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Innovation and the economic downturn: Insights from Portuguese firms[1]

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Abstract

Recent research has found evidence of a variety of business profiles regarding innovation during the economic downturn. Several studies reported that firms were reducing or abandoning innovation activities and dropping related expenses while other authors have found that some firms are exploring the economic turbulence as an opportunity for creative destruction and to gain competitive advantage. This article explores the data collected from the last waves of CIS (Community Innovation Survey) in Portugal (2006-2008-2010-2012) to understand the changes in the determinants of the development of innovation activities, product and process innovation, before, during and in the peak of the crisis. The empirical study presents limited dependent variable models to analyse the relevance of structural factors, absorptive capacity and strategic variables in the different periods. The article concludes with implications for the behaviour of firms and innovation resilience.

JEL Classification: C21, C25, O31, O32, O38

Keywords: *CIS; crisis; exploitation; exploration; innovation; persistence; resilience*

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1. Introduction

The relation of economic crisis and innovation is a crucial concern of studies of economic growth and technology, not least since Joseph Schumpeter's seminal depiction of the economic cycles and renewal of the economic system as a process of 'creative destruction' (Schumpeter 1942). The macroeconomic context influence national innovation systems (Edquist 2005) and thus the environment both restricting and enabling the innovative behaviour of firms and other relevant research organisations (Archibugi, Filippetti and Frenz 2013; Cruz-Castro and Sanz-Menéndez 2015).

It is with no surprise that the macroeconomic fluctuations and the economic slowdown initiated with the 2007 economic crisis have had impacts on the innovative performances of different countries (Makkonen 2013), affecting some member-states more heavily than others (Kastrinos 2013). Several studies (Archibugi, Filippetti and Frenz 2013b; Frenz and Prevezer 2012; Paunov 2012) reported that firms were reducing or abandoning innovation activities and dropping related expenditures while other authors have found that some firms are exploring the economic turbulence as an opportunity for creative destruction and to gain competitive advantage. Turbulence, imbalances and a diversity of shocks to the socio-economic systems have brought to bear a series of contributions that highlight the connections of innovation with the economic downturn. Nevertheless, much can be learnt a decade after the beginning of the financial crisis.

Portugal was one of the countries more deeply impacted by the economic instability generated as a result of the financial crisis in the European Union. This member-state received a bailout from the Troika, constituted by the European Commission, International Monetary Fund and European Central Bank, in 2011. This external intervention implied measures to control public expenditures the public deficit and to restructure labour laws. These policies led to a strong economic recession and increased unemployment (EC 2014). The impact of the crisis has also been reflected in the number of innovative enterprises in Portugal. Community Innovation Survey (CIS) data reported a reduction in the share of innovative companies in Portugal, higher than the fall in European average (with 28 member-states) (Eurostat newsrelease 15/2015). Facing these deep impacts in the innovation dynamics, Portugal is an interesting case to be analysed with greater detail.

In the next sections the article will present an empirical study that aims to understand how the determinants of firms' innovation change as a result of the country's economic slowdown. It focuses on firm-level innovative activities and performance before and during the crisis, using micro-data from the Portuguese innovation survey. The objective of the research is to identify how firms' innovation changes as a result of the economic recession at national level. For this purpose, we use data from the waves of CIS in Portugal (2006-2008-2010-2012).

The article is organized as follows. It briefly presents the relation of innovation and economic context, and the notions of persistence and of resilience. The article continues with the empirical study, presenting econometric models to analyse the relevance of structural factors, innovative efforts and strategic variables, in the different periods, for explaining innovation activities, product innovation and process innovation. The article finishes with a conclusion that summarizes some empirical findings, suggesting possible policy implications, and the way forward for this research.

2. Determinants of innovation

2.1. Absorptive capacity and the exploration-exploitation dichotomy

The innovative capacity of firms is a central issue because it has a relevant macroeconomic impact (Evangelista and Fabrizio 2009). It depends on a wide range of factors. Innovation in firms is associated with organizational and structural determinants, such as size, profitability, capital intensity, diversification, export capacity, ownership and technical knowledge, but also the determinants of the environment such as competition and concentration of firms, technological opportunities, conditions of appropriability of innovation and demand growth, and finally, context determinants, related to the type of industry, the degree of innovation in the sector, the stage of development of products and firm life cycle. There is a strong association between business innovation and economic growth (Hasan and Tucci 2010).

The ability to absorb and apply new knowledge is particularly crucial to the innovative capacity. Cohen and Levinthal's (1990) notion of 'absorptive capacity' stress the relevance of developing a company's knowledge base, through in-house R&D and innovation activities, in order to understand and benefit from the technological advances that are realized in their external environment. The level of qualification of the workers is one of the elements of firms' absorptive capacity, influencing the organization and the diversity of the functions that develop it. However, the lack of R&D investment restricts the development of this capacity to benefit from external sources. In-house R&D and innovative activities contribute to the ability to recognize the value of external information and knowledge, and to absorb, explore and apply it internally. The fact that this capacity is developed enables a better access and use of knowledge developed externally. Existing knowledge defines the capacity for organizations to absorb new knowledge.

The analysis of absorptive capacity has received increased attention. Empirical studies focus on the estimation of knowledge production functions taking as reference the firm as a statistical unit (O'Mahony and Vecchi 2009). A relevant example is found in Vinding (2006), which emphasizes the importance of human capital for the company's innovative performance, demonstrating, from a study of Danish firms, that the percentage of highly skilled workers and the application of management practices are not only positively correlated with innovative capacity but also negatively correlated with the degree of imitation of innovation. Escribano et al. (2009) also explored the role of firms' absorptive capacity in moderating external knowledge flows. Using data from firms in Spain, the authors argued that companies with high levels of absorptive capacity can manage the external knowledge more efficiently and thus take advantage of the best information to innovate. Innovations are generated through processes where new knowledge is added, modified, reinterpreted or simply eliminated.

The absorptive capacity differences in sectors of high and low technological intensity is explored by Grimpe and Sofka (2009) from a sample of companies from thirteen European countries. The authors conclude that firms with distinct technological capabilities differ in their patterns of information demand. Muscio (2007), focusing on a sample of Italian SMEs, emphasizes that the ability to leverage information from outside the firm depends on internal R&D and the qualification of human resources. Difficulties in the innovation process in these cases lead SMEs to collaborate more actively, creating a favourable environment for creative ideas. Fabrizio (2009) studies the link between absorptive capacity and the process of building innovative activities, concluding that basic research carried out at universities can be more easily used in subsequent applied research if it is developed in partnership with a company with adequate absorptive capacity. The study also underlined the importance for the innovation process of the relationship between universities and firms.

Understanding the role of absorptive capacity in less knowledge-intensive regions is particularly relevant by highlighting dimensions that have greater impact on knowledge exchange activities and the creation of innovative dynamics (Gomez and Vargas 2009; Artes 2009). In a context where in-house activities are more limited, access to external knowledge becomes paramount, and the firms which are most willing to tap into universities and other public research organisations to access knowledge are precisely those that already have a significant level of contacts and proximity to the academic community (Decter et al. 2007). This capacity is of crucial importance with the increasing development of open innovation processes (Chesborough 2003).

Besides the absorptive capacity, the firm's strategic approaches to access knowledge are also relevant. Here the distinction between exploration – knowledge development – and exploitation – knowledge use – can be useful (Winter 1971; Levinthal and March 1981). These can be seen as alternative strategies, between developing new information and thus improving future earnings, or using the information available to improve current earnings. March (1991) developed further this idea suggesting a direct trade-off between exploitation and exploration. While exploration involves the pursuit of new knowledge, exploitation is directed at the use and development of already identified artefacts and processes (Levinthal and March 1993). Exploration and exploitation compete for resources in the firm, which require a mix of exploitation and exploration activities (Lavie et al. 2010). While the direct benefits from exploitation are more certain, leading higher short-term performance, focusing on such short-term perspective may cause long-term constraints, as it may reduce the capacity to absorb new knowledge. Even if this debate is well present in the literature, the exploration-exploitation dichotomy is still underexplored in empirical studies, especially regarding its impact in innovation in different phases of the economic cycle.

2.2. Persistence and the innovation resilience

When debating the impacts of macroeconomic cycles in innovation a key aspect is the consistency of innovative activities. Theories on the impact of the economic crisis on innovation derive two contradictory insights (Archibugi and Filippetti 2012). Is it a pro-cyclical phenomenon, moving at the flavour of economic waves, or is it persistent, a process with high viscosity that depends on past behaviours and path dependencies? The answer to this question is not definitive as economic cycles have for sure a deep impact on the innovative activities but these are not completely dependent on short-term constraints as governments, firms and other research actors use innovation as a long-term strategic tool.

One of these strands of literature deals with the persistence of innovation, trying to understand, mostly using micro-level data, the influence that economic cycles have on firms' innovation activities and their introduction of different types of innovation in the market. Commonly three types of arguments are put forward to support the thesis of the persistence of innovation (Clausen and Pohjola 2013; Peters 2009). The first idea is that innovation generates more innovation. Success breeds success also by broadening technological opportunities and generating internal funds that can finance additional innovations (Mansfield 1968; Granstrand et al. 1997). The second argument underlines the relevance of economies of scale and learning-by-doing in the continuous process of knowledge accumulation. A third argument states that the transformation of invention into innovation takes time and is likely to incur in sunk costs; R&D activities usually pay-off only in the medium and longer term creating an incentive for its continuity. The impact of discontinuing long-run activities by short-term restrictions would outweigh the benefits related to a

reduction of short-term expenditure, by reducing the ability to reap future benefits from previous long-term investments in innovation.

A number of recent studies have used CIS data to analyse the persistence of innovation. Persistence is here understood as the characteristic of firms that developed innovation, usually discriminating by types of innovation, in two consecutive periods. One of the most recognized contributions is Peters's (2009) German CIS analysis using a Probit dynamic random effects model. He found that firms' export capacity, the qualification of employees and public funding were important determinants of the persistence of innovation, while other factors such as size or market structure had no clear impacts. Frenz and Prevezer (2012) used a similar approach with UK CIS data. They found firms' knowledge base to have a positive impact on persistence while the knowledge base from research organisations had an ambiguous effect. R&D expenditures and firm size, measured by employment, had a positive effect; belonging to a group was negative. Other interesting variables to understand persistence, such as technological opportunities, cumulativeness, or appropriability were not relevant.

Clausen and Pohjola (2013), using CIS data in Norway, underlined that R&D intensity, R&D personal, and export capacity had a significant and positive impact on persistence. Firm size and belonging to a group seemed to have a negative impact. More recently, Ganter and Hecker (2013) underlined the fact that R&D continuity, qualification of employees, size and public support were particularly important to persistence. Another interesting finding from this study is that the determinants of persistence vary considerably by type of innovation and the degree of innovativeness. This result is also underlined by Tavassoli and Karlsson (2015), using CIS data in Sweden, that evidenced the contrast between the various types of innovation. The lagged variables of innovation have different capacities to explain different types of innovation. While in product and process innovation they are quite relevant, underlining the persistent character, in marketing and organisational innovations they do not show the same degree of relevance. Variables that are commonly considered essential for innovation and its persistence, such as R&D continuity, export capacity, human capital, were quite relevant for product innovation but not for process innovation. The determinants of organisational and marketing innovation are relatively more similar to those of process innovation than product innovation. Size, a variable often found significant in other studies, was only statistically relevant for organisational innovation. These results suggest that caution and attention should be paid to discriminate determinants by the types of innovation, at least between product and process innovation that exhibit important differences. Some key aspects for these empirical studies are summarized in table 1.

Table 1: Innovation studies influencing the selection of variables

Article	Data	Objective	Independent Variables
Peters (2009)	3 waves of CIS in Germany (1994-2002), 3933 manufacturing and 1974 service firms	Understand persistence of innovation (dependent: expenditure in innovation activities)	Employees (log), market structure (Herfindahl-Hirschman index), export, employees with higher education, public funding
Frenz and Prevezer (2012)	3 waves of CIS (4,5,6) in UK, a balanced panel of around 4000 firms	Analyse the persistence of different types of innovation (product, process, new-to-market, new-to-industry)	Knowledge base (firms), knowledge base (research organisations), R&D expenditure, group, technological opportunities, appropriability, cumulativeness, employment
Clausen and Pohjola (2013)	3 waves of CIS in Norway, 1997-2006, a balanced panel of 1644 firms	Study the persistence in breakthrough (new to market) and incremental (new to firm) innovation	R&D intensity, firm size, group, export, industry, R&D personal
Ganter and Hecker (2013)	3 waves of CIS in Germany (IV, 2007 and 2009), balanced panels of around 600 to 1000 observations	Measure persistence by types of innovation (dependents: organizational, technological, product, new-to-market, new-to-firm, process)	Size, public support, group, dummies for knowledge intensive industries, services, qualification of employees, R&D continuity, export intensity
Tavassoli and Karlsson (2015)	5 waves of CIS (2002-2012) in Sweden, a balanced panel of 574 firms	Understand persistence by types of innovation (product, process, marketing, organizational)	Size, cooperation, R&D continuity, human capital, sector dummies
Archibugi, Filippetti and Frenz (2013b)	3 waves of CIS in UK, a balanced panel of around 2500 firms	Find differences in the determinants of innovation investment (dependent variable: change in innovation expenditure) before and during the crisis	Innovation expenditure, new-to-market innovation, new firms, internal R&D, size (log employees), financial obstacles, industrial property utilisation, export, qualification of employees, exploration, exploitation and ambidexterity (use of both channels)

Source: Own elaboration.

Despite the relevance of the contributions of literature on the persistence of innovation, the study presented by Archibugi, Filippetti and Frenz (2013a) was particularly inspiring for the current article as they used the same dichotomy exploration-exploitation that this article is following. Their study is not focused on persistence but in the understanding of the determinants of change in innovation efforts, measured by the innovation expenditure, before and during the crisis. They showed that the determinants of innovation expenditure varied significantly if considering the phases of the economic cycle. Many results are worth mentioning. The level of expenditure was important but with a negative impact. Internal R&D, industrial property activities, new-to-market innovation – a variable defined as 'great innovators', were significant and positive during the crisis. Export intensity and size, in terms of employees, were important but more so before the crisis. Financial obstacles and the age of the firm were not relevant. Qualification of employees, associated with absorptive capacity, was always significant but more important during the crisis. Regarding knowledge utilisation strategies, exploration was particularly relevant during the crisis and exploitation was more important before the crisis. The use of both strategies was particularly significant during the crisis.

Another strand of literature - in fashion particularly in regional studies and planning – that addresses the impacts of economic downturn is the study of regional resilience (Cooke, Parrilli and Curbelo 2012). Resilience is understood as the capacity of a socio-economic system, usually a territory of variable geometry, to cope with negative shocks by resisting, recovering, re-orienting, and/or renewing the trajectories of development pathways (Martin and Sunley 2014). Resilience accommodates not only the understanding that systems are subject to external shocks and may recover previous trajectories, but also that a shock may come from internal systemic failures (Boschma 2015). Resilience often requires the development of new pathways grounded in explicit or latent capabilities of the system, rather than simply returning to a pre-shock state (Pinto and Pereira 2014). In fact, the notion of persistence of innovation thus has some similarities with the idea of resilience, by assuming the adaptive capacity of the system to maintain its behaviour in the face of external shocks.

This article suggests that the notion of resilience can contribute to understand how innovation is affected when facing negative shocks like the ones generated by the financial crisis. The 'innovation resilience' regards the capacity of a specific innovation system to continue its innovation activities after turbulence and disruption. Innovation systems are here understood as complex adaptive systems, with a multitude of layers, from the individual to the macro-context, and emergent properties, that interconnect the diverse levels originating specific responses (Cooke 2012). Focusing the firm level, innovation resilience can be understood as the capacity of the firm to continue its innovative efforts and generate innovation despite shocks. Developing innovation activities after a shock is one of the key features for detecting the presence of innovation resilience.

3. Methodological considerations

3.1. Clarifications for the empirical research

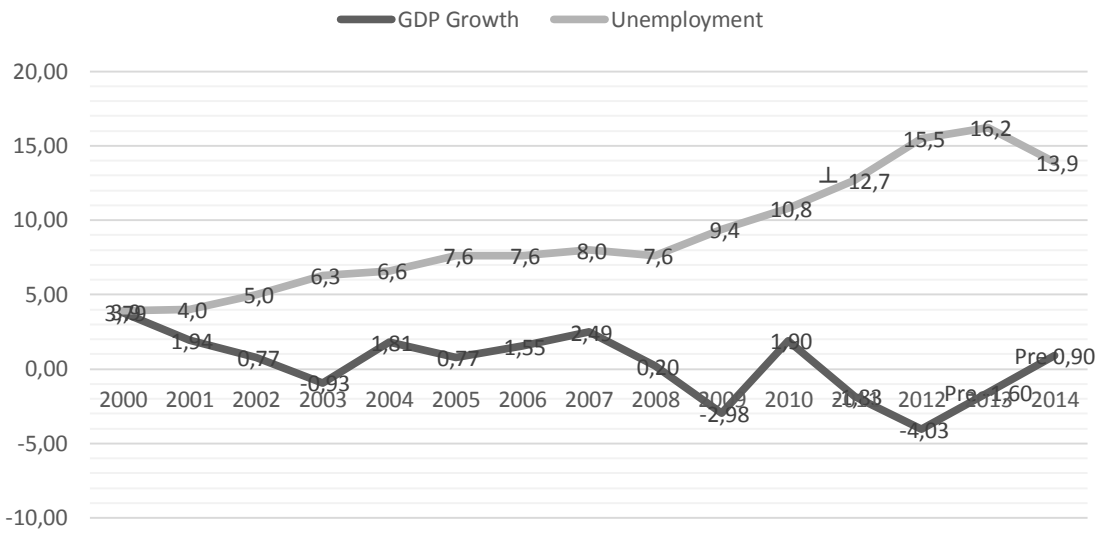
The Community Innovation Survey is an extensive firm-level dataset collected every two years by the European Commission and implemented separately by each member state's national statistical office in order to find out the degree and effects of innovation across European countries. CIS data regards firm-level information based in a large innovation survey. It is based on the improvement of several waves of innovation surveys in Europe and benefits directly from the efforts to stabilize the collection of innovation data, namely following the references of the Oslo Manual (OECD 2005). CIS data has been successfully

used for comparative studies (for a review of the history of CIS see Smith and Arundel 2013). CIS data is extremely comprehensive and detailed, covering all sectors of the private economy, and capturing information on many aspects of firm's innovative behaviours (Derbyshire 2014).

The main limitations regard the definition and construction of some of its key variables, and the fact that the majority of information is self-reported. This can lead to the so-called Kruger-Dunning effect (Kruger and Dunning 1999), where less innovative firms classify their achievements as more innovative when compared to other more qualified firms, which are more moderate in classifying their innovation efforts. It is also difficult for some respondents to differentiate the types of innovation and the degree the innovativeness. For example, less innovative firms find it difficult to understand if an innovation is new-to-the-firm or new-to-the-market. The samples collected in the CIS are also biased, as micro firms are not included, and neither are public services. In addition, doing-using-interacting forms of innovation tend to be under-represented (Capello and Lenzi 2013). These limitations notwithstanding, CIS has facilitated a variety of studies of innovation dynamics in the last years (Fagerberg, Mowery and Nightingale 2012).

In parallel, it is not easy to delimitate economic fluctuations in time. Constraints in socioeconomic systems often begin before the impacts can be visible in GDP or unemployment figures and negative effects commonly stay long after the economic recessions are statistically over. In the case of Portugal, and for the purpose of the empirical study it is assumed that the year 2006 corresponds to a period before the economic crisis, 2008 represents the onset of the crisis in Portugal, when effects are still reduced, 2010 is in the midst of the crisis, and 2012 is its peak (cf. Figure 1).

Figure 1: The evolution of GDP and Unemployment rate in Portugal



Source: Data from Pordata http://www.pordata.pt
(INE | BP - *Contas Nacionais Anuais* (Base 2011) and INE - *Inquérito ao Emprego*).

The analysis uses CIS data from the waves of 2006, 2008, 2010 and 2012. The existence of an external economic crisis, and a dataset that was consistently collected before and during the crisis, creates the opportunity to compare the effects of the economic recession on firms' innovative behaviour.

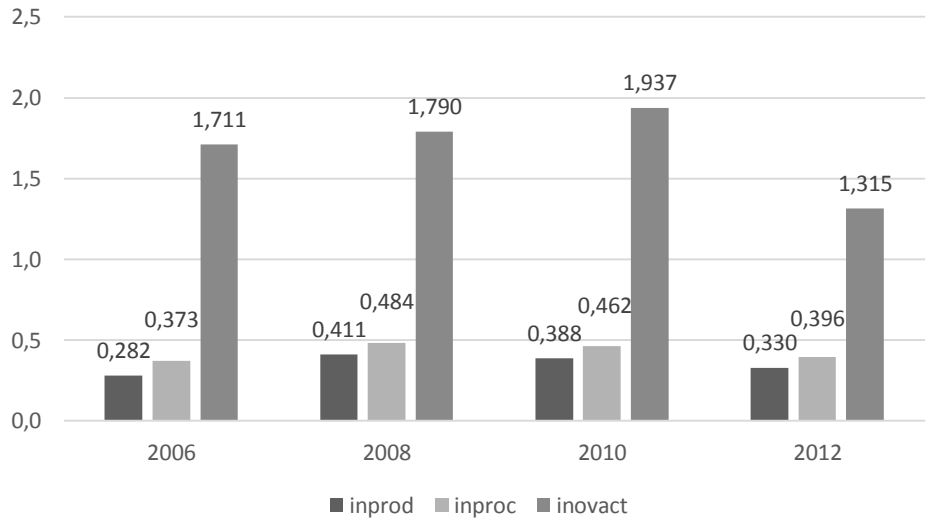
3.2. Variables

The analysis aims to understand the relative importance of specific structural factors and strategic variables in the different periods to innovation. To analyse different facets of innovation three dependent variables were selected:

- INOVACT – count variable (1 to 7) with the breadth of innovation activities implemented.
- INPROD – binary variable 1 if firm introduced product innovation.
- INPROC - binary variable 1 if firm introduced process innovation.

These three variables show related but significantly different phenomena. In figure 2 we can analyse the evolution of these variables in the different CIS waves collected for the Portuguese case. These three variables grew from 2006 to 2012 but contracted with the emergence of the economic turmoil. The reduction of the breadth of activities was falling in 2012 and the generation of product and process innovation began to decrease in 2010.

Figure 2: Evolution of breadth of innovative activities, product innovation and process innovation (annual average, Portugal)



Source: Own calculations based in CIS data.

The breadth of innovation activities (INOVACT) regards the mechanisms that a firm uses to stimulate innovation. They refer to a group of activities reported in CIS of innovation activities within the company, extramural R&D, machinery, equipment supplied and software acquisition, other external knowledge, training for innovation activities, and design. With this variable we intend to understand the variety of ways (or inputs) firms use to innovate and if they shrink or expand with the crisis.

The most common variables of innovation in the CIS are also analysed in this study. Product innovation (INPROD) regards a new product or variety that is introduced in the firm's market. Process innovation (INPROC) involves new methods for the production, taking as a common consequence

additional efficiency derived from the reduction of costs. Both the product and process innovation are outputs of the innovative activities performed by the firm. Product innovation and process innovation follow distinct logics. Process innovation is less dependent on STI modes of learning and the absorptive capacity of employees. Persistence of innovation is more intense in product innovation (Tavassoli and Karlsson 2015).

The selection and design of independent variables is directly inspired in variables used in innovation literature, in particular those already presented in table 1. The independent variables were organized in three groups of variables. The first group includes 6 variables linked with structural aspects of the firms. The second group of 5 variables focused explicit innovative efforts of the firms. The third group regards the strategic dimension of the firms. It is relevant is to underline that our exploration-exploitation variables definition was inspired by Archibugi et al. (2013b). Table 2 clarifies the used independent variables and shows their mean values for the different waves of CIS.

Using the data available in CIS, the analyses also paid attention to the obstacles of innovation (FINOB - Sum of scores of financial obstacles, and MKTOB - Sum of scores of market obstacles). We decided to eliminate these two variables from the analysis, as they had no statistical significant explicative capacity for any of the dependent variables in any of the waves.

Table 2: Mean values of selected independent variables, by CIS wave

	Variables		2006	2008	2010	2012
Structural	IND_MAN	Dummy, 1 if firm from manufacturing sector.	0.471	0.4764	0.4745	0.5263
	GP	Dummy, 1 if belongs to group.	0.282	0.2718	0.2755	0.2749
	EXPO	Dummy, 1 if operates in external markets.	0.507	0.5125	0.55065	0.6028
	LOGTO	Total turnover (€) (for estimation purposes it was used in log format).	1.498	1.397	1.482	1.472
	GROWTH	Evolution of turnover (in %).	5.731	3.953	1.126	1.539
Innovative Efforts	KNBASE_MKT	Sum of scores given to suppliers, competitors and clients as source of information.	2.377	2.902	2.842	2.965
	KNBASE_SC	Sum of scores given to universities and other public research organisations as source of information	0.531	0.6698	0.7320	0.7693
	CO	Dummy, 1 if firm cooperates with external entities in innovative activities.	0.1178	0.2086	0.1571	0.1293
	INOVINT	Total investment in innovative activities (€) (for estimation purposes transformed in ratio of the total turnover)	0.541	0.3447	0.0402	0.030
	EMPQUAL	Dummy, 1 if company has 25% or more of employees with a HE degree.	0.177	0.1887	0.2292	0.2278
Strategic	FUND	Dummy, 1 if received public funding for innovation.	0.072	0.0997	0.1588	0.1582
	EXPLOR	Sum of Scores given to strategy and goals focused in developing new products and new markets.	1.606	2.401	2.330	4.868
	EXPLOT	Sum of Scores given to strategy and goals focused in reducing costs, increasing market share, increasing turnover, and market flexibility.	2.392	3.654	3.349	1.190

Source: Own elaboration using CIS data.

3.3. Econometric options

The econometric model used an ordinal Probit for INOVACT and Probit estimators, with robust standard errors, for INPROD and INPROC. OLS versions for all models were estimated as robustness checks. We also estimated alternative versions of the models by controlling for additional variables, such as measures of innovation barriers, and size of firm by number of employees. The results were consistent.

We opted to estimate the models using a cross-sectional approach instead of a panel data approach, even if this method, anchored in the proposal of Wooldridge (2005), using random effects Probit models, gained relevance in the literature to study persistence with CIS data. Woolridge's approach has two limitations for our specific research objectives. The first in that the creation of a balanced panel of persistent innovators has a huge impact in the reduction of the sample size, excluding many firms, innovative or not, that are only present in a specific wave. The second is that the process implies the elimination of younger firms, inducing a sample bias towards more old and consolidated ones. Because the current study is particularly interested in analysing the relative significance and signal of selected independent variables on innovation during the different periods, to comprehend possible effects of the crisis on innovative behaviour, a cross-sectional approach seemed a convenient method. We are not interested in producing an aggregated model for the four-time periods, the main result achieved with the standard approach of Woolridge. Nonetheless our option, we agree that Woolridge's approach is extremely valuable for studying persistence of innovation[5].

Cross-sectional analyses using CIS data, using limited dependent estimators, are not only common in the literature, as they are currently being used to assess different sorts of contemporary effects in innovation. Classical examples can be found for initial CIS waves (Kleinknecht, Mohnen and Macmillan 2001), but more recent studies[6] are focusing a variety of topics such as collaboration (Lhuillery and Pfister 2009), open innovation practices (Janeiro, Proença and Gonçalves 2013), innovation in services (Pires, Sarkar and Carvalho 2008) or eco-innovation determinants (Horbach, Oltra and Belin 2013). Our goal is to compare the statistical significance and signal of key variables in a specific functional form and its fluctuations concerning the four CIS waves available. We tried to anchor our decision of inclusion of independent variables in the literature review. Nonetheless it is relevant to point that it is difficult to control reverse causality in many variables that are both a cause and a consequence of the innovative dynamics of the firm, and in the literature appear interchangeably as explanatory of explained variable.

In this way, and because we are interested in knowing the differences in the drivers of innovation in different phases of the crisis, we decided to retain the complete sample for each CIS wave, and not select a sub-sample of innovators or a balanced panel of persistent innovators. For the year 2006 the sample includes 4,721 observations, in 2008 includes 6,573, in 2010 it has 6,160, and in 2012 it has 6,840 firms.

[5] For a recent application of this method to Portuguese case (Costa, Botelho and Teixeira 2018).
[6] Cf. for example, Pereira & Leitão (2018) in GEE Woking Paper Series.

3.4. Research hypotheses

To facilitate the interpretation of estimation results the following research hypotheses were defined.

H1: Larger firms exhibit more innovation.

The size of firms does not show a clear pattern in innovation studies. Some research finds that flexibility is important to innovation (Clausen and Pohjola 2013; Peters 2009) while others show that the economies of scale may create opportunities for R&D investments, acquisition of external knowledge services, and internal departments dedicated to R&D (Ganter and Hecker 2013; Archibugi et al. 2013b). We want to clarify if in turbulent periods size (LOGTO) is an important determinant of innovation.

H2: High growth firms show more innovation.

Rapidly growing firms, commonly called gazelles, have been found to be more innovative (Grundström et al. 2012). In stable periods the literature suggests that these firms have a key role in innovation (Bleda at al. 2012). But with the economic downturn can gazelles find the appropriate environment to develop innovation-based growth? We will test this assertion with the variable GROWTH.

H3: Firms with the knowledge base anchored in universities and public research organisations show more innovation.

Much has been underlined about the importance of university-industry relations (Pinto & Fernández-Esquinas 2013). Today it is assumed that the firms that are more innovative are those able to capture external knowledge produced by academic organizations. We will look to understand if firms that use universities and other public research organisations as a relevant source of knowledge (KNBASE_SC) are more willing to develop innovation during the economic slowdown.

H4: Higher absorptive capacity increases innovation.

Absorptive capacity is regarded as one of the crucial aspects for the capacity of the firm to capture external knowledge and increase its innovation capacity (Tavassoli and Karlsson 2015). Absorptive capacity is measured by the qualification of employees (EMPQUAL). Nevertheless its impacts are not always direct as some sectors, domains, and types of innovation are more dependent on the formal education of human resources. We will analyse the statistical significance of this variable.

H5: Public funding is crucial for innovation.

Whether the firm has received public support is a factor commonly assumed as crucial for innovation activities (Ganter and Hecker 2013). Particularly during the crisis the access to public funding has been reported as a key factor to continue innovation efforts (Peters 2009). We will analyze the variable FUND and its impacts in innovation activities, and product and process innovation.

H6: Higher intensities of innovation expenditure increase innovation.

The levels of expenditure on innovation activities are drivers of breadth of innovation activities and generation of innovation (Frenz and Prevezer 2012). Nonetheless its importance may differ during the different stages of the crisis. We will analyse the variable INOVINT, innovation expenditure intensity, to provide additional information on this matter.

H7: Exploration and Exploitation strategies increment innovation.

Both these types of strategies are crucial for innovation. The combination of both, or ambidexterity, is commonly considered as a catalyst for innovation in the firm (Archibugi et al. 2013b). Nonetheless its importance can be significantly different if we take into consideration the economic crisis. We will test EXPLOR and EXPLOT to understand the relevance of these strategies to innovation dynamics.

4. Estimation results

This study helps to comprehend the determinants of innovation. The factors that stimulate both input innovation activities, here measured by the breadth of innovation, and output results, measured by the existence of product and process innovation, in firms during different periods of the economic crisis are confronted. The results of the models, estimated using Stata 12, are summarized in table 3.

These results suggest some relevant aspects concerning structural factors. Manufacturing firms were, compared to other sectors, relatively less involved in innovation activities before the crisis. Nonetheless this effect dilutes with the crisis. Size in terms of turnover was more important before the crisis. Turnover growth is relevant during the crisis; it is positive to the breadth of activities but seems to have a significant negative impact both in product and process innovation.

The estimated models help understand the determinants of innovation efforts. Qualification of employees is always relevant but during the crisis it is particularly negative for process innovation. The financial resources dedicated to innovation became more relevant in the peak of the crisis. Suppliers, competitors and clients are relevant sources of knowledge. Universities and other public research organisations seem less central as sources of knowledge, and as the crisis deepens they become even less so, having in fact a negative significant impact in the three dependent variables analysed. Cooperation with external entities, in general, was always crucial, becoming even more important in the peak of the crisis. It is a critical variable for the innovative dynamics.

The models also provide some findings concerning strategic factors. Exploration and exploitation strategies are both important for the breadth of innovation activities but at the peak of the crisis exploration seems to increase. Exploration is particularly important for product innovation but has a negative impact in process innovation. Exploitation strategies, focusing on the reduction of costs, market share, turnover, and market flexibility, have no significant impacts on the three dependent variables during the peak of the crisis. Public funding is always significant but has had a crucial impact at the crisis peak period. Firms do not identify particularly relevant obstacles– only market obstacles were statistically significant before the crisis. These variables were eliminated in the final estimation presented.

Table 3: Determinants of the breadth of innovation (INOVACT), product innovation (INOPROD), process innovation (INOPROC)

	BEFORE THE CRISIS - 2006			ENTERING THE CRISIS - 2008			DURING THE CRISIS - 2010			PEAK OF THE CRISIS - 2012		
	INOVACT	INPROD	INPROC	INOVACT	INPROD	INPROC	INOVACT	INPROD	INPROC	INOVACT	INPROD	INPROC
IND_MAN	-0.1646***	0.0950	0.0447	-0.1173***	-0.0638	-0.0774	-0.0948***	0.0608	-0.1463***	0.0354*	0.0361	0.0413
GP	0.1089**	0.1277*	0.1041	0.0881**	0.0448	0.0368	-0.0020	-0.0181	-0.0730	0.0285	0.0880*	-0.1171*
EXPO	0.0372	0.0103	0.0393	-0.0423	0.0152	-0.0682	0.0185	0.0457	-0.1044**	-0.0255	-0.0154	-0.0136
LOGTO	0.0809***	0.0447**	0.0672***	0.0920***	0.009	0.0401***	0.0794***	0.0283*	0.0577***	0.0617***	0.0433***	0.0965***
GROWTH	2.25E-06	-0.0001	-0.00001	20.62E-10***	10.65E-09***	90.04E-07	0.0001***	0.00002	0.00003	-0.0003**	-0.0006***	-0.0002*
KNBASE_MKT	0.2343***	0.1320***	0.1583***	0.1549***	0.0830***	0.1688***	0.1649***	0.09776***	0.1600***	0.2582***	0.2427***	0.2944***
KNBASE_SC	0.0257	0.0152***	-0.0897***	0.0156	-0.0457**	-0.0776***	-0.0157	-0.0451**	-0.070***	-0.0219*	-0.0704***	-0.0869***
CO	0.5376***	0.2636***	0.6193***	0.6794***	0.3344***	0.4090***	0.62122***	0.4522***	0.2707***	0.6468***	0.5781***	0.3566***
INOVINT	0.0007***	0.0010***	0.6528*	10.96E-06***	30.40E-06***	-30.92E-06***	0.01531***	-0.0130**	0.1061***	0.2622***	0.5923***	0.1064***
EMPQUAL	0.2179***	0.2456***	0.0260	0.2768***	0.3249***	-0.0629	0.2527***	0.1118*	-0.0848	0.1277***	0.2676***	-0.0958*
FUND	0.3290***	0.3492***	0.0603	0.5381***	0.2144***	0.3983***	0.4285***	0.1814***	0.2612***	0.5722***	0.4125***	0.5446***
EXPLOR	0.0758***	0.3966***	-0.1424***	0.1481***	0.3276***	-0.0246	0.1871***	0.4232***	-0.0495**	0.0357***	0.0764***	-0.0054
EXPLOT	0.1925***	-0.0396*	0.3919***	0.1920***	0.0661***	0.2505***	0.1650***	-0.0213*	0.2790***	-0.0073	-0.0119	-0.0088
/CUT1	2.432			2.484			2.348			2.014		
/CUT2	2.900			3.723			3.371			2.750		
/CUT3	3.440			4.263			3.887			3.280		
/CUT4	4.025			4.776			4.357			3.744		
/CUT5	4.644			5.319			4.841			4.216		
/CUT6	5.269			5.953			5.341			4.726		
/CUT7	6.007			6.634			5.969			5.344		
CONST		-2.643***	-2.695***		-1.945***	-2.024***		-2.260***	-2.187***		-2.410***	-2.559***
PSEUDO R2	0.360	0.504	0.579	0.353	0.493	0.519	0.346	0.519	0.527	0.279	0.424	0.457
TESTS	WALD CHI2(13) = 3757.64; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -4742.383	WALD CHI2(13) = 2090.16; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -1393.735	WALD CHI2(13) = 1741.55; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -1312,0334	WALD CHI2(10) = 0. 8133.38; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -7423,6664	WALD CHI2(14) = 4398.74 ; PROB > CHI2 = 0.0000; LOG LIKELIHOOD = -2261.9154	WALD CHI2(13) = 3286.65; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -2193.9315	WALD CHI2(13) = 4836.56; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -7155.298	WALD CHI2(13) = 3162.92; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -1976.2319	WALD CHI2(13) = 2651.20; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -2007.0688	WALD CHI2(13) = 3956.60; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -7423.8971	WALD CHI2(13) = 2340.11; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -2493.9166	WALD CHI2(13) = 2021.89; PROB > CHI2 = 0.0000; LOG PSEUDOLIKELIHOOD = -2491.8036

*** p < 0.01, ** p < 0.05, * p < 0.1

Source: Own elaboration based in CIS data.

Concerning the research hypothesis about the relevance of size, *H1,* LOGTO becomes more significant and positive especially at the peak of the crisis. It can be argued that turnover can create the availability of financial resources to pursue innovation.

High growth firms *(H2*) show an increased breadth of innovation activities during the crisis period. Nevertheless, the sign of this variable turns negative remaining statistical significant both for the breadth of innovative activities, product and process innovation in the peak of the crisis, suggesting that innovation results may slow down intensively during crises in the most rapidly growing firms.

Firms with the knowledge base anchored in universities and public research organisations (KNBASE_SC) show less innovation. We do reject *H3*. The econometric results provide solid evidence that, in all three variables, the dependence of the academic sector as a source of information is negative, especially during the crisis and for process innovation. We could argue that during the crisis firms focus their resources on their activities, reducing the attention given to higher level information sources, the use of which may require greater internal resources.

We do not reject *H4*. Absorptive capacity is one the central aspects for firms to develop a larger breadth of innovation activities and to generate product innovation. Nonetheless our results suggest that the qualification of employees (EMPQUAL) is not so relevant for process innovation, and even becomes slightly negative in the peak of the crisis for the probability of developing this type of innovation. Again, it may be hypothesised that the difference of qualification is mostly reflected on more resources needed.

Public funding (FUND) is always crucial for innovation. We do not reject *H5*. Nonetheless in stable contexts, public funding is not significant for process innovation. During the peak of the crisis public funding is absolutely crucial for all dependent variables studied.

The intensity of innovation expenditure (INOVINT) does not show a clear pattern during the initial phases of the crisis. It is in general not significant to the breadth of activities. It is particularly relevant for process innovation. It is evident that this indicator is crucial to innovation as at the peak of the crisis it is a catalyst of all dependent variables studied. In this way we do not reject *H6*, as higher intensities of innovation expenditure increase the probability of innovating in the peak of the crisis.

Exploration and Exploitation strategies do not influence in the same way innovation during the economic cycles. We do reject *H7*. Exploration (EXPLOR) benefits the breadth of activities and product innovation but is (in the four periods) negatively associated with process innovation. It does not vary significantly with the economic cycle. Exploitation (EXPLOIT) strategies are important for the breadth of activities and process innovation but with the growing intensity of the crisis it loses statistical significance (and the signal eventually turns negative).

5. Conclusion

The economic crisis has had impacts on the innovation systems, specifically in the decision of firms to develop different types of innovation activities, and in their capacity to generate different types of innovation. This article contributed to a better understanding of the extent to which the determinants of innovation dynamics vary with economic cycles. The study connects two related notions, resilience and persistence of innovation. Resilience is being studied as the capacity of a socioeconomic system to adapt

to internal or external shocks and disruptions. Persistence refers to the characteristic of maintaining certain behaviour because of previous trajectories. While the concept of persistence is well developed in innovation studies, resilience is still in an embryonic form in the study of innovation. Future research should go a step further and try to bring the idea of persistence closer to evolutionary views on resilience, one that addresses the capacity of systems to bounce-forward, namely to undergo anticipatory or proactive reorganization to minimize the impact of destabilizing shocks and create new paths.

In this article we suggested the concept of 'innovation resilience' to illustrate how the economic slowdown affects firms' behaviour in terms of their ability to maintain and develop innovative activities and deploy product and process innovation. The main novelty in this concept is that it points directly to the implementation of innovation activities and the generation of innovation during the economic crisis. It contributes to the studies of innovation by incorporating the economic cycle, showing that the determinants of firm behaviours do change with the economic cycle. Firms may continue to pursue innovation with the downturn but the motivations and causes that justify innovation efforts vary.

The present research presents several limitations being the most obvious the ones that result from the limitations of CIS data and from the methodological options of the authors, namely the sample chosen and the econometric estimation procedure. Hopefully future research may overcome these problems, exploring the behaviour of particular types of firms such as those that, despite the economic crisis, continued or increased their innovative efforts, increased their turnover, and introduced new-to-market innovations.

Econometric results underlined the importance of several variables to innovation that were already found in the literature. The knowledge base anchored in market relations, the cooperation activities with external entities, the absorptive capacity, the public funding were aspects that were found relevant to the innovation dynamics in general. But we have found variables that gained or lost significant importance in the peak of the crisis. That is the case of the turnover and its growth, the intensity of innovation that are significantly more relevant in the peak of the crisis. On the contrary, the use of exploitation strategies decreases its relevance with the intensification of the crisis. An evidence-based industrial research and innovation policy should take into consideration the variety of business profiles and also the creation of contingency measures in order to mitigate the effects of economic downturn in the innovative efforts of some firms. It also shows that during crises governments should resist the temptation or external pressures to cut funding for innovation, as such public funds are crucial for the survival and future competitive advantage of firms.

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