth, external relationships have received a limited attention. Indeed, the access conditions to the local pools of knowledge that engender externalities at the firm level represent a relevant factor driving firm-level innovation persistence. With respect to these issues, the increasing availability of long panel databases for conducting empirical analyses and the possibility to make international comparisons in persistence drivers and behaviors accounting for the influence of local and national systems of innovation, will provide new opportunities to further investigate this phenomenon.

References

Acs Z.J., Anselin L., Varga A. 2002. Patents and innovation counts as measures of regional production of new knowledge, *Research Policy*, vol. 31, pp. 1069-1085, 2002.

Aghion, P., N. Bloom, R. Blundell, R. Griffith, and P. Howitt. 2005. Competition and Innovation: An Inverted U Relationship. *Quarterly Journal of Economics* 120: 701–728.

Alfranca, O., R. Rama, and N. von Tunzelmann. 2002. A patent analysis of global food and beverage firms: The persistence of innovation. *Agribusiness* 18: 349–68.

Antonelli, C. 1995. *The Economics of Localized Technological Change and Industrial Dynamics*. Boston MA: Luwers Academics Publishers.

Antonelli, C. 1997. The economics of path-dependence in industrial organization, *International Journal of Industrial Organization*, 15(6), pp. 643-675.

Antonelli, C. 2006 Path dependence, localised technological change and the quest for dynamic efficiency. In: C. Antonelli, Foray D., Hall B.H., Steinmueller E. (Eds.) *New Frontiers in the Economics of Innovation And New Technology. Essays in Honour of Paul A. David*, Cheltenham: Edward Elgar Publishing. 51-69.

Antonelli, C. 2008. *Localized technological change: Towards the economics of complexity*. London: Routledge.

Antonelli, C., ed. 2011. *Handbook on the economic complexity of technological change*. Cheltenham: Edward Elgar.

Antonelli C., Colombelli A. 2013. Knowledge cumulability and complementarity in the knowledge generation function, Department of Economics and Statistics Cognetti de Martiis. Working Papers 201305, University of Turin.

Antonelli C., Crespi F.2012. Matthew effects and R&D subsidies: knowledge cumulability in high-tech and low-tech industries, *Giornale degli Economisti e Annali di Economia*, 71 - N. 1 pp. 5-31.

Antonelli C., Crespi F. 2013. The Matthew Effect in R&D Public Subsidies: the case of Italy, *Technological Forecasting and Social Change*, 80 pp. 1523-1534.

Antonelli, C., F. Crespi, and G. Scellato. 2012. Inside innovation persistence: New evidence from Italian micro-data. *Structural Change and Economic Dynamics*. 23, no. 4: 341–353.

Antonelli, C., F. Crespi, and G. Scellato. 2013a. Internal and external factors in innovation persistence. *Economics of Innovation and New Technology* 22, no. 3: 256–280.

Antonelli, C., F. Crespi, and G. Scellato. 2013b. "Path Dependent Patterns of Persistence in Productivity Growth,"Department of Economics and Statistics Cognetti de Martiis LEI & BRICK - Laboratory of Economics of Innovation "Franco Momigliano", Bureau of Research in Innovation, Complexity and Knowledge, Collegio 201310, University of Turin.

Antonelli, C. Krafft, J., Quatraro, F. 2010. Recombinant knowledge and growth: The case of ICTs, *Structural Change and Economic Dynamics*, 21(1), pp. 50-69.

Archibugi D., Pianta M., 1996. Measuring technological through patents and innovation surveys, *Technovation*, 169, 451-468.

Arrow, K. J. 1962. Economic Welfare and the Allocation of Resources for Invention. In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, ed. R. R. Nelson, 609–626. Princeton NJ: National Bureau of Economic Research and Princeton University Press.

Carpenter R., Petersen B., 2002. Capital market imperfections, high-tech investment and new equity financing. *Economic Journal* 112: 54–72.

Cefis, E. 2003. Is there any persistence in innovative activities? *International Journal of Industrial*

Organization 21: 489–515.

Cefis, E., and L. Orsenigo. 2001. The persistence of innovative activities. A cross-countries and cross-sectors comparative analysis. *Research Policy* 30: 1139–58.

Cefis, E., and M. Ciccarelli. 2005. Profit differentials and innovation. *Economics of Innovation and New Technology* 14: 43–61.

Clausen, T.H., M. Pohjola, K. Sapprasert, and B. Verspagen. 2013. Innovation Strategies as a Source of Persistent Innovation. *Industrial and Corporate Change* 21: 553–585.

Clausen, T.H., Pohjola, M. 2013. Persistence of product innovation: comparing breakthrough and incremental product innovation" *Technology Analysis & Strategic Management*, Vol. 25, No. 4, 369–385.

Colombelli, A., and N.G. von Tunzelmann. 2011. The persistence of innovation and path dependence. In *The Handbook of the System Dynamics of Technological Change*, ed. C. Antonelli, 105–119. Cheltenham: Edward Elgar.

Crespi F., Pianta M. (2008), New Processes and New Products in Europe and Italy, *Rivista di Politica Economica*, vol. II –Marzo-Aprile, pp.119-146.

David, P.A. 1997. *Path dependence and the quest for historical economics: One more chorus of ballad of QWERTY*. Oxford University Economic and Social History Series 020, Economics Group. Oxford: Nuffield College, University of Oxford.

David, P.A. 2007. Path dependence: A foundational concept for historical social science. *Cliometrica: Journal of Historical Economics and Econometric History* 1: 91–114.

Deschryvere, M. (2014) R&D, firm growth and the role of innovation persistence: an analysis of Finnish SMEs and large firms. Small Business Economics. forthcoming, DOI 10.1007/s11187-014-9559-3

Dosi, G., Malerba F. 1996. *Organization and Strategy in the Evolution of the Enterprise*, MacMillan Press.

Duguet, E., Monjon S. 2004. Is innovation persistent at the firm level? An econometric examination comparing the propensity score and regression methods. *Cahiers de la Maison des Sciences Economiques*, Université Panthéon-Sorbonne.

Flaig, G., Stadler M. 1994. Success breeds success. The dynamics of the innovation process. *Empirical Economics* 19: 55–68.

Fritsch, M. and Franke, G., 2004. Innovation, regional knowledge spillovers and R&D cooperation. *Research Policy* 33, 245-255.

Geroski, P., J. Van Reenen, and C. F. Walters. 1997. How persistently do firms innovate ? *Research Policy* 26: 33–48.

Geroski, P., Lazarova S., Urga G., Walters, C.F. (2003), Are difference in firm size transitory or permanent?, *Journal of Applied Econometrics* 18, 47-59.

Geroski, P., Kretschmer T., Walters C. (2009), Corporate productivity growth: Leaders and laggards, *Economic Enquiry* 47 (1), 1-17.

Gilbert, R., and D. Newberry. 1982. Pre-emptive Patenting and the Persistence of Monopoly. *American Economic Review* 72: 514–526.

Gilbert, R.J., 2006. Looking for Mr. Schumpeter: Where are we in the innovation competition debate? In: Jaffe, A.B., Lerner, J., Stern, S. (Eds.), *Innovation Policy and the Economy*, vol. 6, The MIT Press, pp. 159-215.

Hall, B., Lerner, J. 2009 "The financing of R&D and innovation" NBER Working paper 15325.

Haned, N., Mothe, C., Nguyen, U. 2013., Firm persistence in technological innovation: The relevance of organizational innovation, *Economics of Innovation and New Technology*, forthcoming

Hecker and Ganter 2013 Persistence of innovation: Discriminating between types of innovation and sources of state dependence *Research Policy*, 42, 1431-144.

Himmelberg, C., and B. Petersen. 1994. R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries. Review of Economics and Statistics 76:38–51.

Huang, C.H. 2008. A note on the persistence of firms' innovation behavior: A dynamic random effect probit model approach. *Economics Bulletin* 15, no. 5: 1–9.

Huang, C-H., and C-H. Yang. 2010. Persistence of innovation in Taiwan's Manufacturing Firms. *Taiwan Economic Review* 38, no. 2: 199-231

Jang, S.-L., and J.H. Chen. 2011. What determines how long an innovative spell will last? *Scientometrics* 86, no. 1: 65–76.

Johansson, B., and H. Loof. 2010. Innovation strategy and firm performance- What is the long-run impact of persistent R&D. *Cesis Electronic Working Paper Series* no. 240.

Latham, W., and C. Le Bas. 2006. *The Economics of Persistent Innovation: An Evolutionary View*. Berlin: Springer.

Le Bas, C., and N. Poussing. 2014. Is Complex Innovation More Persistent than Single? An Empirical Analysis of Innovation Persistence Drivers. *International Journal of Innovation Management*. Vol. 18, No. 1. February

Le Bas C., Scellato, G. 2014 Firm innovation persistence: a fresh look at the frameworks of analysis. Forthcoming *Economics of Innovation and New Technology,* Forthcoming.

Le Bas, C., C. Mothe, and T.U. Nguyen. 2011. *Technological innovation persistence: Literature survey and exploration of the role of organizational innovation*. SSRN e-library, doi: 10.2139/ssrn.1969293.

Le Bas, C., C. Mothe, and T.U. Nguyen. 2014. The differentiated impacts of organizational innovation practices on technological innovation persistence. European Journal of Innovation Management. Forthcoming.

Lhuillery , S. 2013. Marketing and Persistent Innovation Success, forthcoming *Economics of Innovation and New Technology*.

Malerba, F., Orsenigo, F, 1995. Schumpeterian Patterns of Innovation, *Cambridge Journal of Economics* 19(1), pages 47-6.

Malerba, F., L. Orsenigo, and P. Petretto. 1997. Persistence of innovative activities sectoral patters of innovation and international technological specialization. *International Journal of Industrial Organization* 15: 801–26.

Manez, , J. A., Rochina-Barrachina, M. E., Sanchis, A., Sanchis, J. A. 2009 The Role of Sunk Costs in the Decision to Invest in R&D. The Journal of Industrial Economics, Vol. 57, Issue 4, pp. 712-735

Martínez-Ros, E., and J.M. Labeaga. 2009. Product and process innovation: Persistence and complementarities. *European Management Review* 6: 64–75.

Nelson, R.R. 1982. The role of knowledge in R&D efficiency, *Quarterly Journal of Economics* 97, 453-470.

Nelson, R. R. 1991, 'Why do firms differ and how does it matter?' Strategic Management Journal, 12, 61–74.

Nelson, R., and S. Winter. 1982. *An evolutionary theory of economic change.* Cambridge, MA: The Belknap Press of Harvard University Press.

Peters, B. 2009. Persistence of innovation: Stylized facts and panel data evidence. *Journal of Technology Transfer* 34: 226–243.

Prevezer M., Frenz M. 2013. What Can CIS Data Tell Us about Technological Regimes and Persistence of Innovation? *Industry and Innovation*, 19:4, 285-306

Raymond, W., P. Mohnen, F.C. Palm, and S. Schim Van Der Loeff. 2010. Persistence of innovation in Dutch manufacturing: Is it spurious? *Review of Economics and Statistics* 92, no. 3: 495–504.

Rogers, M. 2004. Networks, firm size and innovation. *Small Business Economics* 22, no. 2: 141–153.

Roper, S., and N. Hewitt-Dundas. 2008. Innovation persistence: Survey and case-study evidence. *Research Policy* 37: 149–62.easuring

Rothaermel, F.T., and A.M. Hess. 2007. Building Dynamic Capabilities. *Organization Science* 18, no. 6, 898–921.

Scellato, G. 2007. Patents, Firm size and Financial Constraints: an Empirical Analysis for a Sample of Italian Manufacturing Firms, *Cambridge Journal of Economics*, Vol. 1, 55-76.

Scotchmer S. 1991. Standing on the Shoulders of Giants: Cumulative Research and the Patent Law, *Journal of Economic Perspectives*, 5(1), pp. 29-41

Stiglitz, J. 1987. Learning to Learn, Localized Learning and Technological Progress, In *Economic Policy and Technological Performance*. Dasgupta and Stoneman (eds.), Cambridge University Press. 125-153.

Suarez, D. (2014) Persistence of innovation in unstable environments: Continuity and change in the firm's innovative behavior. *Research Policy*, 43, pp. 726-73.

Sutton, J. 1991, Sunk Costs and Market Structure, Cambridge, MA: MIT Press.

Sutton, J. 1998, Technology and Market Structure, The MIT Press.

Teece, D. 2007. Explicating Dynamic Capabilities: the Nature and Micro-foundations of (Sustainable Enterprise Performance. *Strategic Management Journal* 28: 1319–1350.

Teece, D.J., G. Pisano, and A. Schuen. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal*, 18: 509–533.

Triguero, A., Córcoles,D., Cuerva, M. 2013. Measuring the persistence in innovation in Spanish manufacturing firms: empirical evidence using discrete-time duration models, *Economics of Innovation and New Technology,* forthcoming.

Triguero-Cano, A. and D. Corcoles-Gonzales. 2013. Understanding the innovation: an analysis of persistence for Spanish manufacturing firms. *Research Policy* 42: 340–352.

Vergne, J.-P., and R. Durand. 2011. The path of most persistence: an evolutionary perspective on path dependence and dynamic capabilities. *Organization Studies* 32: 365–382.

Verona G., Ravasi D. 2003. Unbundling Dynamic Capabilities: An Exploratory Study on Continuous Product Development, *Industrial and Corporate Change*, 12 (3): 577-606.

Weitzman, M. L. 1996. Hybridizing growth theory. *American Economic Review* 86: 207–212.

Weitzman, M. L., 1998. Recombinant growth, *Quarterly Journal of Economics*, 113, 331-360.

Table 1 Main recent empirical contributions on innovation persistence.

Authors	Country time period, industry	Type of econometric model	Main results
Alfranca Rama and von Tunzelmann (2002)	USA 103 global firms in the food and beverage industry (1977-1994)	Time series analysis	Global firms exhibit a stable pattern of technological accumulation in the 'success breeds success' perspective. Potential stimuli to technological change have only transitory effects on innovation.
Antonelli, Crespi, Scellato (2012)	Italy, (1998-2006) Sample of 451 manufacturing firms	Transition probability matrixes and dynamic random effects probit model	Level of persistence differs according to the typology of innovation: higher persistence for R&D investments and for product innovation
Antonelli, Crespi Scellato (2013a)	Italy, (1996-2005) Sample of 7020 manufacturing firms	Transition probability matrixes and dynamic discrete panel data	Evidence of path dependent persistence due to both internal and external factors
Cefis (2003)	UK Patent data on 577 firms (1978–1991)	Transition probability matrixes	Evidence of little persistence characterized by a strong threshold effect. Only great innovators have a stronger probability to keep innovating
Cefis and Ciccarelli (2005)	UK Patent data on (1988-1992)	Bayesian approach and classical estimation methods	Positive effect of innovation on profits. Persistence of profit differentials
Cefis and Orsenigo (2001)	Germany, Italy, Japan, US and France (1978–1993)	Transition probability matrixes	Evidence of weak persistence; both low innovators and great innovators generally remain in their classes
Clausen, Pohjola, Sapprasert, Verspagen (2013)	Norway, 1995-2004	Dynamic random effects probit model	Innovation strategies provide an important source of innovation persistence. Scale of persistence differ between product/ process innovation and low/high tech sector
Clausen and Pohjola (2013)	Norway 1997-	Dynamic random effects	breakthrough product innovation is persistent at the firm level and driven by dynamic learning effects.

	2006	probit model	
Duguet and Monjon (2004)	France 621 manufacturing firms (1986–1996)	Propensity score matching models	Strong evidence of innovation persistence
Huang (2008)	Taiwan 1998-2003	Dynamic random effect probit model	Effect of state dependence+ dynamic increasing return to innovation. Importance of initial conditions
Huang, Yang (2010)	Taiwan, 1990-2003	Dynamic random effect probit model	True state dependence especially within firms rather than between industries. Importance to take into account initial conditions and individual unobserved heterogeneity.
Jang and Chen (2011)	Taiwan 125 publicly listed IT firms (1990–2001)	Survival model	Evidence of the state dependent but transient nature of the competitive advantage attributable to innovative persistence
Johansson, Loof (2010)	Sweden, 1997-2006	Dynamic panel models (Cobb-Douglas production function)	Persistent R&D firms have higher sales, value added and export value
Le Bas, Mothe, and Nguyen (2014)	Luxembourg Panel data on 287 firms (2004-2008)	Multinomial probit models	Organisational innovation is shown to be a determinant factor for innovation persistence
Le Bas and Poussing (2014)	Luxembourg Panel of 243 firms	Probit model (cross section)	Complex innovators (product *and* process innovators) are more persistent than single innovators (product *or* process innovators); pure product innovators have an advantage over pure process innovators
Malerba, Orsenigo, and Petretto (1997)	Five EU countries (1969–1986)	Dynamic panel data model	The econometric evidence shows that innovative activity is persistent

Manez-Castillejo, Rochina-barrachina, Sanchis-Llopis	Spain, 1990-2000	Discrete time proportional hazard models	R&D activities are subject to dynamic economies of scale (success-breeds-success hypothesis). Importance of unobserved heterogeneity and industry characteristics
Manez-Castillejo, Rochina-Barrachina, Sanchis-Llopis (2004)	Spain, 1990-2000	Dynamic binary choice model	Existence of sunk costs in firm's R&D activities. Sunk costs explain the persistence of R&D activities (barrier to both entry and exit from R&D activities) but quick depreciation of the effects of prior R&D activities over time (no many difference between the re-entry costs of a firm that previously performed R&D activities and a firm that never conducted R&D)
Martínez-Ros and Labeaga (2009)	Spain Manufacturing firms (1990–1999)	Random effect probit models	Evidence of persistence with relevant complementarities between product and process innovation
Peters (2009)	Germa-ny 1994-2002 Panel of manufacturing and service firms	Dynamic random effects panel probit model	True state dependence: Innovation is persistent over time. (higher effects of innovation in manufacturing sector)
Raymond, Mohnen, Palm, Van der Loeff (2010)	Netherlands, 1994- 2004 Panel of firms	Dynamic panel data bivariate tobit model	Persistence in the high tech Industries.
Rogers (2004)	Australia (1994-1997) Sample of around 4500 firms	Probit regression model	Persistence of innovation for (non) manufacturing firms + little role for traditional factors of innovation (market share, industry concentration, tech. opportunity..)
Roper, Hewitt-Dundas (2008)	Ireland (1991-2002) Panel of 2277 firms	Quantitative approach and qualitative case-studies analysis	Persistence for product and process innovations. + Persistence of high level of innovative product sales declines monotonically from its initial level.
Suarez (2014)	Argentina (1998-2006)	Random effects dynamic probit	Innovation persistence is strongly conditioned by firm's ability to respond to changes in the external environment.
Triguero-Cano Corcoles-Gonzalez	Spain (1990-2006) Sample of manufacturing firms	Random effects dynamic probit	Differences between input and output dynamics

Source: adapted from Le Bas and Scellato (2013)