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Economic crisis and company R&D in Spain: do regional and policy factors matter?

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ABSTRACT

The economic crisis which began in 2008 has had a far-reaching impact, including effects on the innovation behaviour of firms. Many companies have reduced their innovation-related activities, although some firms have been more resilient than others. Using a representative microdata panel of Spanish firms, we study the probability of companies abandoning in-house R&D during the crisis and its relationship to regional and policy factors. We find significant regional heterogeneity related to regional economic size and the type of the regional innovation system; regional government R&D support only reduces R&D abandonment rates in regions where a strong system of knowledge exploitation is in place.

KEYWORDS

R&D investment; economic crisis; resilience; regional innovation policy

JEL CLASSIFICATION

O31; O18; L20

1. Introduction

The financial and economic crisis which began in 2008 has had a far-reaching impact on countries around the world. Several recent empirical studies have shown that the crisis has also affected the innovation behaviour of firms (Filippetti and Archibugi 2011; Paunov 2012; Archibugi, Filippetti, and Frenz 2013a, 2013b; Peters et al. 2014; Holl and Rama 2016; Teplykh forthcoming) and its components, e.g. in-house R&D.

This paper examines changes in firms' internal R&D expenditure since the onset of the economic crisis and their relationship to regionally specific factors, including regional government R&D policies. The crisis has had different regional impacts (Capello, Caragliu, and Fratesi 2016). Few studies have, however, analysed the role of regional factors in innovation persistence; some recent exceptions are Eickelpasch (2014), Tavassoli and Karlsson (2016) or Holl and Rama (2016). Little is yet known about the degree to which regional factors and regional government innovation policies have influenced companies' innovation behaviour in the context of the economic crisis. There has been very little empirical research into the possible effects of innovation policies on multilevel innovation systems in company R&D and innovation dynamics. To the best of our knowledge no research has included regional R&D policies and regional government R&D budgets in an analysis of

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comparative perspective. For comparison among regions, we distinguish between factors associated to the size of the regional economy, the type of regional innovation system (RIS) in place and the importance of regional R&D policy. Particularly in multilevel systems such as Spain, this can contribute to a better understanding of company innovation strategies and their determinants during the crisis.

There is broad agreement among economists and policy-makers that economic growth is largely driven by the capacity of firms to innovate. As shown by a study of Germany, firms with greater innovation expenditure during the crisis are able to put new products or better quality products into the market earlier than their competitors once the crisis has terminated (Hud and Rammer 2015). Therefore, in-house company R&D expenditure during the crisis may, indirectly, anticipate the recovery of regional and national economies; consequently, the present study is of great interest for both regional and national policy-makers.

There is also evidence that financial constraints upon firms in the pursuit of R&D projects, such as limited internal funds or restricted access to external financing to invest, are key elements to consider in studying the propensity of firms to initiate or discontinue innovation activities (Ali-Yrkkö 2005; Czarnitzki, Hottenrott, and Thorwarth 2011). During economic downturns companies may be faced by even harsher financial constraints, such as a shortage of bank credit or a reduction of public R&D funding as a result of fiscal consolidation policies; given such circumstances, account must be taken of the different roles of the various governments' funding sources and levels, especially regional ones, and previous analyses of multilevel systems must be extended to crisis times.

Spain provides an interesting setting for analysing the role of regions and regional governments in support of local firms and the innovation system. Not only has Spain been one of the countries worst hit by the economic crisis, it also has a highly decentralised, quasi-federal political structure. Spanish regions have very diverse economic structures, different degrees of fiscal and political autonomy and various priorities regarding R&D and innovation; they vary greatly in terms of their innovation performance and in their science and technology policies (Sanz-Menéndez and Cruz-Castro 2005). Moreover, regional responses to the economic crisis have also varied. This paper contributes to the literature on innovation resilience by taking into account characteristics of the regional economy, the RIS, and the role of different levels of government support for private R&D investment.

Our findings show significant regional heterogeneity in innovation persistence, related to regional economic size and the type of RIS. Public R&D funding, especially regional funding, also matters. Those firms receiving public financial support prior to the onset of the economic downturn display a lower probability of abandoning innovation activities. However, our results also indicate that changes in the intensity of regional R&D policies during the crisis have only meant lower rates of the abandonment of innovation by companies in regions where a strong knowledge exploitation system is in place.

The paper continues by reviewing some aspects of the literature to frame our research questions. Section three offers a description of the context of RIS and policies in Spain. The data and methodology are supplied in section four. Section five presents the results and the discussion. The paper ends with some conclusions.

2. Review of the literature and research questions

2.1. The business cycle and company R&D

Most analyses of previous crises support the thesis that innovation tends to be pro-cyclical. Analysing British data for 1948–1983, Geroski and Walters (1995) found 'clear evidence of a long-term secular relation between the level of innovative activity and the level of economic activity' (p. 916). Harfi and Mathieu (2009), focusing on the 1987–2006 period, report similar results. Comin and Gertler (2006) and Barlevy (2007) also provide evidence of the pro-cyclicality of R&D investment in recent decades.

The literature on the 2008 crisis tends to corroborate these research findings. The OECD (2009) has presented evidence that private investment in innovation is mainly pro-cyclical and decreases significantly during economic downturns. Cincera et al. (2012) observed, for 2008–2009, a deceleration of innovative activities in the EU companies most prone to innovation. Archibugi, Filippetti, and Frenz (2013a), (2013b) found evidence to support the hypothesis that the 2008–2009 global crisis negatively affected European companies' investment in innovation and reduced aggregate private investment in R&D. Based on the analysis of a large sample of British firms, Archibugi, Filippetti, and Frenz (2013a) found that the 2008 downturn had produced a substantial reduction in their innovation expenditure. However Cincera et al. (2012) and Archibugi, Filippetti, and Frenz (2013b) also suggest the existence of different types of company response, including a group of firms which increase their R&D investments in years of crisis with the expectation of reaping the benefits in the upswing to come. A pro-cyclical pattern has also been found in other geographical areas; Paunov (2012) in the case of Latin American firms during 2008–2009; Correa and Iootty (2011) for Eastern Europe, and Arvanitis and Woerter (2014) for Swiss manufacturing firms.

2.2. National Innovation Systems and Regional Innovation Systems

As stated above, the business cycle literature has only recently begun to investigate the possible effects of location on the innovation patterns of firms during the 2008 crisis. Analysing companies across 27 member states of the European Union, Norway and Switzerland, Filippetti and Archibugi (2011) observed a strong association between the strength of National Innovation Systems (NIS) and the persistence of company innovative activities during the 2008 crisis. They detected that the features of NIS which counteract the cyclical behaviour of firms are the presence of highly qualified human resources, the availability of private credit and specialisation in high-tech manufacturing sectors. A study of German, French and British companies also emphasises the importance of NIS in this concern (Teplykh forthcoming).

Within a country, regions may also matter. Learning processes underlying innovation are localised and locally embedded, and RIS may also play a role. This quantitative literature has seldom examined whether the regional location of companies within a country may have affected their R&D expenditure level during the crisis. However, some recent exceptions can be mentioned. Eickelpasch (2014) observed that companies in West Germany were more likely than firms in East Germany to engage in R&D during 2009 and 2010. Tavassoli and Karlsson (2016), using data from the Community Innovation Survey in Sweden between 2002 and 2012, analyse various regional characteristics and how they affect innovation persistency. Their results show that firms in regions of larger economic size, with a higher

share of knowledge-intensive service sectors and a greater and more varied extent of related sectors display a greater probability of being persistent innovators. Holl and Rama (2016) found that companies located in the Spanish Basque Country were more likely to persist in innovative activities during the 2008 crisis, and even to increase these activities, than firms located in other regions such as Catalonia or Madrid, even after controlling for regional sectoral differences and firms' structural characteristics; this regional effect is attributed to the relative strength of the Basque RIS.

These studies suggest that, within a particular country, firms located in a specific region may display pro-cyclical behaviour while companies located in another region may display countercyclical behaviour even when firm-specific features are controlled for. The question that remains unanswered in previous studies is which specific traits of a region may contribute to explaining the innovative resilience of firms facing a crisis. The present article contributes to the identification of those specific traits and their interactions with policies.

Several empirical studies suggest that the resilience of firms during economic shocks and the resilience of regions may be interrelated (see, for instance, Carbonara [2002]; Rama and Ferguson [2007]). Embeddedness in certain regions may help firms threatened by a financial crisis to enhance their company-specific advantages. Support for outsourcing and the creative specialisation facilitated by certain locations may aid companies faced with industrial crises to save on resources that can later be channelled to R&D (Suarez-Villa and Rama 1996)**.** What might have failed in other cases is the capacity of the region to organise collective learning processes (Gilly, Kechidi, and Talbot 2014). These considerations suggest that an efficient RIS may contribute to the resilience of innovative activities at company level. However, not all RIS display the same characteristics. Autio (1998) distinguished two building blocks of the RIS: (i) the knowledge application and exploitation sub-system, and (ii) the knowledge generation and diffusion sub-system. The knowledge exploitation system is characterised by a dominance of companies' R&D and their respective innovative networks. By contrast, the knowledge generation system is characterised by regional R&D concentrated in public research institutions such as the government and the higher education sector. RIS differ insofar as they are based more on a knowledge exploitation subsystem or a knowledge generation subsystem. In other words, certain RIS may be mainly 'entrepreneurial', while others may be principally 'institutional' (Cooke 2009). This literature suggests that it is interesting to explore whether the nature of the RIS may influence the ability of regional firms to maintain their R&D activities during a downturn.

Recent contributions to the literature on resilience have emphasised the role of the state, institutions, social and political agents, power relations, network structures and policy interventions in understanding regional differences in resilience (see, for instance, Pike, Dawley, and Tomaney [2010]). However, these concepts have been assessed only rarely in empirical studies of regional resilience. Measurements of growth rates and changes in output or employment have been some of the variables used by empirical literature to evaluate the resilience of regions faced with crises (see, for instance, Davies [2011]; Cuadrado-Roura and Maroto [2016]). Research results suggest that explanations of regional resilience are to be found in a variety of factors, such as large shares of high-tech industries, industrial diversification and workforce skills. Success stories may not be the direct consequence of 'ad hoc' policy implementation but also of historical trajectories and of 'learning from failure' (Wolfe and Gertler 2004; Crespo, Suire, and Vicente 2014).

2.3. Public funding and company R&D

The availability of funding may play a role in resilience innovation, although previous research results are not yet conclusive in this regard and distinction between public and private funding should be made. Using French data for 1993–2004, Aghion et al. (2012) question the Schumpeterian hypothesis that recessions provide firms with an opportunity to correct organisational inefficiencies and innovate, since not all firms are able to borrow funds to move to new activities and invest in R&D. The aforementioned authors demonstrate that firms unconstrained by the availability of credit are able to invest in R&D even during a downturn. Beneito, Rochina-Barrachina, and Sanchis-Llopis (2015) find similar results for the R&D expenditure of Spanish firms. Archibugi, Filippetti, and Frenz (2013a) find no evidence that the availability of internal financial resources in the t–1 period provokes a change in the innovation investments of British firms, either previous to the 2008 crisis or during it. Paunov (2012) also notes that access to private funding had no effect on the innovative behaviour of Latin American firms but, in contrast, those that had enjoyed access to public funding were less likely to halt their innovation projects during the 2008 crisis. For Spanish firms, García-Vega and López (2010) confirm that the probability of abandoning innovation activities in the period 2005–2007 was lower for firms in receipt of public financial support. Busom and Velez (2016), analysing the period 2005–2013, confirm that SMEs were more affected by the trajectory of their sales, but those receiving public subsidies were less likely to abandon innovation projects, at least prior to 2009. However, Antonioli et al. (2013), studying companies located in Emilia-Romagna (Italy), find that firms receiving public funds to support innovation in the pre-crisis period were no more prone than other companies to react to the crisis by innovation.

Regarding a key issue, namely the complementarity or substitutability between public funding and private R&D investments, research results are varied (for reviews, see David, Hall, and Toole [2000]; García-Quevedo [2004]; Zuñiga-Vicente et al. [2014] and Becker [2015]). The empirical results once more show that subsidies or financing granted to company R&D activity and 'their effects on firms' behaviour remains relatively modest and controversial' (González, Jaumandreu, and Pazó 2005; 930). Analysing Spanish data, these authors note that subsidies play a positive role concerning company R&D expenditure in the case of small firms, while their effects diminish in the case of large companies. This strand of literature shows that a percentage of companies, which may vary by country and region, would invest in R&D even in the absence of subsidies. Most of the studies of Spain (e.g. Busom [2000]; Gonzalez et al. [2005]; Arqué-Castells [2013]; Arqué-Castells and Mohnen [2015], Huergo, Trenado, and Ubierna [2016], Busom and Velez [2016]), analysing the effects of the different forms of public support for private R&D activities (direct subsidies, loans or low interest credits) confirm that on average public support has contributed to increase the R&D effort of firms already investing in this field and has helped firms that did not previously invest to start doing so.

Naturally, differing results in this field could be explained by variations in the objectives, instruments and procedures of different public programmes (Borrás and Edquist 2013), but also by the lack of a general model that could be used in empirical analysis (David, Hall, and Toole 2000; Zúñiga-Vicente et al. 2014). Additionally, there are problems of the endogeneity of public funding: agencies grant finance, among other considerations, on the basis of the current performance and the R&D effort of firms, meaning subsidies are likely

to be endogenous. Another potential cause of divergent findings is company persistence in innovation activities (Cefis and Orsenigo [2001]; Peters [2009]; Martínez-Ros and Labeaga [2009]; Antonelli, Crespi, and Scellato [2012], amongst others), meaning that it is necessary to control for past innovation activity, as innovation in one period could have a positive causal effect on the probability of innovating in the following period, with implications for the inducement effects of public policies (Arqué-Castells and Mohnen 2015). Additionally, different sources of funding may exert distinct effects on the innovation behaviour of firms during crises, as shown by previous research on the potential effects of public support for private R&D investment.

Furthermore, the governance of innovation is multilevel (Laranja, Uyarra, and Flanagan 2008). Public subsidies for company R&D may come from different levels of government: local, regional, national and European. Research in this area is somewhat inconclusive but does produce some interesting findings. For instance, the role of regional governments appears to be more important in reducing the entry barrier to technological activities, while national and EU-level subsidies are much more closely linked to the improvement of the performance of pre-existing innovators (e.g. Busom and Fernández-Ribas [2008]; Fernández-Ribas [2009]); further analyses have suggested that each level of government has different priorities concerning innovation and technological policy: regional governments may focus on regional development, while national governments' innovation policy is likely to be more oriented towards large national firms; at the same time, the EU Framework Programme follows a strategy of 'picking the winners'. Support from domestic sources appears to increase the likelihood of companies cooperating for innovation with both national and international partners. Moreover, the respective efficiency of national and regional policies may differ. Using Community Innovation Survey (CIS) data for 2002–2004, Marzucchi and Montresor (2015) find that national policies are more efficient than regional policies in supporting intramural R&D in Spanish firms.

Regional governments assign very different levels of priority to R&D and innovation policies, and display significant differences in their orientation and policy mix (Sanz-Menéndez and Cruz-Castro 2005); at the same time, the specific regional context may influence the impact of national policies in supporting R&D (Herrera and Nieto 2008).

After reviewing the literature on innovation policies, Magro and Wilson (2013) state that more analyses of policy interactions are needed. This is one of the objectives of the present article. We conclude from our review that structural factors may be mediated by space and by the interaction, in a specific region, of policies formulated at different levels: regional, national and supranational. The discussion suggests that the interaction of policies at different spatial levels and the decision of companies to persist in their R&D activities during a crisis are still poorly understood. The conceptual framework developed in this section also points to the possible influence of certain key characteristics of the region itself: the reaction of firms to the crisis depends on the pre-crisis achievements of the company, as claimed by several studies of the business cycle theory, but also on the pre-crisis R&D efforts of co-located companies. Agglomeration effects and outsourcing economies may help firms, especially medium-sized and small firms, to save on resources that can be redeployed to maintain R&D expenditure during a crisis. Cooperation for innovation with other companies and with institutions may enhance the absorptive capacity of firms and enable them to profit from additional resources for R&D obtained from governments. Finally, the dynamic response of regional governments to the crisis is also likely to affect the

behaviour of regional firms. During a severe financial crisis, firms may be hindered from maintaining their R&D expenditure and taking advantage of reorganising and adopting new goals, due to credit constraints. It is then that the availability of R&D public funding can make a difference for firms attempting to prepare for a new phase of the business cycle, when the crisis is over. In order to develop this analysis further, we propose the following research questions:

RQ1: Do regional characteristics influence the innovation resilience of firms?

RQ2: Do changes in regional public R&D budgets during the crisis affect regional firms' resilience in terms of innovation activities?

RQ3: How do regional characteristics mediate the impact of regional R&D policy on innovation resilience?

3. The research and innovation context in Spanish regions[1]

Spain is among the set of countries labelled as 'moderate innovators' by the *European Innovation Scoreboard* (EC 2016). Before the onset of the crisis, Spain was below the EU average in R&D expenditure but undergoing a process of convergence. In 2008, according to INE, the national expenditure on R&D represented 1.35% of GDP, amounting to 14,700 million Euros, while the EU-28 average was 1.84%. The crisis has severely affected GDP, employment and expenditure on R&D activities, which began a gradual and tardy process of reduction, reaching 1.29% of GDP in 2012, while the figure for the EU-28 amounted to 2.01%. It is also well known that Spain has been one of the European countries most affected by fiscal consolidation policies which have produced significant decreases in government R&D budgets (Izsak et al. 2013).

Spanish companies have traditionally underinvested in R&D (0.74% of GDP in 2008), and the situation has worsened as a result of the crisis (0.69% in 2012). Additionally, the Spanish business sector has received high levels of government R&D funding, making it a useful case study to analyse the effect of policies. At the onset of the crisis the contribution of governments (either national or regional) to the funding of company R&D performance was 18% of the total expenditure of the business sector; in 2012 it dropped to 12%. The impact of government funding of private R&D was diverse, according to company size; according to INE, it was 23%, in 2008, for SMEs while the figure was 11% for firms with over 250 employees; in 2012, the share of Government funding in SMEs R&D expenditure fell to 16%, while the level was 10% in the case of large companies. It can be concluded that cuts in the public R&D budget have significantly affected the level of support for company R&D and innovation activities, and especially the R&D and innovation capacity of SMEs.

The territorial distribution of R&D and innovation activities in Spain is very heterogeneous. There is a high level of concentration of R&D and innovation activities in a limited number of regions. According to INE, in 2008, four regions (Andalusia, the Basque Country,

[1]Spanish R&D expenditure data included in this section proceed from the National Statistics Institute (INE) (https://wwwinees/dyngs/INEbase/es/operacionhtm?c=Estadistica_C&cid=1,254,736,176,754&menu=resultados&idp=1,254,735,576,669 Last access on 12 June 2017) EU-28 estimates on R&D expenditure come from EUROSTAT (https://eceuropaeu/eurostat/web/science-technology-innovation/data/main-tables) R&D regional budgetary data come from the Regional Governments Annual Budgets compiled by the Ministry of the Treasury and disseminated by the Fundación Española de Ciencia y Tecnología (FECYT) (https://iconofecytes/indicadores/Paginas/defaultaspx?ind=3&idPanel=1 Last access on 12 June 2017).

Catalonia and Madrid) accounted for 68% of national R&D expenditure and this share increased to 70% in 2012.

Politically, Spain is a highly decentralised quasi-federal country. Regions are structured in 17 autonomous communities (*Comunidades Autónomas*), with regional governments and parliaments that manage a significant amount of resources, mainly devoted to the provision of public health care and education (Cantarero and Pérez González 2009).

Spanish public universities are regionalised and higher education institutions are overseen and funded by the regional governments; funding for public higher education also suffered from significant budgetary reduction between 2008 and 2012 (Cruz-Castro and Sanz-Menéndez 2016).

R&D and innovation policies are a competence shared between national and regional governments. Regional governments have developed their own science, technology and innovation policies with significant budgets to promote and finance R&D and innovation. Nevertheless there have been differences in the approach, the policy mix or the orientation of regional innovation policies, some of which are more oriented towards capability creation (or science push) and others towards support for knowledge exploitation.

Sanz-Menéndez and Cruz-Castro (2005) analysed the differences in orientation and policy mix in the early 2000s in five Spanish regions (Andalusia, the Basque Country, Catalonia, Galicia and Madrid) accounting for 74% of Spanish R&D expenditure. They identified two different strategies. The dominant approach was based on classical academic research policies, and only the Basque Country had a policy mix oriented towards the application and exploitation of knowledge within firms. Differences are related to the ability of academics to interact with firms and to exploit academic patenting (Martínez, Azagra-Caro, and Maraut 2013).

In aggregate terms, in 2008 the R&D budgetary resources allocated from all regional governments together was similar to the overall non-financial budget of the national government; thus, it is useful to analyse its impact. After the crisis, the practice of budget cuts adopted by regional governments has mainly affected non-earmarked budget categories, basically competitive and discretionary funding for research and innovation (Cruz-Castro and Sanz-Menéndez 2016), and such cuts have impinged on the funding for firms more than on funding for universities and public research organisations, as the radical reductions in the amount and share of public funding for firms indicate.

Despite the fact that there has been a general expansion of R&D and innovation policies and plans approved by all regional governments – in recent years in connection with the regional Smart Specialisation Strategies (S-3)-, when analysing the priority levels of regional R&D funding as a share of the total regional budget, or as the sum of public R&D investment per inhabitant, it is clear that they have been significantly different across regions (see Tables 1 and 2).

According to FECYT, in 2008, the total figure for R&D regional government budgets was 2677 million Euros, representing 1.65% of total regional budgets; in 2012 the amount was reduced to 1870 million Euros, or 1.09%. However, the absolute levels and the R&D budget shares are quite diverse among regions, ranging from 15 to 590 million Euros, related to the size of the region and the policy priority. These data show that it is also very important to know which level of government (national or regional) funds R&D in each region.

Table 1. Regional characteristics 2008.

Region	GDP (Million euros)	GDP per capita ES = 100	GERD as % of GDP	BERD as % of GERD	BERD as % of GDP	BERD per capita (Euros)	Regional Government R&D budget per capita (Euros)
ANDALUSIA	152,137	77	1.01	34	0.34	64	72
ARAGON	35,615	111	0.99	59	0.58	156	44
ASTURIAS	23,989	92	0.96	44	0.41	93	39
Balearic Islands	27,194	105	0.36	21	0.07	19	16
Canary Islands	42,582	85	0.63	23	0.14	30	153
CANTABRIA	13,279	94	1.06	41	0.41	93	24
CASTILE-LEON	57,092	92	1.30	62	0.80	180	105
CASTILE-LA MANCHA	40,389	82	0.66	56	0.37	73	22
CATALONIA	209,005	117	1.57	61	0.96	274	57
VALENCIAN COMMUNITY	108,508	89	1.03	44	0.45	98	19
EXTREMADURA	18,155	68	0.86	19	0.17	28	72
GALICIA	58,584	87	1.00	48	0.48	102	47
MADRID	202,035	133	1.93	58	1.11	359	20
MURCIA	29,137	84	0.84	39	0.33	67	32
NAVARRE	18,739	125	1.91	69	1.32	401	169
BASQUE COUNTRY	67,698	130	1.99	81	1.61	504	147
LA RIOJA	8,275	108	0.98	58	0.55	144	53

Source: INE and FECYT (see footnote 1).

Table 2. Change in regional R&D variables: 2008–2012.

	ΔGERD	ΔGERD %GDP	ΔBERD	Δ regional R&D budget
SPAIN	−8.91	−2.50	−12.38	−30.2
ANDALUSIA	−3.80	4.54	3.52	−15.8
ARAGON	−11.23	−2.88	−20.37	−30.8
ASTURIAS	−14.71	−4.45	1.65	−49.1
Balearic Islands	−7.66	−2.71	−29.86	−61.2
Canary Islands	−21.33	−16.26	−28.18	−86.2
CANTABRIA	−10.39	−1.78	−20.56	−83.1
CASTILE-LEON	−16.55	−10.92	−16.81	−44.0
CASTILE-LA MANCHA	−13.24	−6.59	−2.99	−30.4
CATALONIA	−8.99	−2.95	−16.66	−41.7
VALENCIAN COMMUNITY	−9.47	1.55	−16.10	36.2
EXTREMADURA	−17.88	−11.45	−14.88	−39.5
GALICIA	−16.50	−9.48	−20.15	−32.3
MADRID	−11.78	−9.55	−15.99	5.4
MURCIA	−6.47	2.47	−7.80	−51.8
NAVARRE	−3.34	3.25	−4.09	−41.0
BASQUE COUNTRY	6.36	12.98	−0.30	−6.2
LA RIOJA	−14.45	−7.51	−22.32	208.4

Source: INE and FECYT (see footnote 1).

4. Data and methodology

4.1. Data

Our main data source is the Spanish Technological Innovation Panel (Panel de Innovación Tecnológica, PITEC), a representative panel subsample of the Spanish CIS performed by

the Spanish Statistical Office (Instituto de Estadística Nacional, INE). PITEC includes information on the technological innovation activities of all the principal sectors in the Spanish economy, and has provided consistent information since 2004.[2] As compared with the CIS database, an advantage of the PITEC database is that data are collected annually and that each firm has a unique identifier which allows the linking of observations between the annual surveys. Thus, PITEC constitutes a true enterprise panel data-set.

Exploiting the longitudinal information of the data-set, we can analyse the same firms before and after the onset of the economic crisis. We have chosen the period 2008–2012 for our analysis. In 2008, internal private sector R&D was at its peak. In 2009, internal private sector R&D started to drop significantly and between 2008 and 2012 fell by over 12%. Although a reversal of this downward trend has only been visible since 2015, our period of analysis spans the years of the most drastic reductions in the science and technology sector in Spain.

For the years 2008 and 2012, PITEC provides a sample of 11,336 manufacturing and service firms. Of these, 1724 responded in 2008 but had disappeared by 2012, while there are 154 firms which did not respond to the survey in 2008 but did so in 2012 (new incorporations). Thus, we are left with a sample of 9458 firms for which information on innovation expenditure is available for both 2008 and 2012. We further restrict our sample to firms undertaking internal R&D expenditure in the year 2008, leaving us with a final sample of 4619 firms. We therefore focus on firms that were active in R&D before the onset of the economic crisis and analyse their changes in internal R&D. This latter restriction to firms with internal R&D expenditure in 2008 is also necessary for our regionalised analysis. PITEC does not provide information on the location of firms' headquarters, but it does provide information on the spatial distribution of firms' internal R&D expenditure among Spanish regions; our choice is also consistent with the fact that for Spanish firms R&D is the most important and stable component of innovation expenditure. We use this information to create our regional dummies and to relate our firm-level data to regional characteristics and policies. By including only companies with internal R&D expenditure, our analysis focuses on firms active in innovation before the onset of the economic crisis. Furthermore, some firms report internal R&D expenditure in more than one region. They account for only 4.8% of our sample, but they are excluded from the analysis because we cannot clearly ascribe such companies to a single region.[3]

In our final sample of 4619 firms from the PITEC survey there are 1318 that ceased spending on internal R&D between 2008 and 2012. This latter figure represents nearly a third of the firms that were active in R&D before the onset of the economic crisis.

[2]PITEC is composed of a sample of companies with 200 or more employees (approximately 73% of these firms were included in the initial year), all businesses which perform internal R&D, a representative sample of firms with less than 200 employees that undertake external R&D but not internal R&D, and a representative sample of companies with less than 200 employees and no expenditure on innovation.

[3]As an alternative, we have also tested for the robustness of our results when we ascribe the company to the region where it reports the majority of its internal R&D expenditure. The results are qualitatively unchanged. We are also aware that representativeness for smaller regions with a limited innovation base may not be guaranteed. A small number of observations for such regions means that we need to interpret results for those regions with caution, e.g. the Canary and Balearic Islands.

4.2. Model

This paper is concerned with how regional factors are related to company decisions regarding innovation expenditure following the onset of the economic crisis. Specifically, we analyse the probability that firms abandoned expenditure on internal R&D between 2008 and 2012. Let internal R&D expenditure abandonment y_i by firm $i = 1, 2, ..., N$ be captured by a binary choice model,

$$y_i = \begin{cases} 1 \text{ if } y_{it}^* \geq 0 \\ 0 \text{ else} \end{cases} \quad (1)$$

where the latent variable y_i^*, representing firm *i*'s underlying propensity to cease spending on internal R&D in the period 2008–2012, is a function of observable firm-specific characteristics c_i and regional-specific characteristics a_r

$$y_i^* = c_i\beta_1 + a_r\beta_2 + \nu_i \quad (2)$$

The term ν_i captures the effects of unobserved factors and is assumed to be i.i.d. normal.

Given the binary character of our dependent variable, probit regressions are used for the empirical analysis. The empirical design corresponds to the type of 'before-after' impact control; considering the trend in R&D and innovation expenditure in Spain we assume that 2008 represents data from 'before' the crisis and 2012 data corresponding to 'after' the onset of the crisis

4.3. Independent variables

Our principal variables of interest refer to the characteristics of the region where firms locate their R&D. Specifically, we examine the role of the economic size of regions, the characteristics of the RIS and regional public support for private R&D investment. Additionally, we include a wide range of firm-specific variables potentially related to company decisions regarding innovation expenditure, to control for company-level heterogeneity among regions. We include firm-level characteristics that reflect the endowments and resources which companies have at their disposal to undertake innovation. Here, we distinguish between the internal resources of firms and their access to external resources.

4.3.1. Accounting for regional factors and R&D policies

In order to address our first research question we start by testing regional dummies for the 17 Spanish regions. Regions in Spain have, as has been stated, diverse economies and varying degrees of fiscal and political autonomy. The inclusion of regional dummies will take account of such regional differences. Secondly, we try to open the 'black box' and test for specific regional characteristics. We include regional GDP in 2008 to proxy the economic size of regions. Next, we characterise the RIS. We use the location quotient to measure the dominance of the specific RIS subsystem. The variable LQ_BERD in 2008 is defined as the share of regional business expenditure in R&D (BERD) in regional gross expenditure in R&D (GERD), divided by the national share of BERD in total national GERD; in this way the comparative RIS type (knowledge exploitation vs. knowledge generation) among regions is measured. To address our second research question, and to account for the importance of

R&D in regional budgets for R&D investment, we use the change in regional R&D budgets: (Δ regional R&D budget: 2008–2012). In order to answer our third research question we include the interaction between LQ_BERD and the change in regional R&D budgets; this will show whether the RIS subtypes influence policy outcomes and under what conditions the changes in regional R&D budgets may have reinforced company resilience.

To the best of our knowledge this is the first time that regional government budgets assigned to R&D have been included as an explanatory factor of firm-level changes in in-house R&D.

4.3.2. Accounting for firm-specific characteristics

We draw on the firmly established literature which has analysed various firm-specific characteristics and their relationship to innovation persistence in general (see Cefis and Orsenigo [2001]; Peters [2009]; Martínez-Ros and Labeaga [2009]; Antonelli, Crespi, and Scellato [2012] amongst others).

4.3.2.1. Size. The Schumpeterian hypothesis proposes that large firms are more likely to be innovative because they have the capacity to benefit of capital market imperfections and to spread innovation costs over many units (Cohen 1995). Company size has also been related to persistence in innovation (Cefis and Orsenigo 2001; Peters 2009). Concerning the possible effect of size on resilience, the empirical evidence is, however, inconclusive. Results indicate that the persistence of R&D investment in SMEs could also depend on the location. Here we include the variable SIZE, measured as the log of firms' total number of employees.

4.3.2.2. Productivity. High productivity is an aspect of economic performance which may encourage firms to continue with their innovative projects in spite of the crisis (Antonioli et al. 2013; Zouaghi and Sánchez 2016; Teplykh forthcoming). We include the variable PROD measured as total turnover divided by total number of employees.

4.3.2.3. Export status. The export status of firms appears to be relevant for innovation activities; Latin American exporters were less likely to abandon R&D projects during the crisis (Paunov 2012), while for British companies no association between exporting activities and the propensity to increase innovation activities during the crisis was found (Archibugi, Filippetti, and Frenz 2013a). EXPORT is a dummy variable taking the value of 1 if a company reports sales in international markets and zero otherwise.

4.3.2.4. Pre-crisis innovation level. Other studies point to the innovation level prior to the crisis as a factor contributing to the explanation of why some firms have been able to use innovation to cope with the current crisis, arguing that 'innovation calls innovation' (Antonioli et al. 2013). At the same time, the literature on the dynamics of companies' innovation behaviour has shown that innovation is strongly persistent, suggesting that 'success breeds success' (Cefis and Orsenigo 2001; Peters 2009; Archibugi, Filippetti, and Frenz 2013a). This might imply that 'old' innovators are more likely to maintain or expand their innovation activities during crises. In order to account for firms' pre-crisis innovation levels we include the number of R&D employees (R&D_EMP). The second variable is the number of patents the firm has registered in the pre-crisis period (PATNUM). This is also an indicator of the innovation capacity of companies in the pre-crisis period. In a sample

of British firms, Archibugi, Filippetti, and Frenz (2013a) found that innovation intensity is likely to account for increased investment in innovation during the crisis and that companies which had applied for a patent or registered a design have been more likely to proceed with their innovative activities during the crisis. By contrast, Cincera et al. (2012) observe that EU firms which are highly R&D intensive tended to reduce their R&D investment in 2008–2009 (size, sector and other variables were checked in their model). We also include the variable CONTINUE which takes the value of 1 if the company reports continuous innovation activities as opposed to engaging in innovation only occasionally. In analysing the innovation behaviour of Spanish firms in 2008–2012, Zouaghi and Sánchez (2016) also distinguished between continuous and sporadic pre-crisis innovators.

4.3.2.5. Cooperation. Networking provides access to external knowledge and resources for innovation and has been signalled as a factor contributing to the resilience of industries and companies faced with crises (De Propris 2013). Firms engaged in cooperation for innovation were indeed more likely to innovate during the 2008 crisis (Archibugi, Filippetti, and Frenz 2013b; Zouaghi and Sánchez 2016). We distinguish between companies that report cooperation with universities, research centres and public research organisations (COOP_UNI) and firms reporting cooperation with other private sector partners (COOP_OTHER).

4.3.2.6. R&D finance. The impact of public financing on company R&D projects has been included in a limited number of studies (Peters 2009; Filippetti and Archibugi 2011; Paunov 2012; Antonioli et al. 2013). In general, firms receiving public funding were more likely to continue to innovate than innovators with no public funding. To the best of our knowledge, previous research has not analysed the possible effects of different types of funding (regional, national and supranational) on company R&D expenditure during the crisis. We include three dummy variables. FINA_EU takes the value of 1 if the firm reported R&D funding from European Union programs in 2008. FINA_STATE takes the value of 1 if the company reported R&D funding from the central government in 2008 and FINA_LOCAL takes the value of 1 if the firm reported R&D funding from regional and local administrations. This enables us to analyse in depth the effects of different sources of funding on company resilience during the crisis.

4.3.2.7. Sectors. Previous studies have shown that industrial structure matters for resilience (Davies 2011; Groot et al. 2011; Arvanitis and Woerter 2014). In all our estimations, we include industry dummies based on the sector aggregation provided in PITEC, which is an aggregation of the CNAE (the Spanish acronym for Spain's National Classification of Economic Activities) classification of 44 sectors. These detailed sector dummies account for differences in the sectoral composition of regions and control for industry-specific dynamics that affect company innovation behaviour and their response to the economic crisis in terms of innovation expenditure.

Our independent variables refer to the base year 2008, except in the case of the regional R&D budget variable which is based on its four-year change over our study period. This choice is justified since independent variables show certain persistence from one year to another and firms are likely to adjust their internal R&D only gradually. Independent

variables are summarised in Appendix 1 together with descriptive statistics. Appendix 2 presents the correlation matrix.

5. Results and discussion

The results from probit estimations of Equation (2) are presented in Tables 3–5. They show the probability of firms having abandoned internal R&D expenditure since the onset of the economic crisis. In column (1) of Table 3 only firm-specific characteristics are included. In line with previous studies we find that larger firm size reduces the probability of having abandoned innovation activities during the recession period, as does export market participation. Concerning the EXPORT variable, our results support those of Zouaghi and Sánchez (2016), referring to Spanish agro-food firms and also those of Paunov (2012) for Latin American firms; she also found that exporting firms were less likely to abandon innovation activities in times of recession. The stimulus represented by export activities for the maintenance of R&D activities may depend on the content of exports and on their destination.

Furthermore, our estimation results provide support for arguments concerning the persistence of innovation activities in companies. Those firms with more R&D employees at the onset of the economic crisis, a higher patenting activity and which were continuously engaged in innovation activities were also significantly less likely to have abandoned their innovation activities during the recession years. Our results are in line with previous research. We also find evidence that firms engaged in cooperation networks were less likely to abandon their innovation activities. R&D financing also matters; those firms that have received R&D funding from EU programs, the national government or regional and local authorities have also displayed a lower probability of having abandoned their innovation activities.

Column (2) adds industry-fixed effects. Most variables show a very similar coefficient, except for company productivity and cooperation with universities, research centres and

Table 3. Firm-specific determinants of the decision to abandon innovation expenditure.

	(1)	(2)	(3)	(4)
				(dy/dx)
SIZE (log)	−0.068** (0.029)	−0.131*** (0.034)	−0.137*** (0.033)	−0.040***
PROD(log)	−0.099 (0.225)	−0.710*** (0.241)	−0.614*** (0.245)	−0.179***
EXPORT	−0.306*** (0.028)	−0.241*** (0.039)	−0.244*** (0.043)	−0.071***
R&D_EMP	−0.007** (0.003)	−0.005* (0.003)	−0.005* (0.003)	−0.001*
PATNUM	−0.027*** (0.011)	−0.019* (0.010)	−0.020** (0.010)	−0.006**
CONTINUE	−0.588*** (0.052)	−0.545*** (0.056)	−0.547*** (0.054)	−0.159***
COOP_UNI	−0.111* (0.066)	−0.098 (0.074)	−0.096 (0.075)	−0.028
COOP_OTHER	−0.130*** (0.039)	−0.165*** (0.044)	−0.155*** (0.043)	−0.045***
FINA_EU	−0.344*** (0.120)	−0.366*** (0.120)	−0.363*** (0.121)	−0.106***
FINA_STATE	−0.186*** (0.045)	−0.126*** (0.048)	−0.123*** (0.061)	−0.036***
FINA_LOCAL	−0.170** (0.083)	−0.160** (0.079)	−0.132** (0.067)	−0.038**
Industry fixed effects	N	Y	Y	Y
Region fixed effects	N	N	Y	Y
Number of observations	4619	4619	4619	
Log likelihood	−2478.84	−2395.29	−2379.55	
Pseudo R^2	0.103	0.133	0.138	

Notes: (1) Robust standard errors in column 1 and 2 and clustered standard errors in column 3 are presented in parentheses; ***, **, * = statistically significant at the 99, 95 and 90% levels. (2) All estimations include a constant. (3) Industry fixed effects are based on 43 unreported sector dummies (4) Firm-specific characteristics also includes 5 type of company dummies.

public research organisations; company productivity becomes significant, indicating that, conditional on sectoral heterogeneity, higher productivity does reduce a firm's probability of abandoning innovation. In turn, cooperation with universities, research centres and public research organisations now loses its significance, leaving only cooperation with suppliers, clients, competitors and private R&D centres as significantly related to rates of abandoning innovation. Cooperation with different types of partners appears to have different effects on the resilience of firms. Since part of the projects undertaken by firms with universities may consist of basic R&D, the effect of these collaborations on corporate R&D may take some time to bear fruit. By contrast, company projects with other agents may have immediate effects, since the content of such collaborations is likely to be applied R&D.

In column (3) we add our regional dummies. The firm-level independent variables are robust to this inclusion and even remain markedly similar in magnitude. Column (4) shows the marginal effects for the specification of column (3). For instance, being a continuous innovator decreases the probability of abandoning innovation activities by 0.159. The predicted probability of resilience in a firm receiving public funding at the onset of the crisis is (depending on the source of public funding) between 0.036 and 0.106 greater than the probability of resilience in a firm not in receipt of such funding. Our results contradict those of Antonioli et al. (2013) concerning firms located in Emilia-Romagna since, in their model, companies that had received public funding in the pre-crisis period were not necessarily more resilient during the crisis as concerned their R&D activities. As stated in the theoretical background, 'crowding out' effects of public funding may take place in some cases and not in others. By contrast, our findings support those of Busom and Velez (2016); different types of funding need to be taken into account in order to predict company R&D investment decisions, since their respective impact on resilience differs.

Table 4 gives the estimated coefficients for our regional dummies. Column (1) shows the results of the estimation of Equation (2), when only regional dummies are included and firm-specific and industry effects are not controlled for. The Basque Country serves as our reference group. In column (2) we add our industry effects and in column (3) we further add all firm-specific controls, as in Table 3. Even after controlling for firm-specific differences among firms and differences in sectoral distribution, companies located in the Basque Country still exhibit a significantly lower probability of having abandoned their innovation expenditure than firms in other regions. In other words, companies in all other regions show a higher such probability, confirming the results reported in Holl and Rama (2016). Column (4) shows once more the marginal effects for the specification of column (3).

In Table 5 we present the estimation results from the inclusion of further variables, capturing regional characteristics and policy factors. It should be noted that all estimations now include all the firm-specific variables, as in Table 3, industry fixed effects and the regional dummies. The regional characteristics and policy factors are introduced progressively. The estimation results indicate the following: firms whose R&D activities are in economically larger regions display greater resilience (column 1). The type of RIS in place also matters; companies in regions characterised by knowledge-exploiting systems have also been less likely to abandon their R&D activities (column 2). In column (3) we add regional R&D policy.

The change in the regional R&D budget over the recession period also proves negatively and significantly associated with the probability of abandoning in-house R&D once regional GDP and the RIS subtype (column 3) are controlled for. This indicates that, conditional on

Table 4. Region specific determinants of firms' decision to abandon innovation expenditure.

	(1)	(2)	(3)	(4)
				(dy/dx)
Regional dummies				
ANDALUSIA	0.326***	0.293***	0.305***	0.089***
ARAGON	0.097***	0.125***	0.132***	0.038***
ASTURIAS	0.406***	0.434***	0.406***	0.118***
Balearic Islands	0.912***	0.724***	0.463***	0.135**
Canary Islands	0.916***	0.902***	0.733***	0.214**
CANTABRIA	0.424***	0.401***	0.366***	0.107**
CASTILE-LEON	0.095***	0.071***	0.090***	0.026***
CASTILE-LA MANCHA	0.276***	0.246***	0.113***	0.033***
CATALONIA	0.183***	0.216***	0.241***	0.070***
VALENCIAN COMMUNITY	0.332***	0.321***	0.313***	0.091***
EXTREMADURA	0.606***	0.482***	0.490***	0.143***
GALICIA	0.317***	0.257***	0.241***	0.070***
MADRID	0.158***	0.153***	0.273***	0.079***
MURCIA	0.402***	0.386***	0.372***	0.108***
NAVARRE	0.389***	0.364***	0.365***	0.106***
BASQUE COUNTRY	–	–	–	
LA RIOJA	0.372***	0.369***	0.378***	0.110***
Firm-specific controls	N	N	Y	Y
Industry fixed effects	N	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
Number of observations	4619	4619	4619	
Log likelihood	−2733.7	−2623.3	−2379.55	
Pseudo R^2	0.010	0.050	0.138	

Notes: (1) Clustered standard errors are presented in parentheses; ***, **, * = statistically significant at the 99, 95 and 90% levels. (2) All estimations include a constant. (3) Industry fixed effects are based on 43 unreported sector dummies. (4) Firm-specific controls are given in Table 3. (5) The Basque Country serves as reference region.

Table 5. Region specific determinants of firms' decision to abandon innovation expenditure: regional characteristics.

	(1)	(2)	(3)	(4)
Regional characteristics				
GDP 2008	−0.006*** (0.001)	−0.009*** (0.001)	−0.007*** (0.001)	−0.001*** (0.000)
LQ_BERD 2008		−0.402** (0.208)	−0.133** (0.059)	−0.978*** (0.074)
Δ regional R&D budget: 2008–2012			−0.034*** (0.013)	2.084*** (0.192)
Interaction LQ_BERD 20,008 × Δ regional R&D budget: 2008–2012				−2.006*** (0.181)
Firm-specific controls	Y	Y	Y	Y
Industry fixed effects	Y	Y	Y	Y
Region fixed effects	Y	Y	Y	Y
Joint significance test for regional dummies (*P*-value)	0.000	0.000	0.000	0.000
Number of observations	4619	4619	4619	4619
Log likelihood	−2379.6	−2379.6	−2379.6	−2379.6
Pseudo R^2	0.138	0.138	0.138	0.138

Notes: (1) Clustered standard errors are presented in parentheses; ***, **, * = statistically significant at the 99, 95 and 90% levels. (2) All estimations include a constant. (3) Industry fixed effects are based on 43 unreported sector dummies. (4) Firm-specific controls are given in Table 3.

regional economic size and the type of RIS subsystem, regional policy can contribute to the innovation resilience of companies. The change in the regional R&D budget variable is also negative and significant if it is introduced together either with the regional economic size variable or together with the regional innovation subtype variable instead of jointly with

both, as in column 3. However, in the latter case it shows a significantly higher coefficient and greater significance. This suggests that the change in the regional R&D budget has a mainly positive impact on innovation resilience, conditional on the RIS type in place in the regions.[4]

In order to further investigate this phenomenon, in column 4 the LQ_BERD variable is interacted with the change in the regional R&D budget. The interaction term is negative and significant whereas the coefficient for the change in the regional R&D budget variable now proves positive and significant. This indicates that increases in the regional R&D budget since the onset of the economic crisis have only resulted in lower probabilities of abandoning innovation in regions where a strong knowledge exploitation system was in place, at least in the short run. Including the interaction effects between 'R&D budget changes' and the 'type of RIS' helps to qualify the necessary conditions in which the favourable 'changes in R&D budgets' could favour resilience of company R&D, only in regions with an R&D system oriented towards knowledge exploitation. The policy consequences are clear. Increases in regional R&D budgets are only effective for the purpose of improving R&D resilience if they occur in regions where exploitation RIS are in place. This can explain part of the Basque Country success story outlined in Holl and Rama (2016).

6. Conclusions

In this paper we have tried to ascertain why certain Spanish companies did not discontinue their internal R&D expenditure during 2008–2012. We began by exploring firm-specific characteristics. We found that the probability of companies maintaining internal R&D expenditure during the 2008 crisis tended to be associated with larger firm size, higher productivity and exporting activities prior to the crisis, even when industry-fixed effects and regional effects were taken into account. Resilient firms also tended to have a larger number of R&D employees and were more likely to have already been granted several patents by the onset of the crisis. They also tended to be continuous innovators and engaged in cooperation for innovation with other companies and private research centres. Furthermore, they were more likely to have had their R&D activities funded by public sources in 2008, whether at the EU, national or regional level. The fact that firms with access to public funding in the pre-crisis period were less likely to abandon innovation activities during the downturn suggests a positive role for public research policy, including regional R&D policy.

Regions are, however, not homogeneous. We have observed highly uneven patterns of innovation abandonment across regions and our main focus has been on assessing the impact of certain characteristics of regional factors which cause regional companies to operate in specific contexts. We found that regional size and the relative dimension of their business R&D also had positive effects on the resilience of companies in the R&D field, even when firm-specific and industry-specific effects are controlled for. Interestingly,

[4]These unreported estimations are available upon request. Furthermore, the change in the regional R&D budget over the recession period proves to be positive and significant when introduced individually and without control for regional GDP and the RIS subtype. Our variable for changes in regional R&D budgets does not include a distinction between the sectors targeted with such budgets (academics or firms). When we consider this variable alone, the data could be either funds for academic science or the stimulation of company R&D. In this case, the positive coefficient could arise from an increase in R&D regional budgets that in turn could be associated with a decrease in the R&D activities in firms in the region, if most of the budgets is directed at academic research.

increases in the regional public R&D budget during the crisis had, per se, no positive effect on the behaviour of companies as regards their R&D expenditure. However, conditional on a regional innovation subsystem with substantial regional business R&D (in contrast to regions where the RIS is dominated by the government sector), regional public R&D expenditure during the crisis has contributed to lowering the rates of regional innovation abandonment. Our results show that regional policy does not operate in a vacuum and that regional contexts moderate the effectiveness of policies. An open question is to what degree this is, for example, related to institutional quality (Rodríguez-Pose 2013; Glückler and Lenz 2016). The results also suggest that the presence of regional externalities is crucial in determining the success of regional policies, notably the pouring of additional R&D resources into regions strongly affected by the crisis.

The differences in resilience that we have observed are likely to have long run consequences regarding the competitiveness of regions. In line with the simulation results of Capello, Caragliu, and Fratesi (2016) for European regions, our results also point towards a widening of within-country disparities.

Finally, it is important to emphasise that the results should not be taken to prove causal relations but rather to demonstrate significant associations. Although we have controlled for a wide set of firm-specific characteristics, firms may still make decisions regarding their internal R&D expenditure together with decisions concerning factors that cannot easily be controlled for in our estimations. Moreover, as indicated above, regional government R&D support may also be endogenous. One solution would be to make use of instrumental variables methods. However, finding suitable instruments – variables that are correlated with the changes in the regional R&D budgets but with no independent effect on firm-level R&D abandonment rates – is extremely difficult. Regarding further research, we have used the data for 2008 and 2012 to compare the effects of the crisis; however, the crisis continued until 2013–2014, and thus it would be interesting to repeat the analysis when the 2014 data become available.

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Appendix 1. Explanatory variable description and summary statistics

Variable	Definition	Mean	SD
SIZE	Log (total number of employees) in 2008	4.16	1.55
PROD	Log (turnover/total number of employees) in 2008	2.47	0.08
EXPORT	Dummy variable taking 1 if the company reports sales in international markets between 2006–2008, and 0 otherwise	0.74	0.44
R&D_EMP	Total number of R&D employees	16.1	41.4
PATNUM	Number of patents applied for between 2006–2008	1.17	15.0
CONTINUE	Dummy variable taking 1 if the company reports having engaged in R&D activities continuously, and 0 if the company reports having engaged in R&D activities sporadically in 2008	0.79	0.41
COOP_UNI	Dummy variable taking 1 if the company reports cooperation with universities, research centres and public research organisations between 2006–2008, and 0 otherwise	0.13	0.33
COOP_OTHER	Dummy variable taking 1 if the company reports cooperation with suppliers, clients, competitors and private research centres between 2006–2008, and 0 otherwise	0.39	0.49
FINA_EU	Dummy variable taking 1 if the company has obtained R&D support from EU programs in 2008 , and 0 otherwise	0.06	0.23
FINA_STATE	Dummy variable taking 1 if the company has obtained R&D support via state grants and contracts in 2008 , and 0 otherwise	0.24	0.43
FINA_LOCAL	Dummy variable taking 1 if the company has obtained R&D support via grants and contracts from regional and local authorities in 2008, and 0 otherwise	0.25	0.43
GDP	Regional Gross Domestic Product in 2008 (in billions)	127.1	74.0
LQ_BERD	Share of regional BERD in regional GERD in 2008 divided by the national share of BERD in total national GERD in 2008	1.05	0.25
Δ regional R&D budget: 2008–2012	(Regional R&D budget 2012 – regional R&D budget 2008)/regional R&D budget 2008	−0.17	0.37

Appendix 2. Correlation matrix

	Size	Prod	Exp.	R&D-emp	Patnum	Cont.	Coop-uni	Coop-other	Fina-Eu	Fina-State	Final-ocal	GDP	LQ-BERD	Δ R&D-budget
Size	1													
Prod	0.275	1												
Export	0.180	0.279	1											
R&D_emp	0.359	0.054	0.089	1										
Patnum	0.068	0.013	0.036	0.139	1									
Cont.	0.079	0.008	0.073	0.128	0.035	1								
Coop_uni	0.174	0.036	0.067	0.235	0.100	0.128	1							
Coop_other	0.118	0.012	0.016	0.185	0.053	0.147	0.411	1						
Fina_Eu	0.098	−0.106	0.020	0.316	0.055	0.099	0.343	0.189	1					
Fina_State	0.106	−0.078	−0.007	0.245	0.068	0.146	0.227	0.279	0.301	1				
Fina_local	−0.033	−0.127	−0.036	0.146	0.020	0.082	0.164	0.273	0.217	0.288	1			
GDP	0.071	0.053	0.087	0.057	0.005	0.066	0.012	−0.096	0.014	−0.044	−0.247	1		
LQ_BERD	−0.018	0.071	0.039	0.022	0.033	0.022	0.037	0.045	0.023	0.055	0.100	0.001	1	
Δ R&D budget	−0.018	−0.033	−0.009	0.027	−0.000	−0.004	0.010	0.033	0.048	0.023	0.057	−0.084	−0.033	1