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Economic downturn and investment in innovation

Is accumulation more creative than destruction?

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Abstract

The 2008 economic crisis has severely reduced the short-term willingness of firms to invest in innovation. But this reduction has not occurred uniformly and a few firms have even increased their investment in spite of the adverse macroeconomic environment. On the ground of a fresh European Survey carried out by Innobarometer, this paper compares drivers of innovation investment before, during and following on from the crisis. Using the two Schumpeterian models of technological accumulation and creative destruction the paper shows that before the crisis incumbent firms were more likely to expand their innovation investment, but that the crisis has reverted this picture, giving space to a restricted number of small firms and new entrants that swim against the stream and are expanding innovative activities.

JEL classification: O12, O30, O52

1. Is the financial crisis bringing gales of creative destruction?

The 2008 financial crisis has severely reduced the short-term willingness of companies to invest in innovation (e.g. Kanerva and Hollanders, 2010; OECD, 2009). While on the whole firms' investment in innovation declined during the economic downturn, a small but significant minority of firms are "swimming against the stream" and have increased their investment (Filippetti and Archibugi, 2010). The aim of this paper is to explore the characteristics of these firms and to compare them with those that increased investment into innovation prior to the crisis.

Who are these firms that have decided to respond to the crisis by innovating more rather than less? There are two possible scenarios.

(a) These firms are the most dynamic ones; those that cannot survive without changing their products and services. The competitive advantage of these firms resides in the generation and upgrading of new knowledge and they innovate continuously irrespectively of the business cycle.

(b) Or, alternatively, these firms are new entrants that were not necessarily involved in innovation before the crisis. These firms might be smaller in size or entirely new enterprises that exploit the crisis to compete for market shares of incumbent firms.

Point (a) assumes that innovation and technical change is rooted in cumulative learning processes, leading to path-dependent patterns that are woven into organizational routines and that favour innovation by established firms (Dosi et al., 2002; Nelson and Winter, 1982; Teece and Pisano, 1994). Point (b) is based on the assumption that economic turbulence makes it possible for new and small firms to emerge in a competitive market through innovation (Henderson and Clark, 1990; Perez, 2002; Tushman and Anderson, 1986; Simonetti, 1996).

As most insights in the field of innovation, points (a) and (b) are also derived by the theorizing of Joseph A. Schumpeter. Schumpeter and his followers suggested that economic cycles are the consequence of innovation, but also that innovative activities and the nature itself of innovative organizations are re-shaped by economic crises. In particular, we interpret the canonical debate between the two models elaborated by the young and the old Schumpeter in the following way:[1] during an upswing in the business cycle innovation is carried out in a cumulative fashion. Firms carry out innovation along established technological trajectories and develop into incumbents that carry out innovation as a routine also to prevent the entrance of newcomers (Schumpeter, 1942). Following Pavitt et al. (1989) and Malerba and Orsenigo (1995), we call this process *creative accumulation*. An economic turmoil, on the contrary, generates a shakeout in established industries and technological fields; new firms in new sectors play a relatively bigger role than the incumbent firms in inducing innovations. New firms are eager to exploit new technological opportunities also as a way to challenge incumbent corporations: as the young Schumpeter suggested, "it is not the owner of the stage-coaches who builds railways" (Schumpeter, 1911 (1934)). Following Schumpeter, we call this process *creative destruction*.[2]

The evolutionary perspective claims that changes at the aggregate level emerge from the dynamics at the micro level (Nelson and Winter, 1982; Dosi, 1997), and it is the micro level that this paper explores. Phenomena observed at the aggregate level, such as economic cycles, are the result of dynamic interactions among agents at the micro level characterized by a high degree of heterogeneity, both in terms of behaviour and characteristics. For the purpose of this paper the two ideas of creative accumulation and destruction (linked to points (a) and (b) above) are ideal types of two possible aggregate outcomes that emerge from the micro behaviour, and are operationalized at the level of the firm.

Our paper is an attempt to test the interplay between the forces of creative destruction and accumulation in innovation before, during and after the financial crisis that started in the Fall of 2008. Our analysis is made possible thanks to the latest wave of the *Innobarometer Survey* designed and collected by the European Commission in 2009 (European Commission, 2009a). Each year the Innobarometer introduces a different topic and the current survey emphasises innovation related expenditure,

[1] For an effective presentation of the innovation models presented by the young Schumpeter in his *Theory of Economic Development* (1911 (1934)) and the old Schumpeter in *Capitalism, Socialism and Democracy* (1942), we draw on Freeman et al., (1982).

[2] The processes of creative destruction is widely described in Schumpeter's *Theory of Economics Development* (Schumpeter, 1911 (1934)), although the term itself was used for the first time in his *Capitalism, Socialism and Democracy* (Schumpeter, 1942). Paradoxically, the book which introduced the term "creative destruction" vindicated instead the importance of creative accumulation.

including the effects on it of the economic downturn. Enterprises from the 27 EU member states, plus Norway and Switzerland responded to the survey.

The paper is structured as follows. Section 2 discusses the state of the art against which the paper is set. Section 3 develops the conceptual framework by providing a sketch of the two ideal typical models of creative accumulation and creative destruction. Section 4 introduces the dataset and methodology. Section 5 presents the results that are discusses in Section 6. Finally, Section 7 concludes.

2. Innovation generated through technological accumulation and economic creative destruction

The concepts of technological accumulation and creative destruction are at the very core of Schumpeter and Schumpeterian economics. The young Schumpeter looked at innovation as an event that could revolutionize economic life by brining into the fore new entrepreneurs, new companies and new industries. The mature Schumpeter, on the contrary, observed and described the activities of large oligopolistic corporations, able to perform R&D and innovation as a routine by building on their previous competences.

On the ground of these insights, the Schumpeterian tradition has further investigated the relative importance of the two processes (see Nelson and Winter, 1982; Bottazzi et al., 2001; Breschi et al., 2000; Malerba and Orsenigo, 1995, 1997; Patel and Pavitt, 1994). Creative destruction is described as a result of a regime characterized by low cumulativeness and high technological opportunities, leading to an environment with greater dynamism in terms of technological ease of entry and exit, as well as a major role played by entrepreneurs and fierce competition. Creative accumulation is associated with a technological regime that is characterized by high cumulativeness and low technological opportunities, bringing about more stable environments in which the bulk of innovation is carried out by large and established firms incrementally, leading to a market structure with high entry barriers and oligopolistic competition.

There are arguments supporting the relevance of cumulativeness and of reinforcing patterns of technological development and innovation, and arguments lending support to a 'destruction/discontinuous hypothesis'. Concerning the former, several studies suggest that learning processes that underlie innovation activities are both local and cumulative resulting in path-dependency (e.g. Pavitt et al., 1989; Antonelli, 1997; Dosi and Grazzi, 2010; Pavitt, 2005). In addition, empirical evidence indicates that there is a degree of persistence in innovation and among innovators (Cefis and Orsenigo, 2001; Geroski et al., 1997). Concerning the latter, it has often been stressed that there are periods of turbulence associated with a change in the leading sectors and/or the emergence of new sectors, which brings about a decline of technological and profit opportunities in established industries (Perez, 2002, 2009). This, in turn, might lead to a change in the knowledge and technological base for innovation activity and could substantially affect the hierarchy of innovators. Other research has stressed the fact that firm-specific organizational routines and capabilities can bring about inertia and hamper the capacity of established firms to keep up with major discontinuities (Henderson and Clark, 1990; Leonard-Barton, 1992; Levinthal and March, 1993).

This should also be related to the "continuity" thesis advocated by Chandler (1977) and his followers on the grounds of the fact that the population of incumbent, large firms has remained stable over the last decades. This thesis has been challenged by Louca and Mendonca (1999), and by Freeman and Louca (2001), who claim that a stream of new firms has joined incumbent firms during periods of radical discontinuities. This can also be contingent to the specific knowledge base and technical skills attached to different industries. For example, while Klepper and Simons (2000) show that firms established in making radios were successful in developing colour TVs, Holbrock et al. (2000) illustrate that this pattern is not mirrored in the evolution of the thermionic valves into the semiconductor industry. Levinthal (1998) bridges the gradual and discontinuous perspectives, using the punctuated equilibrium framework of evolutionary biology applied to an historical study of wireless communication.

In this paper the emphasis is not on specific industries or technologies, but rather on how an external shock, represented by the financial crisis, is affecting companies' innovative strategies. This evolutionary approach predicts a great deal of heterogeneity across firms that face the same contexts in terms of market demand, technological opportunities and information (Dosi, 1997). These conditions can largely vary across industries and countries, and we will make an attempt to take them into account in the empirical analysis. As a result, we expect to find an array of different innovation drivers both before and in response to the crisis. These are examined in view of the changes at the macro level, as we aim at understanding whether the crisis has led to some variation/discontinuity at the aggregate level, as a result of a different composition in the innovation behaviour across firms.

3. An attempt to identify the core characteristics of creative destruction and technological accumulation

To guide the analysis we elaborate on the ideal typical models of creative destruction and creative accumulation as two possible aggregate outcomes of micro behaviours. Creative destruction describes a dynamic environment in which new firms emerge as the most significant innovators as a result of a major discontinuity such as an economic downturn. Creative accumulation is underpinned by a more stable pattern of innovation which emphasizes cumulativeness and persistency of innovative activities in response to the crisis. We make here an attempt to identify these two patterns in relation to firm behaviour rather than to the evolution of technological regimes. In this sense, our approach is complementary to the research pioneered by Malerba and Orsenigo (1995) to identify Schumpeterian patterns of innovation with reference to various technological fields rather than to companies' behaviour.

A sketch of the differences between the models of creative destruction and creative accumulation is given in Table 1 where four categories are singled out: (i) characteristics of the innovating firm, (ii) type of knowledge source dominant in the innovation process, (iii) type of innovations, for example, radical or incremental, and (iv) characteristics of the market. The remainder of this section is structured around the four dimensions, starting with the characteristics of the firm.

Table 1 here

In the empirical part of the paper some of these factors, those more directly associated to our data, will be used to test if the two ideal typical models can be related to the patterns of innovation investment at the firm level.

3.1 Characteristics of the innovating firms

The creative accumulation model assumes that incumbent firms explore systematically technological opportunities. For them, to innovate is a routine, and it is one of the core things that the top management supervises. They have to upgrade periodically their products, often because they operate in concentrated oligopolistic industries. A stream of incremental innovation does not only guarantee that costs and prices are kept competitive, but also that products are differentiated and improved compared to those of the competition. This provides the possibility to accumulate knowledge and often not just in the areas of their core products (Granstrand et al. 1997). When new technological opportunities are identified, these companies may also be quick in entering into new fields and industries, thanks to their wide accumulated knowledge. However, when firms diversify, they tend to do so along some kind of technological relatedness, defined as *coherence* (Piscitello, 2004; Teece et al., 1994) or *technological speciation* (Cattani, 2006). Pavitt makes this point clear: "Given the increasingly specialized and professional nature of the knowledge on which they are based, manufacturing firms are path-dependent. […] it is difficult if not impossible to convert a traditional textile firm into one making semiconductors" (Pavitt, 2005, p. 95).

By contrast, the creative destruction model emphasizes the role played by individual inventors and entrepreneurs. This model reflects a more uncertain landscape of early stages of new technologies. By anticipating or even creating technological opportunities, these far-sighted individuals manage to generate new firms and often new industries that substantially change the economic landscape. These individuals can be independent, e.g. setting up or owning their own business, but they can also be dependent and employed by (sometimes large) organisation.

These individuals do not find the most conducive environment in existing organizations since learned and accumulated routine activities, organizational settings, and decision processes somehow discourage an entrepreneurial stance. Moreover, the larger the company, the greater might be a resistance to change by the company as a whole. Thus, patterns linked to creative destruction are associated at the firm level with innovation driven by smaller size, and new entry into markets alongside established firms, as entrepreneurial activities might be greater due to lower inertia, greater flexibility and responsiveness to changes in demand conditions and technological discontinuities. This type of innovative behaviour could be found in spin-offs from established companies, universities or simply new businesses.

3.2 Type of knowledge sources

In creative accumulation routine-based research is more important as a key source in the innovation process than something closer to a sudden insight. This favours the large firm that; i) has the capacity and the resources to set-up and maintain internal R&D laboratories, ii) can use interactions with others, and iii) has well-established internal functions (including design, production, and marketing). High-tech companies are also able to plug into the knowledge base of other companies, public institutions and countries. They are in the position to reduce the risks and costs associated with exploring new technological opportunities through strategic technological agreements, they have qualified personnel able to interact periodically with universities and public research centres, they can also establish intra-firm but international research networks through subsidiaries in other countries. All these factors allow them to build up on their already existing competences.

Creative destruction on the contrary will be based on internal sources that in some occasions and for limited periods of time represent the bulk of the firm's economic activity, as it has happened for companies in emerging fields such as bio-technology and software. This will also be combined to the concentric exploration of new opportunities, to specific ventures with companies operating in other industries, or generating symbiotic contacts with university departments (see Breschi et al., 2000). In the case of small or newly established firms, the development of new products, services or processes is likely to favour external collaborations and strategic alliances over and above than in the case for large corporations. Such set-ups help to overcome possible resource, finance and capability constraints within new and comparatively small firms.

3.3 Type of innovations

Creative destruction is linked to patterns of path-breaking innovations and radically new solutions that are incompatible with traditional solutions. Creative accumulation is linked with frequent, but more incremental innovation patterns. Accumulation or cumulativeness suggests that firms innovation activities are driven by past innovation activities. Current technologies build on past experience of production and innovation specific to the firm. Malerba and Orsenigo (1995, 1997) and Breschi et al. (2000) suggest that cumulativeness is high when: i) the firm is established and can build on a history of innovation success, ii) there is a tradition of research carried out inside the firm, and iii) that cumulativeness in innovation positively affects the rate of concentration of innovation.

In an environment with technological discontinuities, where new capabilities and skills are required, Tushman and Anderson (1986) suggest that existing firms could be disadvantaged by a lack of relevant competence. This is referred to as "competence-destroying discontinuities" (e.g. Henderson and Clark, 1990). Similarly, Leonard-Barton (1992) argues that each firm builds a knowledge set based on core capabilities, systems and values, and that the "core competencies" can turn into "core rigidities" in the sense that they can create inertia to change and innovation that is driven from outside the core competencies of the firm.

March (1991) and Levinthal and March (1993), who investigate the issue from an organizational and learning perspective, suggest that the chance of firms to survive is linked to their capacity to put forward effective processes of organizational adaptation; that firms are able to exploit their current knowledge, while at the same time exploring future technologies (see also Tushman et al., 2004). Moreover, Christensen and Rosenbloom (1995) and Christensen (1997) emphasize the fact that the advantage of the 'attacker' – the new firm establishing itself alongside the incumbent firm – relies on the fact that the latter's business is nested in a value network defined as the context within which a firm competes and solves customers' problems. In case of innovations, that change the structure of the relevant value network, large firms fail to keep up not for a lack of technological competences but rather because they are stuck in their old contexts and bound to existing customers.

Pavitt and his colleagues suggested that incumbents might have a resilience to survive and to adapt to major changes (Pavitt et al, 1989, Patel and Pavitt, 1994, Granstrand et al., 1997). He states that large firms "know more than they do", that is to say that their competences are spread over a wider range of fields than those associated with their core products, and that they have learnt how to assimilate new fields of knowledge through their internal competences in order to manage technological discontinuities. Methé et al. (1996) present empirical evidence showing that established firms often are sources of major innovations, for example in telecommunications and medical instruments. In a similar vein, Iansiti and Levien (2004) suggest that, despite the many predictions about incumbents' failures, technological transitions in the computer industry were survived by the overwhelming majority of firms.

3.4 Characteristics of the market

In a Schumpeterian model, firms compete to become oligopolistic in their market. This allows them to gain extra profit trough the appropriation of the return of their innovations. In a dynamic context, the oligopolistic structure is seen as a necessary evil to foster dynamic efficiency led by the continuous introduction of innovations (following Schumpeter, 1942; see Galbraith, 1952; Sylos Labini, 1962; for a review see Scherer, 1992; Kamien and Schwartz, 1982, Cohen, 1995). Creative destruction has been associated with a market structure characterized by high dynamism and competition, as well as high rate of change in the hierarchy of innovators. On the contrary, creative accumulation patters are linked to oligopolistic market structure with high entry barriers and high degree of stability of innovators.

Nelson and Winter (1982) suggest that the market structure in a specific industry, the degree of concentration and rate of entry, are influenced by the degree to which technological opportunities arise and the ease with which innovations can be protected from imitation (i.e. the appropriability conditions). High technological opportunity together with low appropriability causes lower concentration in an industry and vice versa. These arguments are picked-up and empirically tested by Breschi et al. (2000) and Malerba and Orsenigo (1995, 1997) in their work on technological regimes and their role in the evolution of industrial structures, hierarchy of innovators and innovation activities.

Technological opportunities are often associated with the productivity of R&D. The higher the technological opportunities, the higher the expected return of a unit of R&D expenditure (under a given level of appropriability).[3] Within this perspective, high levels of new technological opportunities favour creative destruction because the presence of technological opportunities increases the expected return of insight and idea generation of entrepreneurs and new firms. On the other hand,

[3] Also assuming constant demand and fixed technologies, but here the emphasis is on the role played by appropriability.

industries characterized by low technological opportunities are less attractive for new entrants and potential innovators. Consequently, low technological opportunities are associated to the creative accumulation model.

Overall this section looked at firm and market level characteristics that are more or less strongly associated with creative destruction and creative accumulation. In the empirical chapter, and after operationalizing the factors summarised in Table 1, we test if the determinants of innovation investment before, during and following on from the crisis differ. The following section, however, introduces first the dataset and the variables.

4. Data and methodology

4.1 The data

The empirical part of the paper analyses the *Innobarometer Survey 2009* that is designed and collected by the European Commission (European Commission, 2009a). In each of the 27 EU Member states, plus Norway and Switzerland, 200 enterprises from most manufacturing and private service industries with 20 or more employees were sampled.[4] 5,238 telephone interviews were completed between the 1st and 9th of April 2009. The sample is a random sample, stratified by country, enterprise size (5 size bands) and industry (2-digit industry codes). A detailed description of the survey, including the sampling and data collection methods, can be found in a methodological report by the European Commission (2009b).

Since 2001, Innobarometer is conducted on a yearly basis. Each year the survey highlights a different issue/theme, which is picked up on in additional and specific questionnaire items over and above a core set of variables. The focus of the current, 2009 survey is on innovation related expenditures and the effects of the

[4] In the smallest EU countries, Cyprus, Malta, and Luxembourg, the sample consisted of 70 enterprises and in non-EU countries, Switzerland and Norway, the sample size was 100. The industry sectors included are: aerospace, defence, construction equipment, apparel, automotive, building fixtures, equipment, business services, chemical products, communications equipment, construction materials, distribution services, energy, entertainment, financial services, fishing products, footwear, furniture, heavy construction services, heavy machinery, hospitality and tourism, information technology, jewellery and precious metals, leather products, lighting and electrical equipment, lumber and wood manufacturers, medical devices, metal manufacturing, oil and gas products and services, paper, (bio)pharmaceuticals, plastics, power generation & transmission, processed food, publishing and printing, sport and child goods, textiles, transportation and logistics, utility.

economic downturn on innovation related expenditures. It is this section of the questionnaire from which our key variables are developed. In the remainder of this section we introduce our dependent and independent variables and discuss the methodology.

4.2 The dependent variables

Our dependent variables measure change in innovation related investment as it is reported by the firms themselves and with reference to different time periods (before, during and following on from the crisis). Innovation related investment are captured in a wide sense, incorporating, not only expenditures on in-house R&D, but also technology embodied in the purchase of machinery, equipment and software, licensed-in technology (patents or other know-how), training of staff in support of innovation, and expenditures on design of products, process and services. This broad definition (in line with the definition adopted in the Community Innovation Surveys) has advantages over a narrow definition, such as investment in R&D. R&D expenditures will not be able to capture short-term responses to the financial crisis on the grounds that R&D projects are typically commitments made for a prolonged period of time (e.g. several years). Moreover, R&D is also concentrated in a few firms and sectors. In contrast, the wider definition of innovation related investments used in this paper that includes other innovation related expenditures over and above R&D, is better suited to capture short-term adjustments due to changes in the economic environment. Firms are quicker in cutting training for innovation, design budgets or purchases of software, than they are to adjust R&D projects.

Our dependent variables are based on firms' responses to the following three questions.

(a) before the crises: "*compared to 2006 has the total amount spent by your firm on all innovation activities in 2008 increased, decreased or stayed approximately the same*?",

(b) during the crisis: "*in the last six months*[5] *has your company taken one of the following actions as a direct result of the economic downturn; increased total amount of innovation expenditures, decreased […] or maintained […]?*", and

[5] The interviews were conducted between 1 and 9 April 2009, and, thus, the question relates to the period starting October 2008 ending with March 2009.

(c) following on from the beginning of the crisis: "*compared to 2008, do you expect your company to increase, decrease or maintain the total amount of its innovation expenditure in 2009?"*.

The observations feeding into the empirical analysis are all those firms that were innovation active and, thus, firms that stated they increase, decrease or maintain their innovation investment in the three periods respectively.

It is a weakness of our dependent variables – change in innovation related investment – that the scales are categorical rather than continuous (e.g. three choices as opposed to the total amount spent on innovation); but it is strength of our dependent variables that they provide a unique possibility to distinguish between three different time periods around the crisis.

Table 2 provides the descriptive statistics for the three dependent variables, including the number (frequency) and percent of enterprises that increased, maintained and decreased innovation investment under (a) time proxy for 'before the crisis', (b) proxy for 'during the crisis' and (c) proxy for 'following on from the crisis'.

Table 2 here[6]

Table 2 reveals two patterns. Firstly, 38% of enterprises reported that they increased innovation related investment in 2008 compared with their investment in 2006 (T1); but, in T2 only 9% and in T3 13% of enterprises reported increased investment. Thus, there is a strong drop in the number of firms that increased innovation related investment during the crisis and following on from the crisis. This pattern is mirrored in a shift from few firms to many firms reporting decreased investment over time. In T1 only 9% of firms decreased their innovation related expenditures, but in the midst of the financial crisis, in T2, 24% decreased investment and 30% planned to decrease investment in 2009 compared to investment levels in 2008. This might, at the aggregate level point towards destruction.

[6] The Innobarometer survey reports a lower number of non-innovation active firms compared with similar datasets, and specifically the Community Innovation Surveys. The following factors might contribute: (a) a difference in the industrial composition – "the enterprises interviewed in Innobarometer were sampled from sectors that are likely to be innovative" EC (2009), and (b) Innobarometer includes firms with 20 or more employees while the Community Innovation Survey includes enterprises with 10 and more employees.

Secondly, a large share of firms (about half of all firms) reported that they maintained innovation related investment irrespectively of the crisis leaning towards an accumulation hypothesis.

In Table 3 we report the cross-tabulations and Chi^2 statistics between the dependent variables producing three cross-tabulations: before the crisis (T1) with during the crisis (T2); before the crisis (T1) with following on from the crisis (T3); and during the crisis (T2) with following on from the crisis (T3). We present the cross-tabulations to gain insight into the level continuity/discontinuity in innovation investment decisions. For example, are the firms that increased investment during the crisis also among the firms that increased investment before the crisis?

Table 3 here

In the cross-tabulations we report frequencies plus column percentages below the frequencies. In the first column total of the top cross-table we report that 438 firms increased investment during the crisis (T2), and, in the first cell of the first cross-tabulation, we report that, out of these 438 firms, 332 also increased investment before the crisis (T1). The latter is equal to stating that 76% of firms that increased investment during the crisis are firms that already increased investment before the crisis. These 76% or 332 firms indicate some consistency of investment patterns and may already point towards, despite of the crisis, a confirmation of the importance of technological accumulation.

But, out of the 438 firms that increased investment during the crisis (and 603 that increased investment following on from the crisis), 24% (and 42%) decreased or maintained investment before the crisis. And, it is among these firms that we could see a shift in firm characteristics and market conditions associated with increased innovation investment before, during and following on from the crisis.

From the information presented in Table 3 we also know that there is greater stability in the investment choices of firms between the two periods during (T2) and following on from (T3) the crisis, also resulting in the higher measure of association ($Chi^2(4) = 1,400$; $p<0.01$), compared with before the crisis(T1 and T2, T1 and T3).

To fully address our research question of who the firms are that increase investment (top row of Table 2) in the midst of the crisis – (a) the most dynamic ones that compete largely on continuous upgrading or (b) new players that could be newly established firms or firms less relevant in aggregate innovation – we use a set of measures capturing firm and market characteristics to which we now turn, and that we use to predict innovation related investment across T1, T2 and T3 in the results section of the paper.

4.3 The independent variables

Table 4 contains an overview of the independent variables arranged by the categories already introduced in Table 1: characteristics of the innovating firms; type of knowledge sources; type of innovations; and market characteristics.

Table 4 here

The first column in Table 4 gives the variable names of the independent variables and the second column the variable description. All our independent variables are dummy variables coded 1 if a characteristic is met and zero otherwise. We rely on dummies because of a lack of more detailed information. In the first category entitled 'characteristics of the firm', the first variable is called 'newly established' and this variable is coded 1 if a firm was established after 1 January 2001 and 0 if it was established earlier. This variable is used as a proxy to identify new entrants. The second set of variables is made of three dummies that we use to proxy firm size. Small firms (20 to 49 employees) are used as the base comparison group in the regressions. The final variable proxies the innovation intensity of firms or the stock/level of investment in innovation related activities with reference to the calendar year 2008. High innovation intensity is measured as a share of turnover – at least 5% – is spent on innovation related activities.[7] Low innovation intensity (i.e. below 5% of turnover) is the base group.

Under the heading 'type of knowledge sources' are six variables; first, a variable that captures if the enterprise engaged in in-house R&D, second, if it engaged in extramural R&D. The remaining four variables relate to linkages or joint knowledge sources; specifically, collaboration on innovation with other businesses, collaboration on innovation with educational and other research institutions,

[7] The dataset has a fourth category – innovation related expenditure above 50% of turnover – but less than 1% of firms fell into this group and this is why we merged it with the next smaller band.

collaborations with partners located abroad, and investment in companies located abroad. All variables are coded 1 for yes answers and zero for no answers.

Under ‘type of innovations’ or innovators we include four variables that are proxies for the strategic orientation of the firms with respect to their innovations: whether or not firms compete based on their innovations, based on improvements to existing products, based on a new business model, or based on cost savings. Competing on innovation might lean more closely to activities at the frontier and might be seen as more closely related to path-breaking developments vis-à-vis the remaining categories. While improvements lean towards incremental innovations, new business models might be indicative of a new service. Competing on cost might favour the upgrading of processes. There is, of course, much blurring and overlap across such categories when attempting to translate competitive orientation into ‘type of innovations’.

Under the final heading ‘characteristics of the market’ are four variables. The first one captures the use of IPRs, specifically whether or not the firm applied for a patent or registered a design. The next two variables are used to capture the technological opportunities and market opportunities as assessed by the responding firms. 1 indicates that the firm perceived that there were opportunities (technological or market) and zero suggests a lack of opportunities. The final variable takes values of 1 if the enterprise operates in international markets and zero otherwise.

Table 5 provides and overview of the descriptive statistic for all independent variables.

Table 5 here

The dependent variables are observed for 4,664 firms (out of 5,234 observations in the initial database) in T1 (and 4,645 and 4,671 in T2 and 3 respectively) and Table 5 presents descriptive statistics for the independent variables based on these 4,664 observations. With respect to some of the independent variables we have missing observations where respondents stated that they did not know the answer. Specifically, 4,298 respondents provided a valid response with respect to their innovation intensity and so on. Because of missing values (and missing values not occurring systematically by appearing within the same observations) we have a final dataset of 3,959 observations in T1 (3,886 T2 and 3,890 T3) that is used in the final results section and contains observations for all dependent and independent variables.

In Table 5, the column entitled 'mean' gives the mean value for our variables. Because these are all dummy variables, this column is the share of enterprises that engage in a specific activity, e.g. 0.08 or 8% of firms were newly established, 40% were small, 50% of firms reported that they operated in international markets.

4.4 Methodology

We use regressions to analyse the relationship between our dependent and independent variables. Table 6 provides the zero order correlations among the dependent and independent variables, reporting polychoric correlations for the categorical dependent variables and tetrachoric correlations between the binary independent variables.

Table 6 here

The correlations reveal, in line with our expectations and our Table 3, that there is a higher correlation between the dependent variables 'investment during the crisis' and 'following on from the crisis', than with 'investment before the crisis' (both with respect to T2 and T3). Among the independent variables, the highest overlap exists between in-house R&D and bought-in R&D ($r=0.63$; $p<0.01$). Previous studies have shown that internal and bought-in R&D activities are complementing strategies, rather than substitutes (Cassiman and Veuglers, 2006). A high overlap also exists between 'international collaboration' and 'investing in companies located abroad' ($r=0.65$; $p<0.01$), and both these variables and 'operating in international markets' ($r=0.54$; $p<0.01$ and $r=0.53$; $p<0.01$ respectively), suggesting that these variables taken together might be indicative of an international orientation of firms.[8] The variables in the category 'type of innovations' are mutually exclusive groups and this is why the tetrachoric correlations return a value of -1. Competing on cost is our base comparison group in the regressions.

[8] In order to address an issue of multicollinearity between these variables, we have computed all regressions (a) without the variable international collaborations and (b) without the variable 'operating in international markets'. The findings remained unchanged. Results are not published, but are available upon request from the authors.

It is a limitation of our dependent variables that we do not have continuous data, and, as a reulst, we cannot use the classic linear model. The dependent variables are categorical variables that take the following categories: 1 = decrease in innovation related investment; 2 = innovation investment maintained; 3 = increase in innovation related investment.

We report the results from two estimation models: a logistic regression model and a multinomial logistic regression model. The logistic regression predicting increased innovation investment compared to both the remaining outcomes taken together (decreased and maintained) is presented because the interpretation of the coefficients is easier; however, the model ignores that the firm is presented with three choices – to increase, decrease or maintain investment. The latter is picked up by the multinomial logistic regression. The logistic model is:

$$\Pr(y_j = 1) = \frac{\exp(x_j b)}{1 + \exp(x_j b)}$$

where x_j is the row vector of the values of the independent variables. The multinomial logistic that picks up the three choices is:

$$p_{ij} = \Pr(y_j = i) = \begin{cases} \dfrac{1}{1 + \sum_{m=2}^{k} \exp(x_j b_m)}, & \text{if } i = 1 \\ \dfrac{\exp(x_j b_i)}{1 + \sum_{m=2}^{k} \exp(x_j b_m)}, & \text{if } i > 1 \end{cases}$$

where p_{ij} is the probability that the j^{th} observation is equal to the i^{th} outcome. 1 is assumed to be the base outcome, k is the number of categories (in our case 3), b_m is the coefficient for the outcome m (in our case either 2 or 3), and as before x_j is the row vector of the values of the independent variables. Based on one multinomial logistic regression, three sets of coefficients are reported: the first set of coefficients compares the choice to increase investment with maintained investment; the second set compares increase with decrease in investment; and the third set compares the effects of the independent variables on maintaining investment compared with decreasing investment. We now turn to the presentation of the empirical results in the next section.

5. Results

Two models are presented in this section. The first – logistic regression – reports coefficients that are indicative of the probability to increase innovation investment if the independent variables – all dummies – take a value of 1, i.e. the characteristic such as 'newly established' is met. It is reported in Table 7 below.

Table 7 here

Before the crisis (column T1 in Table 7), and with respect to the *characteristics of the innovating firms*, the coefficients suggest that firms are more likely to increase innovation investment if they exhibit high innovation intensity (our proxy for stock of investment). The coefficient b=0.97; p<0.01 is the largest coefficient in the column T1. Size and age are not significantly associated with increased investment; but the positive sign of the coefficients is in line with technological accumulation patterns (as per Table 1). During the crisis (T2), 'large size' is negatively associated with increased investment, meaning that small firms (our base group) are statistically more likely to increase investment compared with the group of large firms. The coefficient b=-0.64; p<0.01 is the most influential coefficient in the column T2. Following on from the crisis (T3) new entrants are more likely to increase investment (b=0.27; p<0.10). Both patterns, small firms in T2 and new entrants in T3, lean towards the creative destruction hypothesis (as per Table 1).

In relation to *type of knowledge sources*, our second category of independent variables, there are positive and significant coefficients for 'in-house R&D' and 'bought-in R&D' before the crisis supporting accumulation of technology before the crisis. But, 'in-house R&D' is not significant during the crisis but also positively associated with increased investment following on from the crisis, while 'bought-in R&D' is not significant in either T2 or T3 and the sign of the coefficients are negative. 'Link with other firms' as well as 'international collaboration' is significant throughout and irrespectively of the time period (T1, T2 or T3). We use 'link with other firms' as a proxy for access to applied knowledge that we thought less closely linked to accumulation compared with generic knowledge (proxied by 'links with universities and research institutes' that remains insignificant throughout). Thus, the collaboration variables do not suggest a change in pattern from before the crisis to during the crisis. Finally, firms that invested in companies abroad appear less likely to increase innovation investment following on from the crisis (no effect before then in columns T1 and T2). This variable, albeit restricted to the time period starting 2006, might capture if a firm was part of a larger, multinational company. Interpreted that way, the finding is closer to a destruction hypothesis. From our theoretical point of departure, the drop in significance of in-house and bought-in R&D during and following on from the crisis lends some support for the destruction hypothesis. But the findings in this category are less clear with respect to applied and generic knowledge sources as the coefficients are consistent across our three time periods.

Our proxies for *types of innovations* reveal that throughout the three periods, firms that increase investment in innovation are less likely to compete on cost, than they are to compete on innovations (confirming the results achieved with other methodology by Bogliacino and Pianta, 2010). Firms competing on cost are also less likely to increase investment compared with firms that compete on improvements before and following on from the crisis, but not during the crisis. The size of the coefficients increases over the three time periods, which indicates that firms that compete on costs are increasingly less likely to increase innovation related investment, specifically in T3 where the coefficients (compete on innovation, improvements and business model contrasted with competing on costs) have the strongest impact in the regression model. The sole significance of competing on innovation during the crisis, coupled with the increase in negative impact of 'competing on cost' is perhaps less indicative of accumulation as it is of destruction in T2 and T3.

With respect to the *characteristics of the market*, our final category of independent variables, the coefficients in Table 7 for IPRs are positive and significant both before and during the crisis (but not following on from the crisis T3). The coefficients for 'market opportunities', too, are positive and significant in T1 and increasing in terms of the size effect in T2 (during the crisis). 'Technological opportunities', however, are positively and significantly associated with increased investment only before the crisis. Strong 'IPRs' lean towards the accumulation hypothesis both before and during the crisis.

In Table 8, a pattern consistent with that in Table 7, but with greater detail with respect to the differences in the choices to maintain investment and decreasing investment is reported. Table 8 (a-c) contains one regression model for T1, T2 and T3 respectively, but three sets of coefficients are reported: (a) the first set of coefficients contrasts increase in innovation investment against maintaining of investment; (b) contrasts increase in innovation investment against decrease in investment; and (c) maintaining in investment against decrease in investment.

Table 8 here

One caveat that Table 8 reveals, and that cannot be seen in Table 7, is that firms that maintain investment as opposed to both increase (Table 8.a) and decrease (Table 8.c), report lower innovation intensity during the crisis. Thus, reacting to the crisis by either increasing or decreasing innovation related investment are the two choices made by the more innovative firms.

Another caveat taken from Table 8 is related to large firms. Before the crisis, large firms are more likely to increase investment (as opposed to decrease investment – Table 8.b) and are more likely to maintain investment (as opposed to decrease investment – Table 8.c). In contrast, during the crisis large firms are less likely to increase investment as opposed to both the alternative choices – to maintain or decrease investment (Tables 8.a and b). This, in line with the findings reported in Table 7, suggests that the role of small firms in innovation during the crisis is greater (a) than before the crisis and (b) compared with large firms during the crisis, supporting the destruction hypothesis.

Finally, comparing the choices increase and decrease in investment in the time period following on from the crisis, Table 8.b reports (as Table 7 before) newly established firms as more likely to increase investment. Among the remaining coefficients of the same set of coefficients, Table 8.b also reports that firms with low innovation intensity (stock) increase investment in T3. But, among the same set of coefficients, 'in-house R&D' and 'links with the knowledge base', as well as 'IPRs' are significant, providing a mixed picture with some characteristics closer to creative destruction ('newly established' and 'low innovation intensity') and others closer to accumulation ('in-house R&D', 'links with the knowledge base' and 'IPRs'). Thus, while we might have expected the patterns between T2 and T3 to be highly similar but different from T1, increased investment is not necessarily done by firms with the exact same characteristics and environments across T2 and T3, and some of the patterns dominant (significant coefficients) in T1 re-emerge in T3.

6. Discussion and limitation of results

This paper made an attempt to identify the core characteristics associated with the two Schumpeterian models of creative destruction and technological accumulation, summarised in Table 1. This framework looks at characteristics of the innovating firms, type of knowledge sources, type of innovations, and characteristics of the market. Thanks to the data made available by Innobarometer, we tested two hypotheses, namely: a) that in periods of economic expansion firms that are already innovating are the most important drivers of the increase in innovation investment, supporting the technological accumulation hypothesis; and b) that economic crises generate turbulence and that newcomers are eager to spend more to innovate, confirming the creative destruction hypothesis.

The empirical results somehow support both the hypotheses. Of course, we did not expect a clear-cut division between the two models: both patterns of creative destruction and accumulation are likely to exist at the same time as the four dimensions we have singled out in Table 1 will not form a perfect fit at the individual firm level. Thus, it is not surprising to find some variables that suggest the presence of creative destruction before the crisis and factors that lean towards accumulation during and following on from the crisis.

However, there are two points that strongly support our argument. First, the economic downturn has produced a significant shift in the innovation environment. Second, firms that increase innovation investment before the recession more closely resemble patterns of creative accumulation, while those "swimming against the stream", by increasing innovation investment during and following on from the crisis, appear to generate creative destruction.

At the micro level, the identikit of the innovators has changed considerably. Before the economic downturn, firms expanding their innovation are: (i) well-established; (ii) engaged in formal research activities both internally and bought-in; (iii) exploit strong appropriability conditions; and (iv) involved in collaboration with suppliers and customers. During the economic downturn the few firms that are increasing their innovation investment are: (i) smaller than before; (ii) collaborating with other businesses; (ii) exploring new market opportunities; (iii) using methods of technological appropriation; and (iv) less likely to compete on costs. Last but certainly not least, it also seems that younger firms are more likely to increase innovation investment after the crisis. While before the crisis technological opportunities have a positive impact on investment, during and after the crisis this is no longer true. On the contrary, in response to the crisis firms are more likely to explore innovative solutions by looking at opportunities in new markets.

At the aggregate level, the results suggest that the crisis has led to a change in the innovation environment. While before the crisis the model of creative accumulation seems to be better able to explain the results, after the crisis the model of creative destruction seems to dominate. Three facts justify this conclusion. First, during the crisis small firms seem to be more reactive than large firms. This is in tune with those studies which argue that small firms have an advantage in coping with the uncertainly which characterizes fundamental discontinuities (Acs and Audretsch, 1990). Second, before the crisis, firms expanding innovation are those with R&D activities coupled with the exploitation of technological opportunities. This is consistent with a situation in which innovators exploit their cumulative knowledge and competences along established technological trajectories. During the crisis both formal R&D and technological opportunities stop to play a significant role in explaining companies' willingness to expand innovation. This might be interpreted as the result of a decline of technological opportunities in established sectors which is typical during recessions characterized by technological discontinuities (Antonelli, 2002; Perez, 2002). Third, contrary to the previous period, innovation is driven by fresh opportunities in new markets.

We can conclude that creative accumulation is more focussed on upgrading technological knowledge while creative destruction is more associated to market opportunities, and this is certainly an unexpected result within the Schumpeterian economics that for long has associated new technological opportunities to new market opportunities. We can wonder if this is a general rule or is something associated to the current phase of capitalist development, where the manufacturing sector, the core generator of *technological* innovations, is progressively accounting for lower shares of income and employment while, on the contrary, the service sector is gaining shares and is more likely to compete through *non-technological* innovations and by finding new markets. We can speculate that, if the economic recession is reinforcing the shift from manufacturing to services, it would not be a surprise that the firms increasing their innovation investment are more likely to be driven by searching new business lines and business models than by technological opportunities.

The analysis presented here is limited by the data and the statistical models. First, the results are confined to Europe, and exclude the US as well as emerging countries. Second, the data offer information on three time periods for the dependent variables (but not for the independent variables), which allows comparing innovation related investment patterns before, during and following on from the crisis. Time series data would be able to provide much better information on the effects of the crisis, and the next surveys will certainly shed light on this. Third, data do not allow singling out the dynamic at the industry level. Finally, some variables are not totally satisfactory. True, the Innobarometer survey offers a unique opportunity to shed light onto the impact of the recent economic downturn on innovation, but we are well aware of the limitations of having carried out such a clear cut classification.

7. Conclusions

The aim of this paper was to investigate whether the current economic downturn is significantly affecting the innovation environment of firms. During major recessions, the economic landscape is characterized by huge uncertainties affecting, among others, the direction of technological change, demand conditions, and new market opportunities. This paper has identified the effect of such a big change upon micro dynamics. Specifically, our concern was to investigate whether the current crisis would lead to a significant change in the macro innovation environment as a result of a shift in the innovative behaviour of the firm.

We used two well-established, ideal typical models – the creative destruction and creative accumulation – to frame our results. The first significant result at the aggregate level is that the crisis has substantially reduced the number of firms willing to increase their innovation investment, from 38 percent to 9 percent. No doubt that the crisis has brought, at least in its initial stage, “destruction” in innovation investment. But the anatomy of these 9 percent of firms that are still expanding their innovation investment can provide some insights to check if the gales of destruction are also bringing something creative.

We have assumed a clear-cut division according to which in regular times the model of creative accumulation would prevail while in times of crisis the model of creative destruction will affirm itself. We are well aware that a clear-cut division between the two models does not exist. We recognize that both patterns of innovation co-exist and are likely to be also technology and industry specific (as tested empirically by Malerba and Orsenigo, 1995). However, our data suggest that during the depression firms' innovation behaviour is closer to creative destruction, while before the depression there is an overall landscape of creative accumulation.

In fact, eager innovators during the crisis are different from those before the crisis. Previously, well-established firms with R&D activities were more likely to expand further their knowledge base. Technological opportunities represented a major driver for innovative activities. As a response to the crisis, a different, although quantitatively still small, group of innovators arises. It is made of small firms, and younger firms, not necessarily involved in R&D activities, but collaborating on innovation across national frontiers. Openings of new markets represent for them the major driver of innovation. This witnesses an important change in the drivers of innovation as a result of the economic downturn. Since innovation is less based on local searching and cumulative processes, and less based on R&D activities within large firms, we conclude that the relative importance of behaviours is changing from creative accumulation to creative destruction in the snap shot of the business cycle that the Innobarometer makes it possible to observe. The fact that firms exhibit a more "explorative" attitude, vis-à-vis an "exploitative" attitude, is consistent with a situation of greater uncertainty that they face.

It could not be taken for granted that during a period of sustained growth firms' behaviour lean towards accumulative patterns of innovation. During periods of sustained growth firms have access to greater financial resources and thus might be seen more likely to explore radical and risky solutions. Our data do not indicate the technological direction explored by firms, but some research has demonstrated that also when firms diversify, they tend to do so along some kind of technological relatedness, or *coherence* (Granstrand et al., 1997; Piscitello, 2004; Teece et al., 1994). It has been shown that firms extend the range of their innovative activities in a non-random way, diversifying in related technological fields, i.e. fields that share a common knowledge base and rely upon common heuristics and scientific principles (Breschi et al., 2003).

Similarly, it can be conceivably maintained that during a depression large established firms are better equipped to manage a situation of fall in demand and lack of financial supply in the market. However, we show that this is not the case. The number of firms declaring to increase their innovation expenditure has dropped dramatically as results of the crisis. It seems that what matter are not large size and internal R&D, but flexibility, collaborative arrangements and exploration of new markets.

Future work should focus on accessing data which allows for estimates based on longer time periods, the inclusion of more countries and more precise indicators on innovation intensity and the direction of technological change. In particular, we suspect that the crisis is reinforcing the shift from the manufacturing to the service industries and that a greater share of firms willing to expand their innovations are to be found in the service industries. In order to corroborate this hypothesis a definition of innovation able to capture the process of change in both manufacturing and services is needed. For many years, the Schumpeterian economics has concentrated on the *technological* dimension of innovation, which is typical of the manufacturing industries, and has somehow denied the *non-technological* dimension, which is more common when innovating in services. Times are ready to use a wider understanding of innovation, similar to what was pioneered by Schumpeter himself a century ago in the first edition of the *Theory of Economic Development*. The definition provided by Innobarometer and used in this paper has the advantage to be more inclusive than others.

In terms of policy analysis, it should be seen what the restricted number of firms increasing the innovation investment will generate. Public incentives to promote innovation can either be directed towards supporting the already existing R&D infrastructures or towards fostering new entrants. Identifying the characteristics of the innovators during the turmoil, as we have tried to do here, can shed some light on how policy instruments interact with technological accumulation and creative destruction. In which group of firms will the Bill Gates and Steve Jobs, Larry Page and Sergey Brin of the next generation be found? And are we sure that European governments, more and more concerned with the knowledge base economy, are doing their best to foster creative innovators, even if this will imply the destruction of slow growing wood?

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APPENDIX: Tables

Table 1 Innovative firms characteristics under the creative accumulation and creative destruction models

Categories	*Creative accumulation*	*Creative destruction*
Characteristics of the innovating firms	Innovations are driven by large, incumbent firms that seek new solutions through formal research exploiting their pre-existing capability.	Small firms, new entrants are the key drivers in the innovation process. They use innovation and economic turbulence to acquire market share from incumbent firms.
Type of knowledge sources	High relevance of past innovations and accumulated knowledge. Importance of formal R&D, in-house but also jointly performed or externally acquired.	Higher relevance of collaborative arrangements leaning towards the applied knowledge base (other firms). Exploration of new markets and technological opportunities.
Type of innovations	The innovation process is dominated by a large number of incremental innovations. Organizational routines dominate the generation of innovations.	The emphasis is on path-breaking innovations often able to create new industries. New organizational forms contribute to generate innovations.
Characteristics of the market	Barriers to entry are high due to relative importance of appropriation and cumulativeness of knowledge and high costs of innovation. Dominance of oligopolistic markets. Technological advancement based on path dependent and cumulative technological trajectories.	Low barriers to entry into the new industries. A high rate of entry and exit leads to low levels of concentration and high competition. Discontinuous technologies are available that generate growing markets and new opportunities.

Source: Authors' elaboration.

Table 2 Investment in innovation related activities before, during and following on from the crisis

Dependent variable: change in innovation related investment	Before the crisis (T1)		During the crisis (T2)		Following on from the beginning of the crisis (T3)	
	Frequency	*Percent*	*Frequency*	*Percent*	*Frequency*	*Percent*
Increase	1,985	38	453	9	659	13
Decrease	472	9	1,231	24	1,560	30
Maintain	2,207	42	2,961	57	2,452	47
Innovation active firms	4,664	89	4,645	90	4,671	90
No innovation activities	328	6	457	9	343	7
Missing observations	242	5	132	3	220	4
Number of observations	5,234	100	5,234	100	5,234	100

T1 refers to the change in innovation related investment in the calendar year 2008 compared to 2006; T2 refers to the change in innovation related investment in the six months period October 2008 to March 2009; T3 refers to the expected change in innovation related investment in 2009 compared with 2008.

Source: Authors' elaboration on Innobarometer, European Commission (2009a).

Table 3 Innovation investment before, during and following on from the crisis. Cross-tabulations of the dependent variables

			During the crisis (T2)			
			Increase	Decrease	Maintain	Total
Before the crisis (T1)	Increase	*Frequencies*	332	445	1,124	1,901
		Column percentages	76	38	40	43
	Decrease	*Frequencies*	18	255	167	440
		Column percentages	4	22	6	10
	Maintain	*Frequencies*	88	469	1,538	2,095
		Column percentages	20	40	54	47
	Total	*Frequencies*	438	1,169	2,829	4,436
		Column percentages	100	100	100	100

$Chi^2(4)=463; p<0.01$

			Following on from the crisis (T3)			
			Increase	Decrease	Maintain	Total
Before the crisis (T1)	Increase	*Frequencies*	358	631	907	1,896
		Column percentages	58	43	39	43
	Decrease	*Frequencies*	62	225	158	445
		Column percentages	10	15	7	10
	Maintain	*Frequencies*	200	625	1,270	2,095
		Column percentages	32	42	54	47
	Total	*Frequencies*	620	1,481	2,335	4,436
		Column percentages	100	100	100	100

$Chi^2(4)=168; p<0.01$

			Following on from the crisis (T3)			
			Increase	Decrease	Maintain	Total
During the crisis (T2)	Increase	*Frequencies*	192	73	159	424
		Column percentages	32	5	7	10
	Decrease	*Frequencies*	61	812	256	1,129
		Column percentages	10	57	11	26
	Maintain	*Frequencies*	350	544	1,832	2,726
		Column percentages	58	38	82	64
	Total	*Frequencies*	603	1,429	2,247	4,279
		Column percentages	100	100	100	100

$Chi^2(4)=1{,}400; p<0.01$

Source: As for Table 2.

Table 4 Characteristics of the innovating firms, type of knowledge sources, type of innovations and characteristics of the market. Overview of the independent variables

Characteristics of the innovating firms	
Newly established	The enterprise was established after 1 January 2001
Small enterprise	There are four dummies that we use to measure the size of the enterprise. Small enterprises here have 20-49 employees
Medium enterprise	The variable selects all enterprises with 50 to 249 employees
Large enterprises	The variables selects all enterprises with more than 250 employees
Low innovation intensity	The enterprise invests less than 5% of turnover in innovation related activities in 2008
High innovation intensity	The enterprise invests at least 5% of turnover in innovation related activities
Type of knowledge sources	
In-house R&D	The enterprise had expenditures on in-house R&D since 2006
Bought-in R&D	The enterprise had expenditures on R&D performed for the company by other enterprises or by research organisations since 2006
Link with other firms	The enterprise developed strategic relationships in support of innovation with customers, suppliers or other companies since 2006
Link with the knowledge base	The enterprise developed strategic relationships in support of innovation with research institutes and educational institutions since 2006
International collaboration	The enterprise started or increased cooperation with local partners in other countries in support of innovation since 2006
Investment in companies abroad	The enterprise invested in companies located in other countries in support of innovation since 2006
Type of innovations	
Enterprise competes on innovations	The enterprise sees the main competitive advantage in new products, services and processes
Enterprise competes on improvements	The enterprise sees the main competitive advantage in the modification of existing products, services and processes
Enterprise competes on new business models	The enterprise sees the main competitive advantage in the developments of new business models or ways to market products and services
Enterprise competes on cost	The enterprise sees the main competitive advantage in reducing costs of existing products
Characteristics of the market	
IPRs	The enterprise applied for a patent or registered a design since 2006
Technological opportunities	New technologies emerged in the enterprise's market since 2006
Market opportunities	New opportunities to enter into new markets or expand sales in existing markets emerged since 2006
International market	The enterprise operates in international markets

Table 5 Descriptive statistics of the independent variables

Independent variables	*Number of observations*	*Mean*	*Standard deviation*
Characteristics of the innovating firms			
Newly established	4,664	0.08	0.28
Small enterprise (base group)	4,664	0.40	0.49
Medium enterprise	4,664	0.32	0.47
Large enterprise	4,664	0.28	0.45
Low innovation intensity (base group)	4,298	0.68	0.47
High innovation intensity	4,298	0.32	0.47
Type of knowledge sources			
In-house R&D	4,635	0.48	0.50
Bought-in R&D	4,631	0.32	0.47
Link with other firms	4,627	0.67	0.47
Links with the knowledge base	4,628	0.38	0.49
International collaboration	4,602	0.29	0.45
Investment in companies abroad	4,620	0.11	0.31
Type of innovations			
Enterprise competes on innovations	4,558	0.24	0.43
Enterprise competes on improvements	4,558	0.23	0.42
Enterprise competes on business models	4,558	0.16	0.37
Enterprise competes on cost (base group)	4,558	0.34	0.47
Characteristics of the market			
IPRs	4,613	0.15	0.36
Technological opportunities	4,594	0.40	0.49
Market opportunities	4,596	0.58	0.49
International market	4,588	0.50	0.50

Source: As for Table 2.

Table 6 Correlations among the dependent and independent variables

Dependent variables	1	2	3																
Investment in innovation related activity																			
1 Investment before the crisis	1.00																		
2 During the crisis	0.28	1.00																	
3 Following on from the crisis	0.21	0.44	1.00																
Independent variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Characteristics of the innovating firms																			
1 Newly established	1.00																		
2 Small enterprise (base group)	0.09	1.00																	
3 Medium enterprise	0.02	-1.00	1.00																
4 Large enterprise	-0.13	-1.00	-1.00	1.00															
5 Low innovation intensity (base)	-0.03	0.05	-0.02	-0.05	1.00														
6 High innovation intensity	0.03	-0.05	0.02	0.05	-1.00	1.00													
Type of knowledge sources																			
7 In-house R&D	-0.03	-0.29	0.03	0.31	-0.28	0.28	1.00												
8 Bought-in R&D	-0.02	-0.31	0.01	0.33	-0.15	0.15	0.63	1.00											
9 Link with other firms	0.08	-0.15	-0.01	0.19	-0.28	0.28	0.45	0.37	1.00										
10 Links with the knowledge base	0.02	-0.25	0.01	0.27	-0.25	0.25	0.53	0.51	0.58	1.00									
11 International collaboration	-0.06	-0.19	-0.02	0.23	-0.25	0.25	0.41	0.36	0.47	0.37	1.00								
12 Investment in companies abroad	-0.06	-0.25	-0.09	0.34	-0.16	0.16	0.38	0.35	0.39	0.29	0.65	1.00							
Type of innovations																			
13 Enterprise competes on innovations	-0.01	-0.02	0.01	0.02	-0.20	0.20	0.21	0.18	0.18	0.17	0.13	0.13	1.00						
14 Competes on improvements	0.05	-0.06	0.03	0.04	0.03	-0.03	0.04	0.00	0.09	0.05	0.04	-0.07	-1.00	1.00					
15 Competes on business models	-0.04	0.01	-0.04	0.03	-0.05	0.05	0.04	0.06	0.13	0.08	0.06	0.12	-1.00	-1.00	1.00				
16 Competes on cost (base group)	-0.02	0.02	0.00	-0.03	0.14	-0.14	-0.17	-0.15	-0.20	-0.20	-0.14	-0.11	-1.00	-1.00	-1.00	1.00			
Characteristics of the market																			
17 IPRs	-0.05	-0.24	-0.06	0.31	-0.26	0.26	0.53	0.44	0.37	0.39	0.38	0.36	0.19	0.05	0.00	-0.18	1.00		
18 Technological opportunities	0.00	-0.18	0.00	0.21	-0.31	0.31	0.39	0.32	0.48	0.43	0.30	0.28	0.18	0.07	0.08	-0.19	0.31	1.00	
19 Market opportunities	0.03	-0.16	0.02	0.18	-0.27	0.27	0.35	0.28	0.48	0.31	0.41	0.29	0.18	0.04	0.13	-0.16	0.33	0.50	1.00
20 International market	-0.02	-0.23	0.01	0.26	-0.17	0.17	0.35	0.26	0.25	0.22	0.54	0.53	0.11	0.02	0.01	-0.05	0.36	0.22	0.37

Polychoric correlations between the dependent variables, and tetrachoric correlations between the independent variables, are reported. The variables Compete on innovations, improvements, business models and cost are mutually exclusive and thus yield a tetrachoric correlation of -1. Source: As for Table 2.

Table 7 Factors explaining the choice to increase innovation investment compared to maintaining or decreasing investment (combined) over time

Dependent variable: increase in innovation related investment Estimation method: logistic	Before the crisis (T1)	During the crisis (T2)	Following on from the crisis (T3)
Characteristics of the innovating firms			
Newly established	-0.19 (0.13)	-0.12 (0.20)	0.27* (0.16)
Medium enterprise	0.13 (0.08)	-0.13 (0.13)	0.10 (0.11)
Large enterprise	0.12 (0.09)	-0.64*** (0.16)	-0.15 (0.13)
High innovation intensity	0.97*** (0.08)	0.20* (0.12)	0.01 (0.10)
Type of knowledge sources			
In-house R&D	0.33*** (0.08)	0.21 (0.14)	0.20* (0.12)
Bought-in R&D	0.26*** (0.09)	-0.08 (0.13)	-0.07 (0.11)
Link with other firms	0.36*** (0.08)	0.33** (0.15)	0.23* (0.12)
Links with the knowledge base	0.07 (0.08)	0.15 (0.13)	0.15 (0.11)
International collaboration	0.30*** (0.09)	0.38*** (0.13)	0.35*** (0.11)
Investment in companies abroad	-0.02 (0.13)	-0.05 (0.19)	-0.33** (0.17)
Type of innovations			
Enterprise competes on innovations	0.29*** (0.10)	0.36** (0.15)	0.58*** (0.13)
Enterprise competes on improvements	0.24** (0.10)	0.22 (0.16)	0.61*** (0.13)
Enterprise competes on business models	0.14 (0.11)	0.15 (0.17)	0.52*** (0.15)
Characteristics of the market			
IPRs	0.27** (0.11)	0.32** (0.15)	0.16 (0.13)
Technological opportunities	0.20*** (0.08)	0.04 (0.12)	0.07 (0.11)
Market opportunities	0.16** (0.08)	0.40*** (0.13)	0.17 (0.11)
International market	-0.16* (0.08)	-0.02 (0.13)	0.00 (0.11)
Industry dummies	Included	Included	Included
Country dummies	Included	Included	Included
Number of observations	3,959	3,886	3,890
Wald Chi^2 (64)	524***	150***	179***
Pseudo R^2	0.11	0.07	0.06

Robust standard errors are reported in brackets under the logistic regression coefficients.
*** p<0.01, ** p<0.05, * p<0.10

Source: As for Table 2.

Table 8.a Factors explaining the discrete choices to increase, maintain, or decrease innovation related investment over time

Dependent variable: increase in innovation investment (base group: maintain) Estimation method: multinomial logistic	Before the crisis (T1)	During the crisis (T2)	Following on from the crisis (T3)
Characteristics of the innovating firms			
Newly established	-0.19 (0.15)	-0.14 (0.50)	0.22 (0.19)
Medium enterprise	0.13 (0.15)	-0.18 (0.17)	0.06 (0.60)
Large enterprise	0.06 (0.56)	-0.67*** (0.00)	-0.21 (0.11)
High innovation intensity	0.99*** (0.00)	0.30** (0.02)	0.15 (0.16)
Type of knowledge sources			
In-house R&D	0.39*** (0.00)	0.23 (0.10)	0.18 (0.14)
Bought-in R&D	0.23*** (0.01)	-0.09 (0.53)	-0.06 (0.62)
Link with other firms	0.42*** (0.00)	0.37** (0.01)	0.28** (0.02)
Links with the knowledge base	0.05 (0.55)	0.17 (0.19)	0.11 (0.36)
International collaboration	0.33*** (0.00)	0.41*** (0.00)	0.36*** (0.00)
Investment in companies abroad	-0.00 (0.98)	-0.04 (0.83)	-0.27 (0.13)
Type of innovations			
Enterprise competes on innovations	0.25** (0.01)	0.22 (0.16)	0.39*** (0.00)
Enterprise competes on improvements	0.21** (0.04)	0.07 (0.64)	0.47*** (0.00)
Enterprise competes on business models	0.14 (0.19)	0.08 (0.65)	0.43*** (0.00)
Characteristics of the market			
IPRs	0.32*** (0.00)	0.34** (0.03)	0.11 (0.43)
Technological opportunities	0.18** (0.03)	0.07 (0.57)	0.10 (0.35)
Market opportunities	0.13 (0.11)	0.39*** (0.00)	0.16 (0.16)
International market	-0.15* (0.09)	0.02 (0.86)	0.06 (0.61)
Industry dummies	Included	Included	Included
Country dummies	Included	Included	Included
Number of observations	3,959	3,886	3,890
Wald Chi2 (64)	652***	431***	419***
Pseudo R2	0.10	0.07	0.06

Robust standard errors are reported in brackets under the multinomial logistic regression coefficients. *** p<0.01, ** p<0.05, * p<0.10

Source: As for Table 2.

Table 8.b Factors explaining the choice to increase, maintain or decrease innovation investment over time

Dependent variable: increase in innovation investment (base group: decrease) Estimation method: multinomial logistic	Before the crisis (T1)	During the crisis (T2)	Following on from the crisis (T3)
Characteristics of the innovating firms			
Newly established	-0.16	-0.09	0.35**
	(0.43)	(0.68)	(0.05)
Medium enterprise	0.16	-0.01	0.16
	(0.23)	(0.95)	(0.20)
Large enterprise	0.40**	-0.54***	-0.04
	(0.01)	(0.00)	(0.79)
High innovation intensity	0.91***	-0.02	-0.22*
	(0.00)	(0.86)	(0.06)
Type of knowledge sources			
In-house R&D	0.04	0.15	0.25*
	(0.79)	(0.33)	(0.05)
Bought-in R&D	0.34**	-0.07	-0.09
	(0.02)	(0.66)	(0.45)
Link with other firms	0.10	0.23	0.14
	(0.45)	(0.15)	(0.29)
Links with the knowledge base	0.13	0.10	0.21*
	(0.35)	(0.51)	(0.09)
International collaboration	0.21	0.32**	0.33***
	(0.14)	(0.04)	(0.01)
Investment in companies abroad	-0.11	-0.06	-0.43**
	(0.58)	(0.77)	(0.02)
Type of innovations			
Enterprise competes on innovations	0.45***	0.71***	0.89***
	(0.00)	(0.00)	(0.00)
Enterprise competes on improvements	0.36**	0.55***	0.83***
	(0.02)	(0.00)	(0.00)
Enterprise competes on business models	0.11	0.29	0.63***
	(0.51)	(0.13)	(0.00)
Characteristics of the market			
IPRs	0.05	0.28*	0.26*
	(0.76)	(0.10)	(0.08)
Technological opportunities	0.31**	-0.04	-0.00
	(0.02)	(0.79)	(1.00)
Market opportunities	0.27**	0.45***	0.20
	(0.04)	(0.00)	(0.10)
International market	-0.22*	-0.15	-0.10
	(0.09)	(0.30)	(0.41)
Industry dummies	Included	Included	Included
Country dummies	Included	Included	Included
Number of observations	3,959	3,886	3,890
Wald Chi2 (64)	652***	431***	419***
Pseudo R2	0.10	0.07	0.06

Robust standard errors are reported in brackets under the multinomial logistic regression coefficients.
*** p<0.01, ** p<0.05, * p<0.10

Source: As for Table 2.

Table 8.c Factors explaining the choice to increase, maintain or decrease innovation investment over time

Dependent variable: maintained innovation investment (base group: decrease) Estimation method: multinomial logistic	Before the crisis (T1)	During the crisis (T2)	Following on from the crisis (T3)
Characteristics of the innovating firms			
Newly established	0.03	0.05	0.13
	(0.88)	(0.74)	(0.32)
Medium enterprise	0.03	0.17*	0.10
	(0.80)	(0.07)	(0.26)
Large enterprise	0.34**	0.13	0.18*
	(0.02)	(0.21)	(0.07)
High innovation intensity	-0.08	-0.32***	-0.37***
	(0.55)	(0.00)	(0.00)
Type of knowledge sources			
In-house R&D	-0.36***	-0.08	0.07
	(0.01)	(0.40)	(0.42)
Bought-in R&D	0.11	0.02	-0.04
	(0.44)	(0.84)	(0.70)
Link with other firms	-0.31**	-0.13	-0.14
	(0.02)	(0.16)	(0.11)
Links with the knowledge base	0.08	-0.08	0.11
	(0.56)	(0.42)	(0.23)
International collaboration	-0.12	-0.09	-0.03
	(0.40)	(0.40)	(0.78)
Investment in companies abroad	-0.11	-0.02	-0.16
	(0.59)	(0.88)	(0.23)
Type of innovations			
Enterprise competes on innovations	0.20	0.50***	0.50***
	(0.20)	(0.00)	(0.00)
Enterprise competes on improvements	0.15	0.48***	0.36***
	(0.33)	(0.00)	(0.00)
Enterprise competes on business models	-0.03	0.21*	0.19*
	(0.83)	(0.07)	(0.08)
Characteristics of the market			
IPRs	-0.27	-0.05	0.15
	(0.13)	(0.66)	(0.20)
Technological opportunities	0.12	-0.11	-0.10
	(0.33)	(0.23)	(0.22)
Market opportunities	0.14	0.06	0.04
	(0.26)	(0.53)	(0.62)
International market	-0.07	-0.17*	-0.16*
	(0.58)	(0.06)	(0.06)
Industry dummies	Included	Included	Included
Country dummies	Included	Included	Included
Number of observations	3,959	3,886	3,890
Wald Chi2 (64)	652***	431***	419***
Pseudo R2	0.10	0.07	0.06

Robust standard errors are reported in brackets under the multinomial logistic regression coefficients.
*** p<0.01, ** p<0.05, * p<0.10

Source: As for Table 2.