



# Innovation in firms, resilience and the economic downturn: Insights from CIS data in Portugal

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## Funding information

FCT, Grant/Award Numbers: DL57/2016/CP1341/CT0013, SFRH/BPD/84038/2012

## Abstract

There is an interest in understanding the effect of economic crises such as the one that hit the financial markets in the late 2000s, on the innovation performance of countries and regions. This paper introduces the concept of “resilience of innovation” 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. Using Portugal as a case study—an EU member-state that was heavily affected by the economic downturn—this paper explores the data collected from four waves of the Community Innovation Survey from 2006 to 2012. It presents two-stage limited dependent variable models to understand the changing impacts of structural factors, innovative activities and strategies in terms of exploration and exploitation of knowledge on the development of product and process innovation. We find knowledge exploration to be particularly important for product innovation, while exploitation is a strong determinant for process innovation. Size, market knowledge sources and public funding for innovation are positively associated with both types of innovation in the peak of the crisis. This reiterates the importance of innovation support efforts to mitigate the effects of economic shocks and boost recovery.

## KEYWORDS

CIS, crisis, exploitation, exploration, innovation, persistence, resilience

**JEL CLASSIFICATION**

C21; C25; O31; O32; O38

## 1 | INTRODUCTION

The relation between economic crises and innovation has long been of interest for scholars 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, 1994 [1942]). The macroeconomic context influences national and regional innovation systems (Edquist, 2005), restricting or enabling the innovative behaviour of firms and other relevant research organizations (Archibugi, Filippetti, & Frenz, 2013a; Cruz-Castro & Sanz-Menéndez, 2015).

The macroeconomic fluctuations and the economic slowdown following the 2007 economic crisis on innovation performance was strongly uneven (Makkonen, 2013), its impact varying strongly across countries and regions (Davies, 2011; Kastrinos, 2013). Studies have found that firms either reduced or abandoned innovation activities and related expenditures during the crisis, or managed to build competitive advantage and benefit from processes of creative destruction (Archibugi, Filippetti, & Frenz, 2013b; Frenz & Prevezer, 2012; Paunov, 2012). Turbulence, imbalances and a diversity of shocks to the socio-economic systems have therefore brought to bear a series of contributions that highlight the connections of innovation with the economic downturn.

A deeper reflection about innovation dynamics is, however, needed. Socio-economic resilience is intrinsically connected with the patterns of knowledge development and use during the economic crises by firms. Changing and turbulent environments require the maintenance of innovation capacity at firm level, that is highly dependent on learning processes associated with exploration and exploitation of knowledge (Archibugi & Filippetti, 2012). Exploration is associated with novel combinations that require risk taking, experimentation, and discovery. In contrast, exploitation is mainly based on existing knowledge and skills, reinforcing processes and structures characterized by routines (March, 1991). Much can be learnt a decade after the beginning of the financial crisis.

The empirical study aims to understand how the determinants of firms' innovation change as a result of the country's economic slowdown. In order to do so we look at the "resilience of innovation," understood as the capacity of the firm to continue its innovative efforts and generate innovation despite shocks. This concept goes beyond the mere capacity to continue its innovative efforts—its persistence—but incorporates both exploration and exploitation mechanisms to enable new development possibilities.

To address the impact of the economic crisis on innovation this study focuses on Portugal, which was one of the countries more deeply impacted by the economic recession and instability generated as a result of the global financial crisis, and of its ramifications in the European Union. Portugal was subject to a bailout from the Troika (the European Commission, International Monetary Fund and European Central Bank) in 2011 which involved austerity measures aimed primarily to control the public deficit, with related impacts in public expenditure, supported by different structural reforms, namely in labour laws. These policies led to a strong economic recession, increased unemployment and emigration (Correia, 2016).

Portugal is therefore an interesting case to understand how innovation is affected by negative shocks like the ones generated by the financial crisis. The Community Innovation Survey (CIS) reported a reduction in the share of innovative companies in Portugal above the EU average in 2010–2012 (Eurostat, 2015). Regionally, the effect of the crisis was felt more especially in Lisbon and Algarve regions, as well as in the regions of Madeira and Azores, in terms of GDP and unemployment levels. In a recent study, using data prior to and after the crisis (Pinto, Healy, & Cruz, 2019), these four regions were part of a cluster of "regions in divergence," considering the evolution of GDP, unemployment and R&D, while the other Portuguese regions were in a group of "intermediate positive situation" in relative terms to European regions.



This study focuses on firm-level innovative activities and performance before and during the crisis, using micro-data from the Portuguese innovation survey waves of 2006, 2008, 2010 and 2012. An econometric approach tested the relative significance and signal of selected independent variables on innovation during the different waves.

The paper is organized as follows. It briefly presents the relation of innovation and economic context, connecting the notions of resilience, exploration–exploitation and persistence. The paper continues with the empirical study, presenting econometric models to analyse the relevance of structural factors, innovative efforts and strategic variables, in the different periods, to explain innovation activities, product innovation and process innovation. The paper concludes by summarizing empirical findings and suggesting policy implications and future research on these issues.

## 2 | INNOVATION IN THE ECONOMIC DOWNTURN

### 2.1 | Regional resilience, knowledge and innovation dynamics

The increasing literature on regional resilience addresses the uneven regional impacts of economic downturns (Cooke, Parrilli, & Curbelo, 2012; Pinto, Noronha, & Vaz, 2018). 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 & Sunley, 2014). Resilience accommodates not only the understanding that systems are subject to external shocks and may recover previous trajectories—the so-called engineering resilience—or that there are maximum threshold to cope with the shocks without changing systemic and behavioural characteristics—the ecological resilience—but also that a shock may stimulate renewal and the creation of new pathways grounded in explicit or latent capabilities of the system, rather than simply returning to a pre-shock state paths (Boschma, 2015).

A number of studies have been undertaken to measure regional resilience (Davies, 2011; Martin, 2012; Martin and Sunley, 2015), stressing aspects such as regional productive structure, strength of the knowledge base and the innovation propensity of knowledge firms, access to knowledge networks, labour markets and other institutional and policy dimensions as factors influencing these differences (Pinto & Pereira, 2018). Most resilient regions are those specialized in dynamic and productive industries and those with more diversified economies (Boschma, 2015; Cuadrado-Roura & Maroto, 2016; Eriksson & Hane-Weijman, 2017; Psycharis, Kallioras, & Pantazis, 2014).

Martin, Sunley, Gardiner, and Tyler (2016) found that economic structure has an influence on resilience but that many other “region-specific” factors are prominent, including the relative importance of small enterprises, the degree of foreign ownership of local industry, export orientation, as well as institutional conditions. Innovation was found to play a key role by Bristow and Healey’s (2018) study on the response of European regional economies to the 2007 crisis. They found that regions identified as innovation leaders were more likely to have either resisted the crisis or recovered quickly from it. Psycharis et al. (2014) found that regional policy played a role at times of crisis. They showed that in the case of Greece policy was pro-cyclical rather than counter-cyclical and thus the reduction in public spending contributed to trapping regions in a downward spiral of decline.

As suggested by Bristow and Healey (2018), socio-economic resilience, in particular of regions, is crucially connected to firms’ innovation capacity and therefore highly dependent on learning processes associated with knowledge. The distinction between exploration—knowledge development—and exploitation—knowledge use—can be here particularly useful (Levinthal & March, 1981; Winter, 1971). 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 & March, 1993). Exploration and exploitation compete for resources in the firm, which require a mix of exploitation and exploration activities (Lavie & Rosenkopf, 2006). While the direct benefits from exploitation are more certain, leading to 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 and innovate.

The concept of “resilience of innovation” may help 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 “innovation resilience” metaphor regards the resistance, recovery, reorientation and renewal capacities of a specific innovation system to pursue innovation 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). Developing innovation activities after a shock is one of the key features for detecting the presence of innovation resilience. Even though it is directly connected with persistence, as will be explored in the next section, it transcends this dimension by incorporating a component of internal transformation through knowledge exploration.

## 2.2 | Innovation and the economic cycles

When debating the impacts of macroeconomic cycles on innovation a key aspect is the consistency and cumulativeness of innovative activities. Theories on the impact of the economic crisis on innovation derive two contradictory insights (Archibugi & 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 likely to have a deep impact on the innovative activities but these are not completely dependent on short-term constraints as firms, research institutes, governments and other actors use innovation as a long-term strategic tool.

Much of the empirical evidence of the linkages between the crises and innovation supports pro-cyclical arguments (Makkonen, 2013). But commonly three types of arguments are put forward to support the thesis of the persistence of innovation (Clausen & 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 (Granstrand & Patel Pand Pavitt, 1997; Mansfield, 1968). 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) analysis based on German CIS. 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 that firms' knowledge base had a positive impact on persistence while the knowledge base from research organizations 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 personnel, 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 organizational 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 organizational and marketing innovation are relatively more similar to those of process innovation than of product innovation. Size, a variable often found significant in other studies, was only statistically relevant for organizational innovation. These results suggest that caution should be paid when considering determinants by 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.

Using the dichotomy exploration--exploitation, Archibugi et al. (2013a) focused not on persistence but on 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 when considering the different stages of the economic cycle. Several results are worth mentioning. The level of expenditure was significant 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 utilization 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.

Using data from Spanish firms, D'Agostino and Moreno (2018) underlined the role that exploration activities have during the crisis. Using co-operation with external organizations as the central variable, their study suggested that exploration is more strongly linked to innovation during the economic recession. The maturity of the firm in co-operation activities also showed a significant impact on innovation performance.

To sum up, while the notion of persistence of innovation has some similarities with the idea of ecological resilience, by assuming the capacity of the system to maintain its behaviour in the face of external shocks, the notion of exploration has connections with the idea of evolutionary resilience, by assuming the adaptive capacity of the system in creating new trajectories in the face of external shocks. Even if this debate is well present in the literature, the exploration–exploitation dichotomy is still underexplored in empirical studies, especially regarding its impact on innovation in different phases of the economic cycle. This paper is an empirical contribution to connect these concepts.

### 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, 2018). CIS data has been successfully used for comparative studies (for a review of the history of CIS see Arundel & Smith, 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 &

**TABLE 1** Innovation studies influencing the selection of variables

Paper	Data	Objective	Independent variables
Peters (2009)	Three waves of CIS in Germany (1994–2002), 3,933 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)	Three waves of CIS (4,5,6) in UK, a balanced panel of around 4,000 firms	Analyse the persistence of different types of innovation (product, process, new-to-market, new-to-industry)	Knowledge base (firms), knowledge base (research organizations), R&D expenditure, group, technological opportunities, appropriability, cumulativeness, employment
Clausen and Pohjola (2013)	Three waves of CIS in Norway, 1997–2006, a balanced panel of 1,644 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)	Three waves of CIS in Germany (IV, 2007 and 2009), balanced panels of around 600 to 1,000 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)	Five waves of CIS (2002–2012) in Sweden, a balanced panel of 574 firms	Understand persistence by types of innovation (product, process, marketing, organizational)	Size, co-operation, R&D continuity, human capital, sector dummies
Archibugi et al. (2013b)	Three waves of CIS in UK, a balanced panel of around 2,500 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 utilization, export, qualification of employees, exploration, exploitation and ambidexterity (use of both channels)
D'Agostino and Moreno (2018)	PI TEC 2004–2013, 9 years, balanced pool of 5,955 firms	Two stage model to investigate the relevance of exploration, though co-operation, during the economic downturn. Radical innovation and innovation in sales were dependent variables	Size, market share, group, barriers to innovation, foreign, international markets, openness, R&D permanent, demand-pull, type of partners, continuity of co-operation, type of co-operation, new firm

Source: Own elaboration.

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. In addition, doing-using-interacting forms of innovation tend to be under-represented (Capello & Lenzi, 2013). The samples collected in the CIS are also biased, as micro firms are not included, and neither are public services. CIS is also limited for the



study of regional innovation in Portugal as the available micro-level data was not identified by region. These limitations notwithstanding, CIS has facilitated a variety of studies of innovation dynamics in recent years (Fagerberg, Mowery, & Nightingale, 2012).

### 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; and
- INPROC—binary variable 1 if firm introduced process innovation.

These three variables show related but significantly different phenomena. Table 2 presents the evolution of these variables in the different CIS waves collected for the Portuguese case. These three variables increased from 2006 to 2012 but contracted with the emergence of the economic turmoil. The reduction of the breadth of activities started in 2012 and the generation of product and process innovation began to decrease in 2010.

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.

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 Science, Technology and Innovation (STI) modes of learning and the absorptive capacity of employees. Persistence of innovation is commonly more intense in product innovation (Tavassoli & 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 six variables linked with structural aspects of the firms. Of particular relevance are two aspects, the impact of size and growth of firms on innovation during the economic downturn. The size of firms does not show a clear pattern in innovation studies. Some research finds that flexibility is important to innovation (Clausen & 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 (Archibugi et al., 2013b; Ganter & Hecker, 2013). The estimated models verify if in turbulent periods size (LOGTO) is an important determinant of innovation. Rapidly growing firms, commonly called gazelles, have been found to be more innovative (Grundström, Sjöström, Uddenberg, & Rönnbäck, 2012). In stable periods the literature suggests that these firms have a key role in innovation (Bleda, Morrison, & Rigby, 2012). But with the economic downturn can gazelles find the appropriate environment to develop innovation-based growth? The variable GROWTH may provide insights for this issue. Absorptive capacity is another aspect regarded as crucial for the capacity of the firm to capture external knowledge and increase its innovation capacity (Cohen & Levinthal, 1990; Tavassoli & 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.

The second group of five variables focuses explicitly on firms' innovative efforts. Much has been discussed about the importance of university-industry relations (Pinto & Esquinas, 2013). Today it is assumed that the firms that are

**TABLE 2** Mean values of variables, by CIS wave

	Variables		2006	2008	2010	2012
Dependent	INOACT	Count variable of innovation activities.	1.711	1.790	1.937	1.315
	INPROD	Binary variable 1 if firm introduced product innovation.	0.282	0.411	0.388	0.330
	INPROC	Binary variable 1 if firm introduced process innovation.	0.373	0.484	0.462	0.396
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
	EMPQUAL	Dummy, 1 if company has 25% or more of employees with a HE degree.	0.177	0.1887	0.2292	0.2278
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 organizations as source of information	0.531	0.6698	0.7320	0.7693
	CO	Dummy, 1 if firm co-operates 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
	FUND	Dummy, 1 if received public funding for innovation.	0.072	0.0997	0.1588	0.1582
Strategic	EXPLOR	Sum of Scores given to strategy and goals focused on developing new products and new markets.	1.606	2.401	2.330	4.868
	EXPLOT	Sum of Scores given to strategy and goals focused on reducing costs, increasing market share, increasing turnover, and market flexibility.	2.392	3.654	3.349	1.190

Source: Own elaboration using CIS data.

more innovative are those able to capture external knowledge produced by academic organizations. The model will look to understand the relevant sources of knowledge (KNBASE\_SC and KNBASE\_MKT). Whether the firm has received public support is a factor commonly assumed as crucial for innovation activities (Ganter & Hecker, 2013). Particularly during the crisis access to public funding has been reported as a key factor to continue innovation efforts (Peters, 2009). The model analyses the variable FUND and its impacts on the likelihood to develop innovation activities, and product and process innovation. The levels of expenditure on innovation activities are drivers of breadth of innovation activities and generation of innovation (Frenz & 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.



The third group regards the strategic dimension of the firms in the use and production of knowledge. It is relevant to underline that the exploration–exploitation variables definition is inspired by Archibugi et al. (2013b). 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. Nonetheless its importance can be significantly different when considering the effect of the economic crisis.

TABLE 2 clarifies the used independent variables and shows their mean values for the different waves of CIS.<sup>1</sup>

### 3.3 | Econometric options

This study opted to estimate the models using a cross-sectional approach because the 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.<sup>2</sup> 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, 2001), but more recent studies focus on a variety of topics such as collaboration (Lhuillery & Pfister, 2009), open innovation practices (Janeiro, Proença, & Gonçalves, 2013), innovation in services (Pires, Sarkar, & Carvalho, 2008) or eco-innovation determinants (Horbach, Ultra, & Belin, 2013).

The decision of inclusion of independent variables is anchored in the literature.<sup>3</sup> Many of the independent variables to be tested—namely exploration and exploitation—are only relevant for those firms that are engaged in innovative activities. This means that there is a selection process that biases the estimation process if a standard OLS approach to the complete sample is used. This is commonly referred to as self-selection, whereby the outcome of interest is determined in part by individual choice of whether or not to participate in the activity of interest (Cameron & Trivedi, 2005). To alleviate this problem a sequential two-step estimation procedure is used. These are types of estimation procedures where the estimate of a parameter of ultimate interest is based on initial estimation of an unknown parameter. These estimators are attractive as they can provide a relatively simple way to obtain consistent parameter estimates (Cameron & Trivedi, 2009).

The econometric model used a maximum-likelihood probit model with sample selection (*heckprobit* command in Stata). This estimation procedure is due to Heckman (1976, 1979) and refined by Van de Ven and Van Pragg (1981). Y1 and Y2 are presented as two binary variables such that Y2 is observable only if Y1 = 1. In the first stage, the selection equation, the dependent variable indicates if a firm developed or not innovative activities (a binary transformation of INOVACT). Independent variables in this stage relate only to the structural characteristics of the firm. The second stage estimates a relationship between the existence of innovation, product or process (INPROD and INPROC), with all the indicated independent variables, particularly the exploration and exploitation variables. The models were estimated with robust standard errors.<sup>4</sup> Studies using this same estimator and CIS data are common, such as Mongo (2013) or Leoncini (2016).

<sup>1</sup>Some variables suffered transformations as indicated, namely logarithm and ratio, for being more easily modelled.

<sup>2</sup>Instead of a panel data approach, even if this method, anchored in the proposal of Woolridge (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 is 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 older and more consolidated firms. More specifically, it is not our objective to produce an aggregated model for the four-time periods, the main result achieved with the standard approach of Woolridge. For a recent application of this method to the Portuguese case cf. Costa, Botelho, and Teixeira (2018).

<sup>3</sup>Nonetheless it is relevant to point that it is difficult to control the endogeneity issue, being caused for the simultaneity or for the 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.

<sup>4</sup>Previous and alternative versions of the models, by controlling for additional variables such as measures of innovation barriers and size of firm by number of employees, were estimated as robustness checks showed consistent results.



## 4 | INNOVATION, EXPLORATION--EXPLOITATION DYNAMICS AND THE ECONOMIC DOWNTURN

### 4.1 | Estimation results

This study helps to understand the determinants of innovation in different phases of the economic downturn. The factors that stimulate both innovation activities, measured here 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.<sup>5</sup>

The study retains the complete sample for each CIS wave. For the year 2006 the sample includes 4,721 observations, in 2008 includes 6,588, in 2010 it has 6,145, and in 2012 it has 6,825 firms. The results of the models, estimated using Stata 12, are summarized in Table 3.<sup>6</sup>

Considering the selection model for firms participating or not in innovation activities, manufacturing firms were, compared to other sectors, relatively more involved in innovation activities. Nonetheless, this effect weakens with the crisis. Being part of a group is relevant but becomes also less relevant with the crisis. The openness to external markets, through export activity, is always relevant but becomes more impactful with the economic turbulence. Size in terms of turnover is always significant. Turnover growth only shows significance when the crisis commences. Absorptive capacity, measured by the percentage of qualified workers, is also positive and significant, especially in the stable economic phase.

The estimated second-step models help understand the determinants of product and process innovation, taking into consideration only the firms that developed innovation activities. Regarding the structural variables some aspects are worth mentioning. Manufacturing is only relevant in the stable phase and for product innovation during the crisis. Belonging to a group is only significant for process innovation but with a negative coefficient, meaning that it reduces the likelihood for this type of innovation. Being an exporter does not seem so critical as, in the selection model, it is only significant for process innovation before the crisis. Size seems to be relevant in stability and in the peak of the crisis. The growth of turnover is relevant in two cases, for product innovation in the entrance of the crisis and for process innovation in its peak.

The variables concerning innovative efforts also show variations with the economic downturn. Suppliers, competitors and clients are relevant sources of knowledge (KNBASE\_MKT) specially to induce process innovation at the beginning and during the peak of the crisis. They are also crucial for product innovation in the peak of the crisis. Universities and other public research organizations seem less central as sources of knowledge (KNBASE\_SC), and as the crisis deepens they become even less so, having in fact a negative (even if this is not statistically significant) impact on the two dependent variables analysed. Co-operation with external entities, in general, seems a critical (positive and significant) variable for the innovative dynamics becoming even more important in the peak of the crisis for product innovation but contrarily losing some impact for process innovation. The financial resources dedicated to innovation (intensity of innovation efforts) is particularly important for product innovation but turns negative with the crisis. Qualification of employees is always relevant for product innovation. For process innovation effects are unclear even if it presents a negative (even if statistically not significant) coefficient. Public funding is significant and positive, in particular for product innovation. It showed a relevant impact for inducing both product and process innovation in the peak of the crisis.

<sup>5</sup>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 for long after the economic recessions are statistically over. In the case of Portugal, and for the purpose of this 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. Annex 1).

<sup>6</sup>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 3** Two-step model, selection model—innovation activities; complete models: product innovation and process innovation, by CIS wave

	Before the crisis—2006		Entering the crisis—2008		During the crisis—2010		Peak of the crisis—2012	
	INPROD	INPROC	INPROD	INPROC	INPROD	INPROC	INPROD	INPROC
IND_MAN	0.179** (0.0680)	0.184* (0.0763)	-0.0195 (0.0517)	-0.0209 (0.0624)	0.148* (0.0593)	-0.0413 (0.0673)	0.0190 (0.0613)	0.0359 (0.0880)
GP	0.126 (0.0735)	0.111 (0.0969)	0.0307 (0.0598)	-0.0144 (0.0672)	0.00838 (0.0642)	-0.0608 (0.0693)	0.108 (0.0602)	-0.138* (0.0688)
EXPO	0.0778 (0.0686)	0.193* (0.0940)	0.0888 (0.0527)	-0.00413 (0.0726)	0.0803 (0.0774)	-0.0593 (0.102)	-0.00624 (0.0750)	0.0359 (0.1119)
LOGTO	0.0806*** (0.0240)	0.136*** (0.0373)	0.00995 (0.0186)	0.0234 (0.0332)	0.0260 (0.0296)	0.0661 (0.0392)	0.0720*** (0.0244)	0.124* (0.0485)
GROWTH	-0.0000913 (0.0000642)	-0.0000268 (0.0000329)	1.64e-09*** (2.14e-10)	0.000247 (0.000199)	0.000160 (0.000469)	0.000868 (0.000634)	-0.000372 (0.000213)	0.00108* (0.000495)
EMPQUAL	0.335*** (0.0830)	0.194 (0.143)	0.351*** (0.0672)	-0.132 (0.0891)	0.131 (0.0760)	-0.0527 (0.0865)	0.341*** (0.0671)	-0.0598 (0.118)
KNBASE_MKT	0.0190 (0.0145)	-0.0364 (0.0206)	0.0190 (0.0118)	0.0509*** (0.0128)	0.0142 (0.0127)	0.0177 (0.0135)	0.0509*** (0.00929)	0.0415*** (0.0110)
KNBASE_SC	0.0323 (0.0204)	-0.0311 (0.0222)	-0.0178 (0.0168)	-0.0189 (0.0187)	-0.0245 (0.0173)	-0.0330 (0.0188)	-0.0190 (0.0159)	-0.0234 (0.0172)
CO	0.172* (0.0755)	0.342* (0.135)	0.250*** (0.0526)	0.263*** (0.0591)	0.398*** (0.0647)	0.228** (0.0706)	0.372*** (0.0639)	0.130 (0.0693)
NOVINT	0.000853*** (0.000250)	0.280 (0.192)	0.00000356*** (0.00000106)	-0.0000043*** (0.000000445)	-0.0204*** (0.00541)	0.978* (0.384)	0.283* (0.135)	0.317 (0.313)
FUND	0.218** (0.0839)	-0.0700 (0.0822)	0.148* (0.0680)	0.257*** (0.0774)	0.0997 (0.0583)	0.134* (0.0656)	0.122* (0.0556)	0.180*** (0.0648)
EXPLOR	0.341*** (0.0270)	-0.147*** (0.0412)	0.275*** (0.0164)	-0.110*** (0.0181)	0.361*** (0.0198)	-0.160*** (0.0213)	0.0991*** (0.0133)	-0.00171 (0.0137)
EXPLOT	-0.0979*** (0.0174)	0.230** (0.0727)	-0.0340** (0.0126)	0.0946*** (0.0136)	-0.103*** (0.0153)	0.155*** (0.0157)	0.00385 (0.0107)	0.00408 (0.0116)

(Continues)



TABLE 3 (Continued)

	Before the crisis—2006		Entering the crisis—2008		During the crisis—2010		Peak of the crisis—2012	
	INPROD	INPROC	INPROD	INPROC	INPROD	INPROC	INPROD	INPROC
_CONS	-2.380*** (0.451)	-2.642** (0.975)	-0.829* (0.347)	0.269 (0.757)	-0.992 (0.657)	-0.372 (0.899)	-1.992*** (0.501)	-1.561 (1.259)
<b>INOACT</b>	<b>selection process</b>							
IND_MAN	0.201*** (0.0426)		0.166*** (0.0344)		0.155*** (0.0359)		0.215*** (0.0356)	
GP	0.208*** (0.0500)		0.122** (0.0451)		0.0919* (0.0446)		0.0261 (0.0411)	
EXPO	0.263*** (0.0410)		0.251*** (0.0334)		0.364*** (0.0345)		0.300*** (0.0337)	
LOGTO	0.167*** (0.0131)		0.156*** (0.0126)		0.175*** (0.0121)		0.181*** (0.0112)	
GROWTH	-0.00000680 (0.00000924)		1.53e-09* (7.13e-10)		0.0000315 (0.0000452)		0.0000309 (0.0000592)	
EMPQUAL	0.411*** (0.0549)		0.338*** (0.0464)		0.271*** (0.0437)		0.280*** (0.0419)	
_CONS	-2.964*** (0.192)		-2.391*** (0.180)		-2.809*** (0.174)		-3.134*** (0.161)	
PSEUDO R2/	0.414	0.478	0.383	0.429	0.420	0.427	0.334	0.357
ATHRHO	0.502* (0.191)	0.836 (0.721)	0.0822 (0.139)	-0.129 (0.374)	-0.0393 (0.259)	0.0514 (0.363)	0.292 (0.183)	0.314 (0.492)
NR OF OBS	4,721		6,588		6,145		6,825	
SELECTED	2,179		3,828		3,403		3,146	

Notes: Standard errors in parentheses.

\*\*\* $p < 0.01$  \*\* $p < 0.05$ ; \* $p < 0.1$ .

ptSource: Own elaboration based in CIS data.



The models also provide some findings concerning strategic factors. Exploration is particularly important—albeit with decreasing impact with the growing of the crisis—for product innovation. It shows, nonetheless a negative impact on process innovation. Exploitation strategies, focusing on the reduction of costs, increasing market share, turnover, and market flexibility are not significant in the peak of the crisis. It is significant in the other periods however, showing a negative impact for product innovation and a positive one for process innovation. This means a clear association between exploration-product innovation and exploitation-process innovation.

In the peak of the crisis what determines product and process innovation is quite distinctive. If for product innovation, co-operation activities, absorptive capacity, and exploration are significant (and positive) variables, belonging to a group (negative coefficient) and growth rate are statistically significant for process innovation. Size, knowledge sources from market and public funding are the three variables that are positively and statistically significant associated with both types of innovation in the peak of the crisis.

These results for the crisis period are consistent with the more general association between exploration-product innovation and exploitation-process innovation. The factors that are significant for the product innovation patterns reflect consistent activities and capabilities that support exploration dynamics. The factors affecting process innovation reflect more circumstantial questions of efficiency and resources that may more directly influence exploitation activities (or leave such activities to be concentrated elsewhere in a corporate group). The results regarding innovation at the peak of the crisis suggest that it is within product innovation activities that one may more clearly identify firm's innovation resilience.

## 5 | CONCLUSION

The global economic crisis has had impacts on the decision of firms to develop different types of innovation activities, and in their capacity to generate different types of innovation. This paper contributed to a better understanding of the extent to which the determinants of innovation dynamics vary with economic cycles. Resilience is in this aspect a crucial concept to understand the capacity of a socio-economic system to adapt to internal or external shocks and disruptions. This study suggested that there are connections between socio-economic resilience and firm level aspects of innovation. Persistence of innovation is particularly crucial for the innovation systems to maintain their activity, a perspective that is highly linked with the understanding of ecological resilience. Exploration of knowledge use seems particularly crucial for the creation of new pathways, as a way of renewal after a shock, as suggested by the evolutionary comprehension of regional resilience.

The econometric results presented in this paper underlined the importance of several variables to innovation that were already found in the literature. The knowledge base anchored in market relations, co-operation activities with external entities, absorptive capacity and public funding were found relevant to innovation dynamics in general. But the study found variables that gained or lost significance in the peak of the crisis, such as exploration and exploitation strategies. Exploration and exploitation have interesting connections with product and process innovation. While the former affects process innovation negatively, and product innovation positively, the latter is particularly relevant for process innovation. The innovation resilience of firms appears to be particularly reflected in their product innovation activities.

This paper presents some important implications for policy. An evidence-based regional 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 shocks 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. Policy acts as a counter-cyclical instrument in stabilizing investment and boosting recovery. During the last crisis many governments, including the Portuguese, undertook relevant cuts in innovation support, namely in the financing to higher education and R&D. Exploration activities, co-operation and qualified staff should be supported by public resources, as they proved to have a crucial effect to stimulate product innovation. Given budgetary pressures, policy



instruments should be more targeted and selective and address those factors that have greater influence on regional innovation dynamics, particularly in support of firms' absorptive capacity and supporting innovation networks with market-related knowledge sources.

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 chosen sample and the econometric estimation procedure. While the current analysis does not allow for a fine-grained analysis of regional variation in innovation dynamics, policy responses should be adapted according to context specific barriers and determinants.

Hopefully future research may overcome these problems and take a step further in to exploring evolutionary resilience, one that addresses the capacity of firms to bounce-forward, namely, to undergo anticipatory or proactive reorganization to minimize the impact of destabilizing shocks and create new paths. While the concept of persistence is well developed in empirical studies of innovation, the connections of exploration with regional resilience are still in embryonic form. A complex understanding of the capacity of firms to develop innovation during the economic downturn, or in other words, the "resilience of innovation" in the firm, needs to go beyond the mere capacity to continue its innovative efforts—its persistence—but deepening the comprehension of knowledge production and use as exploration and exploitation mechanisms to enable new development possibilities.

## ACKNOWLEDGEMENTS

Hugo Pinto gratefully acknowledges the financial support from *Fundação para a Ciência e a Tecnologia* to his post-doctoral research (SFRH/BPD/84038/2012) and Scientific Employment (DL57/2016/CP1341/CT0013). The authors acknowledge the Portuguese National Statistical Office (INE) for making available the results of CIS surveys on the basis of which the present work is developed.

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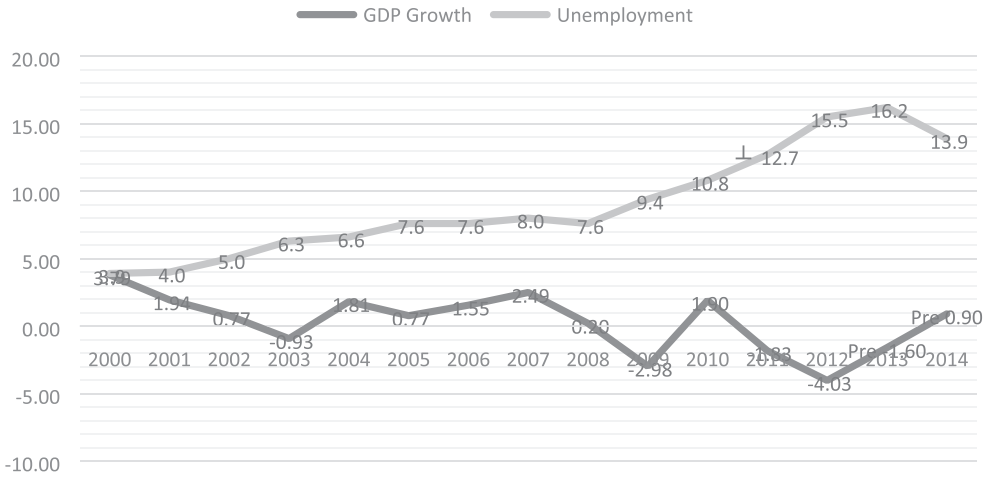


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**How to cite this article:** Pinto H, Pereira TS, Uyarra E. Innovation in firms, resilience and the economic downturn: Insights from CIS data in Portugal. *Reg Sci Policy Pract.* 2019;11:951-967. <https://doi.org/10.1111/rsp3.12243>

### APPENDIX



**FIGURE A1** The evolution of GDP and Unemployment rate in Portugal