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Innovations' Success and Failure in the Business Cycle

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Received: 1 July 2019; Accepted: 31 July 2019; Published: 2 August 2019

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Abstract: This paper examines three channels of influence of the business cycle in the propensity of firms to introduce technological innovations: Aggregate demand (firms initiate more innovation projects in expansion than in recession; risk (the probability that initiated projects fail is higher in contraction than in expansion); and obstacles to innovate (more firms perceive the obstacles to innovate as high in recessions than in expansions and the high obstacles implies lower propensity to initiate innovation projects). With Spanish CIS data we find evidence that the three channels contributed to the fall in the proportion of firms that introduce technological innovations during the Great Recession, compared with the proportion of innovators in the years of expansion. The research methodology consists on estimating a multiprobit model with the probability that firms introduce technological innovations, the probability that firms abandon ongoing innovation projects, and the probability that firms perceive the obstacles to innovate as high.

Keywords: innovation output; abandons; business cycle; financial constraints; Spanish CIS panel data

1. Introduction

Evidence exists of a substantial decline in business innovation in industries and countries around the world during the recent financial crisis [1–3]. The fall in business innovation output during a relatively long period of time undermines the knowledge base of the economy, and the prospects of economic growth. Learning more about the channels through which the business cycle influences the innovation output of firms will help to design and implement policy actions aimed at, reducing the volatility in the number of innovating firms, steadily increase the stock of knowledge capital and contribute to sustained output and employment growth [4].

In this paper we use Spanish firm level data to explain the output from innovation activities in a sample of Spanish firms during the period from 2003 to 2014, when the economy transitioned from years of high economic growth (2003–2008) to the years of severe recession (2009–2014). According to the Community Innovation Survey, CIS, data, in the years of the crisis the proportion of firms that introduced technological innovations in Spain was two-thirds of that in the years before; in 2014, last year of the sample period, there were no sign of turnaround in innovation output. In fact, the OECD (2012) [2] identifies Spain as one of the developed countries where business innovation activity has decreased the most and has taken the longest to recover from the crisis. In the explanation of the fall of innovation output from Spanish firms we postulate and test three channels of influence of the business cycle in the propensity of firms to introduce technological innovations. Each channel could be studied independently of the other two but the paper provides reasons why the three channels of influence should be investigated together in a unified approach.

First, the crisis has been named the Great Recession because the aggregate demand fell sharply and the recovery has been slow in most of the economies around the developed world. Firms experience the fall in the demand for their own products too and adjust the projections of future growth downwards influenced by the general mud of the recession. The contraction of current demand and the negative prospects of growth reduce the value on innovations and fewer firms decide to start innovation projects, compared with those that do so in years of sales growth, both at the firm and the economy level. Since fewer firms initiate projects, there will be also fewer firms that will eventually introduce innovations, the output of the initiated innovation projects. We call this transmission mechanism from the aggregate demand of the economy to the demand of the individual firms, in the incentives of firms to initiate innovation projects, the *aggregate demand* channel effect of the cycle in the number of firms that introduce innovations.

Second, the business cycle affects the risk of the initiated innovation projects. This means that the probability that an initiated project will end with success, i.e., it delivers the innovation the firm was looking for, or the projects fails and the firm abandons it along the way, varies depending on the stage of the cycle. In periods of expansion the surprises along the execution of the initiated projects are likely to be positive, and the rate of success will increase compared with the average. In periods of contraction it will be the opposite, with negative surprises dominating over the positive ones and higher probability of failure. Then, along the cycle firms are exposed to positive and negative surprises (unanticipated events at the time of initiating the innovation projects) that affect the probability that an ongoing innovation project will succeed. In recessions the risk of failure increases because the negative surprises dominate. This is what we call the *risk* channel effect of the business cycle in the number of innovator firms.

Third, the business cycle affects the constraints under which firms perform their innovation activities. The constraints, for example in the form of access to external finance, soften in expansions and tighten in contractions. Firms that would have started new projects or had continued with the ongoing ones in normal times, decide not to do so in bad times because the tighter constraints mean less resources available to innovate or more dim prospects of success. On the contrary, when in the years of expansion, the constraints and obstacles relax more and firms will be able to initiate innovation projects and, eventually, more firms will introduce innovations. This influence of the cycle in the innovation output of firms will be called the *obstacles to innovate* channel.

The interdependency among the channels is evident. Innovation is a risky activity because the output of the innovation activity is uncertain, first in terms of the success or failure of development of the innovation itself, and in the ultimate effect of its application and use in the sales and profits of the innovating firm. Firms dedicate resource to innovate being aware of the uncertainty of the outcome so the resources that a firm dedicates to innovation, together with uncontrolled external shocks, will finally determine if projects end in success or in failure. The introduction of innovations and the abandonment of projects must be explained jointly because they are outcomes produced by the same firms and share the same innovation resources. Firms will likely anticipate all or part of the evolving risk along the cycle and will take it into consideration in the decision of whether to initiate innovation projects or not. Then, it will be important to be able to separate the risk channel of the business cycle that operates through the decision to initiate projects, and the channel operating through unanticipated surprises that force firms to revise the expected payoffs of ongoing innovation projects and decide about their continuation or cancelation. Finally, the constraints faced in the production of innovations will not be independent of the technological and commercial ambition of the innovations that firms try to develop and introduce. Then, the influence of the constraints in the innovation output will be determined simultaneously with the influence of innovation resources and decisions in the tightness of the constraints.

D' Este et al. (2016) [5] were the first to acknowledge the interdependency between the decision to introduce an innovation and the decision to abandon ongoing innovation projects, and the need to account for them in empirical models that explain innovation outcomes, success and failure. The authors empirically model the probability that firms introduce new to the market product innovations, and also model the probability that firms abandon any kind of innovation project. Then they justified the multiprobit estimation of the probability to introduce product innovations and the probability to abandon innovation projects, as the proper way to account for the interdependency among innovation processes in the same firm that sometimes turn into success (the firm introduces a new product) and sometimes in failure (abandon). In this paper we also adopt the multiprobit approach as the way to account for the interdependencies among the three dependent variables, probability that the firm introduces a technological innovation, probability that abandons innovation projects, and probability that perceives the obstacles to innovate as high. The difference with D' Este et al. (2016) [5] is that we model firms' innovation outcomes and constraints (financial obstacles) along the business cycle, while their analysis is cross section. Our research questions focus on three channels of effects of the cycle in innovation outcomes, while their main interest was in innovation resources and capabilities of firms that increase the probability of success and that reduce the probability of failure.

The rest of the paper is organized as follows: Section 2 presents the research framework and related literature. Section 3 presents the information on the data base and the description of the variables. In Section 4 we present the empirical model and how to interpret the results in terms of rejecting the hypothesis or not. Section 5 presents the results from the multiprobit estimation. The conclusions, Section 5, summarize the main results of the paper.

2. Related Literature

In this section we review the literature related to the research objectives of the paper. The revision will be organized in blocks, each covering one of the three channels at a time.

2.1. The Production of Innovations

The decision to innovate, the intermediate outcomes of the innovation activities, and the consequences of innovation for the performance of the innovating firm, are closely interrelated [6–8]. In this paper we model and estimate the production function that explains the introduction of product or process innovations by firms as a function of their respective innovation resource inputs and obstacles to innovate, sector specific effects and macroeconomic conditions common to all firms, in line with previous research with UK [9] France [10], Spain [5,11], Sweden [12], Italy [13], and OECD countries [14] data. It is expected that firms with higher endowment of innovation resource inputs (particularly knowledge capital) will be more likely to introduce technological innovations than firms with lower endowment.

The introduction of innovations by firms reveals innovation outcomes form initiated innovation projects that had been concluded with success. There will be also initiated projects that the firm stops or definitely abandons and that can be considered as a failure because they do not deliver the intended outcome. When information on abandons has been available, researchers have investigated the determinants of the likelihood of abandon (failure) practically with the same production function approach that has been used to estimate the determinants of the probability of success (Baldwin and Lin (2002) [15], Gália and Legros (2004) [16], Mohnen and Röller (2005) [17], Mohnen et al. (2008) [18], Madrid-Guijarro et al. (2009) [19], Silva et al. (2009) [20], García-Vega and López (2010) [21], Gália et al. (2013) [22], Blanchard et al. (2013) [23], and D' Este et al. (2012) [24]). Although it could be initially expected that more innovation resource inputs contribute to reduce the probability of failure, the evidence has been the contrary, and most often the probability of abandon increases with the innovation resources of firms, similar to what happens with the probability of success.

To understand this result is necessary to take into account that ex ante, any initiated innovation project can end up with success or with failure (technological risk). In the decision to initiate innovation projects or not and in the decision on the volume of resources dedicated to the innovation activity, firms will weigh the pay offs and the associated risks (technological and demand risks). More innovation resources in some firms than in others could just indicate that the former is more likely to initiate projects that the latter and, for a given probability of success, more projects will succeed and more will fail in the firm with higher resources than in the one with less resources to innovation. If success and failure are outcomes of projects initiated by the same firms and consuming the same resources, the probability that a firm introduces innovations and the probability that abandons ongoing project must be modeled together. In this paper we follow D' Este et al. (2016) [5] and account for the interdependency with the multiprobit estimation, with one probit on the probability that a firm introduces innovations as a function of the innovation resource inputs, and the other on the probability of abandon, also as a function of the same innovation resource inputs.

2.2. Innovation along the Business Cycle

Two competing views explain the innovation activity of firms along the cycle: The opportunity cost and the resource views. The opportunity cost view claims that innovation projects compete with the demand for resources needed for short-term production. During expansions there is greater demand for funds to finance activities geared towards increasing the production and sales of existing products, while during recessions such demand is lower. Therefore, if innovation projects require diverting resources from production and sales, the opportunity cost of these resources will be higher in expansions than in contractions. Under this argument, innovation should be relatively more intense in periods of low and moderate economic growth than in periods of high growth. The opportunity cost view then predicts that innovation is countercyclical [25,26]. In contrast, the so-called "cleansing" effect in Schumpeter's (1942) [27] theory of creative destruction, in recessions firms more strongly perceive the pressure to innovate and restructure as conditions for surviving in the market and for this reason innovation activity could be more intense in periods of economic contraction than in economic expansion (countercyclical innovation).

In the resource view, information asymmetry between managers and external investors increase the cost of external funds and firms will condition innovation activities to the availability of internal resources [28–32]. Since the internally available funds are higher in economic expansions than in downturns, the resource view predicts that innovation will be pro-cyclical, that is, it will increase in periods of economic expansion and it will decrease in periods of contraction. Aghion et al. (2012) [33] find that relative R&D spending is pro-cyclical only among financially constrained firms.

The building of knowledge capital through R&D investment and/or collaborating with external partners may not overlap exactly with the moment in time a firm decides to introduce a technological innovation to the market. The stock of knowledge capital determines the options for innovation available to firms. In the execution of the options, that is, in the timing of the innovation projects to undertake and the precise moment to introduce an innovation, there are also demand and profit pull effects [34–36]. In general, expectations of higher demand and profits in years of expansion will increase the likelihood that firms introduce innovations in these periods than in periods of contraction, for a given stock of knowledge capital.

The empirical evidence on the innovation of firms during the business cycle broadly confirms a positive demand-pull effect on the innovation output. Geroski and Walters (1995) [37] study the introduction of major innovations (in terms of commercial success) and the patent filings of UK firms and find that the two outputs evolve in a pro-cyclical way. Martinsson and Lf (2009) [38] with data from Swedish manufacturing firms find that the firm's patents are sensitive to the evolution of its cash flows (the proxy for business cycle) but only when the cash flows go down, not when they go up. They conclude that patents are pro-cyclical but only in downturns. Hingley and Park (2017) [39] use country-level data from patent filings at the European Patent Office to study the sensitivity of patents to the business cycle. They find that patent filings are strongly pro-cyclical. The evidence also varies depending on the type of innovation, product or process. Nickell et al. (2001) [40], with data from UK manufacturing firms, finds that, in downturns, firms show relative preference for cost reducing innovations, while Berchicci et al. (2013) [41], with data from Italian manufacturing firms, finds preference for product innovations.

2.3. Innovation Failure along the Business Cycle

The uncertainty around the outcome of innovation projects will be relevant for the decision on the number and composition of innovation projects to initiate. If the uncertainty about the pay offs of the innovation projects is higher in recessions than in expansions the higher uncertainty will determine that fewer projects will be initiated when the economic prospects are of recession than when they are of expansion. Once the decision about the innovation projects to initiate is made, the probability that the projects will fail in the execution stage must not necessarily be intrinsically different in recessions than in expansions. The probability of failure-abandon of innovation projects in different stages of the business cycle is more likely to be affected by the different probability of positive and negative "surprises" (events not anticipated in the initiation stage) in expansions than in recessions. For example, if the expansion period is more pronounced or longer than anticipated, the firm will likely revise upwards the probability of success of ongoing innovation projects, compared with the probability of success estimated when the project was initiated. On the other hand, if the fall in aggregate demand in the recession is higher or the duration of the recession longer than anticipated, then projects with expected positive pay offs ex ante, may turn unprofitable under the worst macroeconomic conditions and the firm may decide to abandon them. The evolution of the surprises along the cycle could then be the determinant of higher likelihood of abandon of innovation projects in recessions than in expansion, even though the innovation projects under way had already been filtered out from the expectations about macroeconomic prospects at the initiation time.

2.4. On the Obstacles to Innovation

The analysis of the effects of the obstacles to innovation in the innovation decisions should make a distinction between those obstacles that impede firms from becoming innovators, and the transitory obstacles faced by regular innovation firms. This subsection focuses only on transitory obstacles, and more particularly on obstacles that the CIS views as potential innovation barriers.

On this issue, previous research has examined what determines that a firm perceives one or more obstacles as high [15,16,24,42], and how the perception of an obstacle as "high" affects the firm's innovation output [43–45]. Among the possible obstacles to innovate, the one more often considered is the firm being financially constrained or not. Savignac (2008) [45], with French data, finds that firms that perceive the financial obstacles as high, firms financially constrained, are less likely to introduce innovations than the unconstrained ones. Hottenrott and Peters (2012) [46] find that internal financing constraints reduce the R&D spending of firms.

But there is also evidence of reverse causality: more innovative firms have greater difficulty in accessing external finance than the less innovative ones [47]. There is then simultaneity between the perception about the obstacle, and the involvement in the innovation activity: In order to perceive an obstacle to innovation as high it may be necessary that the innovation activity is also particularly high [16]. Furthermore, there could be unobservable firm-specific effects correlated with both, the innovation variables and with the perception on the obstacles to innovate [45]. The two circumstances recommend that the perception about the obstacles to innovate and the effect of the perception in the decision to innovate be estimated simultaneously in the multiprobit estimation.

The perception about the obstacles to innovation among firms can also change during the business cycle. There is evidence that in the years of the financial crisis, firms in many countries experienced severe credit constraints, in part because there were fewer funds available to finance capital investment in general and innovation activities in particular [48,49]. Thus, it can be expected that the proportion of firms that perceive the unavailability of external funds to finance the innovation activity as a high obstacle, will increase in the years of the crisis, compared with the proportion that perceived the obstacle as high in the years of expansion.

Firms in the database report on their perceptions about financial and non-financial obstacles to innovate, such as not finding the right employees, technological uncertainty, demand uncertainty, or no interest in innovations by customers. In this study we consider both financial and nonfinancial obstacles to innovation. However much less is known about the pro-cyclical or counter cyclical evolution of the perceptions of firms about the non-financial obstacles so the evolution of the perception on these obstacles along the cycle will be considered as an empirical issue.

3. Database and Variables

3.1. Database

The firms' data come from the Spanish Community Survey on Innovation, CSI that is made available by the open access database PITEC (https://icono.fecyt.es/PITEC).

The sample includes firm-level information for each year from 2003 until 2014 for several thousand firms of all sizes, ages, and economic sectors. The PITEC database comes from a subsample of firms that participate in the Spanish CIS biased towards larger and more intensive innovation firms (firms with 250 employees or more represent more than 20% of the total, while in the CIS sample they represent only 2% and in the total population of Spanish firms less than 0.5%).

The sample in this study is a balanced panel of 5809 firms. To be included in the panel a firm must be a *potential innovator,* in the sense that at some point during the sample period either it dedicates resource inputs to innovation (positive R&D expenditures, internal or external, collaborates with other firms; trains employees in innovation; and receives public subsidies), introduces an innovation project, or abandons one. Firms that disappear during the sample period because they merge or are absorbed by others are excluded from the sample. The main reason why we restrict the sample to surviving innovators is to preserve homogeneity. At this point in the research, properly controlling for the selection decision of becoming an innovator or not is extremely complicated. Then, the results of the research are only valid for samples of potential innovator firms. The Appendix A provides information on the values of the dependent and explanatory variables for all the firms in the PITEC database.

The organization of the data for the purpose of this research is conditioned by the way the CIS formulates the questions on the technological innovation of firms: "indicate if your company has introduced one or more product (process) innovation in the past three years": Yes or No. And the question on abandoning innovation projects: "indicate if your company has abandoned one or more innovation projects in the past three years or not", with no distinction between product or process innovations. Firms respond to these survey questions every year so there is overlap in the answers to the questions on the introduction or abandonment of innovations in the past three years. To avoid the overlap, the total sample period is divided into four blocks of 3-year periods: 2003–2005, 2006–2008, 2009–2011, and 2012–2014. Next, the innovation output of the period is the answer to the survey question in the last year of the period: 2005, 2008, 2011, and 2014. The balanced panel data then comprise information on 5,809 firms in four time periods of three years each.

3.2. Business Cycle

Table 1 summarizes the information on GDP growth rates and unemployment rates for the Spanish economy in each of the 3-year periods, with a tentative indication of the respective stage of the business cycle. Although there are clear differences in the macroeconomic conditions previous to and after 2008, within the expansion and contraction years the GDP growth rates and unemployment rates show some variation. Since 2015 the Spanish economy has been steadily growing but in 2014 that recovery was uncertain (GDP growth rates above 3% and unemployment rate of 16% in 2017).

In the empirical model, the stage in the business cycle of each of the 3-year periods is captured by the time dummy variables *TD-05*, *TD-08*, *TD-11*, and *TD-14*. They, respectively, equal one for all the firms in 2003–2005, 2006–2008, 2009–2011, 2012–2014, and zero otherwise.

Table 1. Macroeconomic variables and business cycle of the Spanish economy

Period	Cumulative 3-Year GDP Growth Rate	Unemployment Rate (Average)	Business Cycle
2003–2005	10.40%	10.30%	Accelerated upturn
2006–2008	9.30%	8.90%	Consolidated growth
2009–2011	−4.50%	19.70%	Accelerated downturn
2012–2014	−3.20%	25.11%	Recession and turn around

Source: Own elaboration with official statistical data (INE).

3.3. Innovation Output

Table 2 shows the distribution of firms in the sample according to their innovation output. The proportion of firms that introduce at least one innovation is 75% in 2006–2008, the maximum in the sample period, and only 61.4% in 2012–2014, a reduction of 13.6 percentage points (17%). Firms stop introducing innovations from the first years of the crisis, 2009–2011, but the largest fall in the number of innovators occurs at the end of the sample period. The number of firms that report abandoning innovation projects remains rather stable at 22% until 2009–2011; in 2012–2014 the number decreases slightly to 21%. When we compare the evolution of firms that abandon projects in relation to those that introduce them, the ratio is at the minimum value of 0.30 in 2006–2008, and the maximum of 0.338 in 2012–2014. Except for the period 2003–2005, the number of firms that report abandonment at conception of the innovation project is higher than the number that reports abandonment in the development stage.

Table 2. Number of firms in the sample, innovation activity and output

Period	Number of Firms	Introduce Innovations	Abandon Innovations	Abandon at Conception	Abandon in Development	Abandon/ Introduce	Development/ Conception
2003–2005	5809	4277	1332	844	935	0.311	1.108
2006–2008	5809	4355	1307	1017	818	0.300	0.804
2009–2011	5809	4051	1329	1029	849	0.328	0.825
2012–2014	5809	3569	1205	929	745	0.338	0.802

Source: Own elaboration with PITEC data.

The number of firms that initiate innovation projects is not directly observable but it can be approximated by the sum of firms that introduce innovations and firms that abandon innovation projects. This sum is 15% lower in 2012–2014 than in 2006–2008 so there is preliminary evidence that fewer firms initiate innovation projects in recession than what they do in expansion (aggregate demand effect). From Table 2, the increase in the ratio of firms that abandon over those that introduce innovations during the crisis, compared with the ratio in the years of expansion, could be interpreted as preliminary evidence of the risk effect: The crisis reduces the innovation output because there is an increase in the proportion of initiated innovation projects that fail. The surprise effect that causes an increase in the rate of abandonment of ongoing projects appears again in the evolution of the ratio of firms that abandon projects in the development stage and those that do so at the conception stage, that increases from around 0.80 in 2006–2008 to 0.825 in 2012–2014. Then, the crisis induced the cancelation of projects in the development stage that were initiated and passed the conception stage under more optimistic expectations about the evolution of the economy.

For the multivariate analysis in the next section, we define the variable *introducing innovations* that equals one if the firm i answers yes to the question of whether it introduces technological innovations in period t and zero otherwise. We define the variable *abandons* that equals one if firm i abandons innovation projects in period t and zero otherwise. We also distinguish between the variable *abandons at conception* that equals one if firm i abandons innovations at the conception stage in period t and zero otherwise; and the variable *abandons in development* that equals one if firm i abandons innovations in the development stage in period t and zero otherwise

3.4. Obstacles to Innovation

The CIS asks firms to rate from low to high the potential obstacles to innovation including access to financial and human resources, technical and demand uncertainty about the innovation output, and the willingness to pay for innovations by the firm's customers. The proportions of firms that perceive each obstacle to innovate as high in every three years period are presented in Table 3.

Table 3. Percentage of firms that perceive the respective obstacle as "high"

Innovation Obstacle High	2003–2005	2006–2008	2009–2011	2012–2014
No access to external finance (%)	29.97	33.65	40.57	37.06
Not finding the right people (%)	9.95	10.29	8.16	6.97
Technical uncertainty (%)	6.68	6.89	5.41	4.89
Demand uncertainty (%)	16.44	20.00	24.10	20.00
Customers do not demand innovations (%)	9.85	8.54	8.07	8.47

Source: Own elaboration with PITEC data.

The obstacle to innovate that a larger proportion of firms perceive as high is not having access to external finance, 35% of firms on average for the sample period, followed by demand uncertainty, with 20% of firms that perceive the obstacle as high. The number of firms that perceive each of the two obstacles as high is lower in the expansion period of 2003–2008 and higher in the years after 2008, with a maximum in 2009–2011. The proportion of firms that perceive the rest of the obstacles as high is much lower, between 6% and 10% on average during the sample period.

The precise definition and measurement of the obstacles variables for the multivariate analysis is as follows. The variable *no access to external finance* equals one if a firm responds that not having access to external funds to finance innovation is a "high" obstacle in at least two of the three years of the time interval and zero otherwise. This restriction ensures that the constraint is tight and persistent. This criterion is maintained in the other innovation obstacles: *not finding the right people* (availability of adequate personnel for innovation), *technical uncertainty* (uncertainty about the resolution of the technical problems during the innovation process), *demand uncertainty* (uncertainty about the acceptance of the innovations in the market), and *customers do not demand innovations* (customers of the firm are unwilling to pay for innovations) where each equals one if the firm responds that it perceives the obstacle as "high" in two of the three years of the time interval and zero otherwise.

3.5. Resource Inputs and Control Variables

The direct innovation resources inputs of firms in each time period determine the level of knowledge capital available to be used in the initiation and completion of projects for new products and processes. This capital comes from several sources: The investment in R&D, both internally and from external purchases, accumulated over time; from collaborations with other institutions (other firms, universities, and research centers); investment in training employees; and public subsidies. For the multivariate analysis we define the proxy variables of knowledge capital as follows: The *stock of R&D capital per employee* is the ratio of the stock of capital that is accumulated through the investment in R&D and the number of employees of the firm. The stock of R&D capital is calculated at the end of year t by using the perpetual inventory model and considering an annual depreciation rate of 15%. The information on the annual flows of R&D investment and on the number of employees comes directly from the PITEC database. Since the dependent variables cover a 3-year period, the capital per employee is the average of the stock per employee in the corresponding three years. We consider that the accumulated stock of R&D capital better captures the accumulated knowledge available to the firm for undertaking innovation projects, and the differences in persistence in innovation activity across firms than the annual investment flow [50].

The variable *cooperate* equals one if the firm reports collaborating with other institutions in at least two of the three years and zero otherwise. The variables, *trains employees* and *public subsidies* equal one if the firm reports, respectively, training employees and receiving public subsidies in at least two of the corresponding three years and zero otherwise. The information on whether a firm collaborates, trains the employees, and receives subsidies comes from the PITEC database. Requiring that the firms perform these complementary activities in at least two of the three years ensures that the firm is committed to the activity so the contribution to the knowledge capital is above a minimum threshold.

The control variables include characteristics of the firms and of their sectors of activity that can directly or indirectly affect the value of the dependent variable. One block of control variables includes the *size* of the firm (log of the number of employees on average for the 3-year period); the ownership of the firm (*group* is a dummy variable that equals one if the firms report belonging to a group and zero otherwise); whether the firm exports or not (*exporter* is a variable that equals one if the firm exports in at least two of the three years); and the production technology that is measured by the ratio of tangible *capital stock per employee* (average of the three years). The stock of tangible capital in year t is calculated with the perpetual inventory method adding the annual flows of investment in machinery and equipment up to year t, reported year by year in the PITEC database, assuming a depreciation rate of 15% per year. We also control for sector effects (44 NACE 2-digit sectors) with a sector dummy variable that equals one for all firms in the same sector and zero otherwise.

The information on the values of the explanatory variables appears in Table 4. The time evolution of the variable *R&D capital stock per employee* is determined by the time evolution of the numerator and the denominator. In this respect, the contraction of 16.6% in capital stock per employee from 2003–2005 to 2006–2008 coincides with an increase in the number of employees per firm of 10% in the same period. As well, the 2% decrease in the stock of R&D capital per employee from 2006–2008 to 2012–2014 coincides with a decrease in the number of employees per firm in two time periods. In any case, during the crisis the R&D expenditures per employee decrease faster than the R&D capital stock per employee. The proportion of firms that cooperate remains rather stale over time, while the proportion of firms that train employees and the proportion that receive public subsidies decrease slightly during the crisis. Overall, the fall in the evolution of the innovation output during the crisis (Table 2) is more pronounced than the fall in innovation resource inputs (Table 4). The evidence indicates that the supply effect, the reduction of innovation output from the reduction in innovation inputs, is not sufficient to explain the fall in innovation output during the crisis and that the demand-pull effect is also relevant.

Table 4. Descriptive information on knowledge capital and control variables.

	2003–2005	2006–2008	2009–2011	2012–2014
Knowledge capital				
R&D capital stock per employees	72,958.24	60,959.47	57,816.34	59,562.28
Cooperate (%)	31.73	31.04	30.59	31.93
Training in innovation (%)	17.39	12.84	11.26	9.85
Public innovation subsidies (%)	40.08	35.43	33.01	30.44
Control variables				
Exporter (%)	47.01	48.11	59.73	63.88
Capital stock per employee	121,065.02	107,813.27	101,237.47	103,244.33
Employees per firm	389.54	428.68	428.37	408.10
Group (%)	36.39	45.76	48.42	50.22
Industry (%)	56.61			

Source: Own elaboration with PITEC data.

The firms in the sample have on average around 400 employees, which confirms the sample bias towards large firms. In the period 2012–2014, almost two-thirds of the firms in the sample are exporters, compared with only 48% in the period 2006–2008 of consolidated expansion. The tangible capital stock per employee evolves over time in a similar way as the R&D capital stock and is influenced again by the evolution of the number of employees per firm. At the end of the sample period 50% of the firms report belonging to a business group, national or foreign, compared with 36% that belong to a business group in 2003–2005.

The firms in the sample belong to 43 different NACE sectors, 56.6% industry and 43.4% service sectors.

4. Empirical Model and Summary of Hypotheses

The multiprobit model to be estimated is summarized in the K probit equations:

$$P\Big(Y_{k,i,i} = 1\Big) = \alpha_k + \beta_k X_{k,i,t} + \varepsilon_{k,i,t},\ k = 1, \ldots K \quad (1)$$

One of the probit model estimates the probability that firm i introduces a technological innovation in period t (dependent variable *introducing innovations*). The second probit model estimates the probability that firm i abandons an innovation project in time period t (dependent variable *abandons*). The rest of probit models, up to five, estimate the probability that the firm responds "high" to its perception about the respective innovation obstacle listed in Table 3. Then $K = 7$. We also present the estimation of the probit model when the variable *abandons* distinguishes between *abandons at conception* and *abandons in development* ($K = 8$).

The explanatory variables are the same for the probability that firms introduce innovation than for the probability that firms abandon innovation projects: the innovation resource inputs (Table 2); the time dummy variables that capture the stages of the economic cycle (Table 1); the obstacles to innovate variables (Table 3); and the control variables (Table 2). The explanatory variables of the probit models of the perception the obstacles as high include the innovation resource inputs, the time dummies and the control variables. The ε_{kit} is the error term of probit model k for firm i in period t. The multiprobit estimation of the parameters of the explanatory variables is more efficient and consistent than the estimation from separated probit models. The reason is that the multiprobit uses the information contained in the matrix of correlation coefficients across the residuals of the multiple probits. This information captures the interdependencies among the jointly determined innovation output and perceived obstacles variables, and/or the correlation between the explanatory variables and unobserved firm and time period specific effects.

We now summarize the way the aggregate demand, the risk and obstacles to innovate channels we expect that will be reflected in the results of the empirical estimation (sings of the estimated coefficients of the explanatory variables). The aggregate demand channel predicts that the propensity of firms to initiate innovation projects is pro-cyclical. If firms anticipate the prospects in the evolution of risk of failure along the cycle in the decision to initiate innovation projects or not and of what kind, the risk effect in the innovation output of firms would show up in the number and characteristics of the projects that are initiated, not in the rate of firms that report failing projects along the cycle. Then the prediction from the aggregate demand effect is that the probability that firms will introduce innovations and the probability that firms will abandon innovation projects will both be pro-cyclical, increasing in the years of expansion and decreasing in the years of contraction, consistent with the evolution in the propensity to initiate projects along the cycle.

The surprise component of the risk along the cycle implies that the probability of abandon and the probability of introduction of innovations can evolve differently along the cycle. The probability of abandons will likely increase in recessions and will decrease in expansions. The reason would be that in recessions (expansions) the surprises are more likely to be in the form of negative (positive) shocks that deteriorate (improve) the prospects of the project with respect to the prospects when the project was started.

From the evidence found in previous research, we expect that the probability that a firm perceive as high the obstacle to innovate from being financially constrained will higher in the recession than in the expansion. If the perception of the obstacle as high is effective in constraining the innovation activity of firms then we expect that the innovation output will be lower among firms that perceive the obstacle as high than among firms that do not because the former will initiate fewer innovation projects than the latter. Therefore, we expect that firms that perceive the obstacle as high will have lower probability of introducing innovations and lower probability of abandoning ongoing innovation projects than firms that do not perceive the obstacle as high.

The effect of the cycle in the probability that the other obstacles different from the financial ones will be perceived as high, and the influence of the constraints from these obstacles in the innovation output will be an empirical issue.

5. Results of the Estimation

The results of the estimation of multiprobit model (1) with *abandon* as a single variable ($K = 7$), i.e., with no distinction between abandon in the conception and in the development stages, are presented in Table 5. The first two columns show the results of the estimation of the probit models on the determinants of innovation outcomes, success and failure. The other five columns show the estimations of the probit models on the probability that the firms perceive the respective obstacle as high. We will first comment on the results from the probability that firms perceive the obstacles as high, and next the results on the determinants of the innovation outcomes, which include among the explanatory variables the perception about the obstacles to innovate as high or not high.

5.1. Obstacles to Innovate

The estimated coefficients of the innovation resource input variables are negative and statistically significant in the column of the obstacle *customers do not demand innovations*, and positive and significant or non-significant in the columns of the rest of obstacles. Firms whose customers do not value innovation invest less in innovation than firms otherwise. For the rest of firms, the probability to perceive the obstacle as high increases among firms that cooperate with others, train their employees in innovation activities and receive public subsidies, compared with the probability among firms otherwise. However, differences in *R&D capital per employee* do not significantly explain differences across firms in the probability that the obstacles are perceived as high. It seems that among those firms whose customers value innovations, the perception as high of the obstacles to innovate does not impede reaching the desired stock of *R&D capital per employee*. With respect to the other sources of innovation inputs, maybe firms that perceive the obstacles as binding respond to the constraint looking for innovation resources in sources alternatives to the own stock of innovation capital.

The probability that firms perceive the obstacles to innovate as high is sensible to the business cycle, although there are differences depending on the obstacle, according to the estimated coefficients of the time dummy variables. Since the omitted time dummy variable corresponds to the expansion period 2006–2008 the estimated coefficients shown in Table 5 must be interpreted as differences with respect to the probability of perceiving the obstacle as high in the omitted time period. The probability that firms perceive as high the obstacle *no access to external finance* increases in the years of the crisis, 2009–2014, compared with the probability in the years of expansion 2003–2008. The probability that firms perceive themselves as financially constrained is then counter-cyclical. The other obstacle that more firms perceive as high in the crisis than in the expansion is *demand uncertainty*, although only during the first years of deepest recession 2009–2011. The probability of perceiving as high the obstacles *not finding the right employees* and *technological uncertainty* is higher in years of expansion than in years of recession, maybe because in the recession firms reduce the number and ambition of the innovation projects that they initiate. Finally, the proportion of firms that perceive as high the obstacle to innovate that their *customers do not value the innovations* is higher in expansions than in the recession period, i.e., customers attach higher value to the innovations of the suppliers in recessions than in expansions.

Table 5. Results of the estimation of multiprobit model (1) with abandon on innovation projects as a single variable. The first two columns show the estimated coefficients of the explanatory variables of the probability that a firm introduces innovations and of the probability that a firm abandons innovation projects. The other five columns show the estimated coefficients of the explanatory variables of the probability that a firm perceives the respective obstacle as high.

	Introduces Innovation			Abandons			No Access External Finance			Not Finding Right Employees			Technological Uncertainty			Demand Uncertainty			Customers Do Not Demand Innovations		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Innovation resource inputs																					
R&D capital stock per employee	0.069	***	0.004	0.018	***	0.005	−0.007		0.004	0.004		0.006	0.006		0.007	0.009		0.005	−0.019	***	0.005
Cooperation in innovation	0.745	***	0.029	0.414	***	0.026	0.159	***	0.025	0.093	***	0.033	0.147	***	0.038	0.125	***	0.027	−0.486	***	0.042
Training for innovation	0.820	***	0.051	0.326	***	0.032	0.117	***	0.032	0.165	***	0.039	0.140	***	0.046	0.032		0.033	−0.376	***	0.064
Subsidies	0.268	***	0.026	0.025		0.029	0.146	***	0.024	0.047		0.030	0.054		0.036	0.110	***	0.025	−0.472	***	0.039
Economic Cycle																					
DT-05	−0.098	***	0.024	−0.045	*	0.027	−0.159	***	0.020	−0.052	*	0.027	−0.026		0.031	−0.149	***	0.023	0.152	***	0.032
DT-11	−0.101	***	0.025	0.064	**	0.028	0.201	***	0.019	−0.114	***	0.027	−0.104	***	0.030	0.141	***	0.022	−0.068	**	0.032
DT-14	−0.374	***	0.027	−0.062	**	0.028	0.100	***	0.023	−0.200	***	0.032	−0.157	***	0.035	−0.012		0.026	−0.036		0.035
High obstacle:																					
No access external finance	−0.460	***	0.090	−0.471	**	0.215															
Not finding right employees	−0.037		0.109	−0.277		0.176															
Technological uncertainty	−0.125		0.120	−0.269		0.172															
Demand uncertainty	−0.318	***	0.091	−0.435	**	0.186															
Customers do not demand innovations	−1.694	***	0.063	0.064		0.123															
Control variables																					
Employees with university degree	0.296	***	0.067	0.399	***	0.071	0.150	**	0.069	−0.117		0.092	−0.252	**	0.104	0.010		0.073	−0.623	***	0.092
Capital per employee	−0.034	***	0.009	−0.014		0.010	−0.017		0.010	−0.008		0.013	−0.034	**	0.015	−0.031	***	0.011	−0.016		0.011
Exporter	0.077	***	0.026	0.121	***	0.026	0.053	**	0.026	0.024		0.034	−0.015		0.036	0.067	**	0.028	−0.095	***	0.035
Log number of employees	−0.038	***	0.011	0.000		0.017	−0.126	***	0.011	−0.084	***	0.016	−0.093	***	0.016	−0.087	***	0.012	0.065	***	0.013
Group	−0.080	***	0.027	−0.082	***	0.031	−0.169	***	0.028	−0.158	***	0.037	−0.152	***	0.040	−0.155	***	0.029	0.042		0.034
Constant	0.371	**	0.163	−0.851	***	0.295	0.701	***	0.162	−0.726	***	0.210	−0.494	**	0.230	−0.727	***	0.182	−1.284	***	0.201

Number of observations: 23,236; number of firms 5809; Wald Chi2 all coefficients of the explanatory variables equal zero 11,742 ($p = 0$). *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$. Standard errors robust and calculated with observations clustered around firms. All probit models include sector dummy variables (44). The null hypothesis that the coefficients for the sector dummy variables are equal to zero is rejected with $p < 1\%$.

Finally, from the results concerning the control variables, larger firms, in number of employees and as members of business groups are less likely to perceive the obstacles to innovate as high than smaller and independent firms, except for the *customers do not value the innovations* where the probability of perceiving the obstacle as high increases with the size of the firm. Firms that are exporters are also more likely to be financially constrained and to perceive the demand uncertainty as a high obstacle to innovate than non-exporters. Exporters probably perceive innovation as more important for their competitiveness than non-exporters.

5.2. Innovation Outcomes

We now turn to the explanation of the determinants of the innovation outcomes, probability that firms *introduce innovations* and probability that firms *abandon* ongoing innovation projects, from the results shown in the first two columns of Table 5. Notice that except for the variable *subsidies*, the estimated coefficients of the innovation resource input variables are positive and significant for the two dependent variables, probability that a firm introduces an innovation (success) and probability that abandons an innovation project (failure). The results are consistent with findings in other related research on the determinants of innovation outcomes [15,16,42]. We interpret the evidence that firms that dedicate more resources to innovate are also firms more likely to report both success and failures in innovation outcomes than firms that dedicate fewer resources to innovate as evidence supporting the hypothesis that firms with more innovation resources initiate more innovation projects that firms with less innovation resources.

The estimated coefficients of the time dummy variables are negatively and statistically significant in the probit with dependent variable *introduce innovations*. Since the excluded time dummy is that of the period 2006–2008, peak of the expansion period, the empirical evidence supports the hypothesis that the introduction of technological innovations is more likely in expansions than in recessions (pro-cyclical behavior). This result would be consistent with the demand demand-pull effect in the likelihood of introducing innovations. The estimated coefficients of the time dummy variables in the probit with dependent variable *abandons* are negative expect for the period 2009–2011 when is positive and statistically significant. The coincidence in the negative sign of the estimated coefficients of the variables *DT-5*, *DT-14* in the two probit estimations, would be consistent with the hypothesis that in recessions fewer firms initiate innovation projects than in expansions and consequently fewer firms will declare having introduced innovations and having abandoned innovation projects at the same time, in recessions than in expansions. If introduction of innovations and the abandons decrease in the same proportion than the decrease in the number of initiated projects, the proportion that abandon will be stable over time and therefore the perceived risk of the innovation projects at the time when they are initiated projects would be stable too.

The estimated positive coefficient of the time dummy *DT-11* in the probit of *abandon* and the negative estimated coefficient of the same time dummy variable in the probit *introduce innovations* is interpreted as evidence consistent with the risk effect from surprises (negative in this case) along the cycle. The crisis that started in 2008 was a surprise for the firms, negative unexpected shock, and they responded to the negative shock reducing the number of initiated projects, which is captured by the negative sign of the coefficient in the probit of *introduce innovations* (first column). But firms respond to the negative surprise with the abandon of innovation projects that were initiated under more favorable macroeconomic expectations, and this is reflected in the positive coefficient of the time dummy in the probit of abandon (second column).

The negative estimated coefficients of the obstacle variables *no access to external finance* and *demand uncertainty* in the probit of *introduce innovations* and in the probit of *abandons* would indicate that firms that perceive these two obstacles as high initiate fewer innovation projects than firms that do not perceive them as high. The perception about the obstacles conditions the decision on the initiation of projects, not so much the likelihood of success and failure of the ongoing ones (which would be the case if the coefficients of the obstacles variables had opposite sign in the probit of success than in the probit of failure). Combining these results with those from Table 4 we find supportive evidence of the obstacles channel effect of the cycle in the probability that firms introduce innovations: In the crisis, the proportion of firms that perceive the *no access to external finance* and *demand uncertainty* as high obstacles to innovate, increases (Table 4). This increase implies that fewer firms initiate innovation projects in the crisis than in the expansion and, finally, with similar risk of failure, the proportion of firms in the whole sample that introduce innovations in the crisis is lower than the proportion that introduce innovations in expansions.

From the estimated coefficients for the control variables, the probability of *introducing innovations* and the probability of *abandon* increase with the proportion of *employees with university degree* and with the firm being an *exporter* and decrease among firms that belong to a business group. Hence, the likelihood of initiating innovation projects is higher among firms with more employees with university degree, among exporters and among independent firms than otherwise. The growing proportion of exporters over time (Table 4) is then positive for increasing the innovation activity of firms, but the growing proportion of firms belonging to groups (Table 4) will have the opposite effect. The estimated coefficient of the size variable *number of employees* in the probit of *introduce innovations* is negative and significant. We obtain this result controlling for the quantity of innovation resource inputs of the firms in the sample, which increase with the size of the firm. The negative sign of the size variable could then be interpreted as evidence of diseconomies of size: Larger firms dedicate more resources to produce innovations than small firms but the efficiency in transforming knowledge into innovations decreases with size. The probability of abandon is not correlated with the number of employees of the firms (size variable).

5.3. Abandon in Conception and in Development

We re-estimate the multiprobit (1) with *abandon* separated into *abandon in conception* and *abandon in development* ($K = 8$). Table 6 shows the results of the two probit models of the respective abandon variables. The other six probit models estimations are omitted because they do not contain information different from that presented in Table 5. The positive estimated coefficients of the innovation resource input variables are maintained except for the variable *subsidies* with positive estimated coefficient in the probit of *abandon in conception* and negative in *abandon in development.* It appears that firms that receive public subsidies for their innovation activity are more conservative in the selection of the innovation projects in the stage of conception than firms that do not receive subsidies. For this reason, in the development stage the rate of abandon is lower in firms that receive subsides than in firms that do not (in Table 5 receiving subsidies or not does not affect the overall probability of abandon).

The increase in abandons in 2009–2011 with respect to the abandons in 2006–2008, attributed to the unanticipated higher risk in the first years of the crisis is distributed evenly in conception and development. The same can be said about the reduction in abandons attributed to the decrease in the number of firms that initiate innovation projects in the crisis, in 2012–2014 with respect to 2006–2008. However, in the years of upturn 2003–2005 after the crisis of the dot.com, fewer firms abandon in conception and more in development compared with those that do abandon in each stage in 2006–2008 (consolidated economic growth). Maybe in the upturn firms are over optimistic in the conception stage and initiate projects that do not pass the viability test in the development stage.

In contract with Table 5, where only firms that perceive as high the *financial* and the *demand uncertainty* obstacles have lower probability of abandon, in Table 6 all the obstacles variables have an estimated coefficient with negative sign in one or the other probit estimation.

Table 6. Estimated coefficients of the explanatory variables of the probit models on the likelihood that firms report that abandon in conception or abandon in development are presented, from the estimation of multiprobit (1) and $K = 8$. The results of the probit models on the firms perceive as "high" each of the five obstacles, and on the firm introduces innovations are not presented because they are similar to the presented in Table 5.

	Abandons Conception			Abandons Development		
	Coef.		**Std. Err.**	**Coef.**		**Std. Err.**
Innovation resource inputs						
R&D capital stock per employee	0.018	***	0.005	0.015	***	0.005
Cooperation in innovation	0.446	***	0.028	0.351	***	0.027
Training for innovation	0.321	***	0.033	0.309	***	0.033
Subsidies	0.088	***	0.028	−0.082	***	0.032
Economic Cycle						
DT-05	−0.167	***	0.025	0.058	*	0.03
DT-11	0.058	**	0.027	0.051	*	0.03
DT-14	−0.058	**	0.027	−0.068	**	0.03
High obstacle:						
No access external finance	−0.339	*	0.185	−0.578	***	0.177
Not finding right employees	−0.353	**	0.169	−0.09		0.237
Technological uncertainty	0.01		0.183	−0.614	***	0.164
Demand uncertainty	−0.516	***	0.135	0.086		0.238
Customers do not demand innovations	−0.358	**	0.148	0.204		0.144
Control variables						
Employees with university degree	0.418	***	0.077	0.376	***	0.074
Capital per employee	−0.01		0.012	−0.017		0.011
Exporter	0.117	***	0.028	0.105	***	0.028
Log number of employees	0.018		0.018	−0.005		0.016
Group	−0.089	***	0.032	−0.037		0.032
Constant	−1.286	***	0.297	−0.964	***	0.269

Number of observations: 23,236; number of firms 5809. Wald Chi2 all coefficients of the explanatory variables equal zero 14631 ($p = 0$). *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$. Standard errors robust and calculated with observations clustered around firms. All probit models include sector dummy variables (44). The null hypothesis that the coefficients for the sector dummy variables are equal to zero is rejected with $p < 1\%$.

5.4. Correlations among the Residuals of the Probits

Table 7 presents the correlations among the residuals of the seven probits from the estimation of multiprobit (1) with $K = 7$. Most of the correlations are positive and statistically significant. The positive signs mean that there are omitted explanatory variables, incorporated implicitly in the error terms of the probit models that correlate positively among them and with the dependent variable of the respective probit model. They are also interpreted as evidence of "complementarity" among the perceptions about the obstacles as high, and among these perceptions and the probability that firms introduce innovations or abandon innovation projects [16]. The common denominator of the complementarity could be that all firms that perceive any obstacle as high share the characteristic of being more engaged in innovation activities than firms otherwise. The statistical significance of the estimated correlations indicates that the complementarity is sufficiently strong to justify the joint estimation of the multiple probits in the single multiprobit estimation.

The exceptions in the signs of the correlation coefficients appear in the bottom line that shows the correlations of the residuals of probit on the obstacle *customers do not value innovations*, and the residuals from the rest of the probit estimations. Now some correlations are positive and others negative. For example, the negative correlation between the residuals of the probit of *customers do not value innovations* and the residuals of the probit of *abandons* would indicate that unobserved shocks that increase the probability of perceiving the obstacle as high are negatively correlated with shocks that increase the probability of abandon (firms do not take high risks in the projects they undertake when customers do not value innovations). The negative correlation with the residuals of the probit perceiving as a high the obstacle *not having access to external finance* could indicate that the shocks that increase the value of the innovations for the customers (lower probability that the obstacle will be perceived as high), also contribute to reduce the probability that the suppliers of these customers will be financially constrained.

Table 7. Estimated correlations of the residuals in the multiprobit model.

	Intro. Innovation		Abandon		Finance		Employees		Technical Uncertainty		Demand Uncertainty	
Introduction innovation	1											
Abandon	0.283	***	1									
No access to external finance	0.366	***	0.488	***	1							
Not finding the right employees	0.114	**	0.346	***	0.268	***	1					
Technical uncertainty	0.168	***	0.355	***	0.260	***	0.735	***	1			
Demand uncertainty	0.294	***	0.455	***	0.323	***	0.306	***	0.353	***	1	
Customers do not demand innovations	0.612	***	-0.139	**	-0.198	***	0.026		0.053	*	0.120	***

*** $p < 1\%$; ** $p < 5\%$; * $p < 10\%$.

5.5. Robustness

The robustness exercise consists in comparing the results of testing the predictions on the three channels of influence of the business cycle in the innovation output of firms with the multiprobit model in Table 5, with the results obtained estimating each probit model independently from the rest. If the simultaneity and interdependence among innovation outcomes and innovation constraints were not present in the generation of the sample data, the results of the two estimation methods would be similar.

The results of the estimated single probit models are presented in Appendix B. They present important differences with the results in Table 5 from the multiprobit estimation. First, the estimated coefficient of the time dummy variable D-11 in the probit of *abandons* that in Table 5 is positive and significantly different from zero, in the single probit estimation changes to not statistically significant (Appendix B). This means that the single probit estimation of the determinants of the probability that firms abandon innovation projects does not detect the risk channel effect of the cycle in the probability that firms introduce innovation, while the multiprobit estimation finds evidence that supports the risk channel effect. The second relevant difference in the results from single probit and multiprobit estimations is that, in the single probit (Appendix B), the estimated coefficients of the explanatory variables, perceiving the obstacles to innovate *not having access to external resources* and the obstacle *demand uncertainty* as high are positive and statistically significant, while in the multiprobit (Table 5) they are negative and significant. Therefore, the single probit estimation would not support empirically the hypothesis that the business cycle affects the probability of firms introducing innovations through the obstacles channel, while the multiprobit estimation empirically supports the obstacles channel effect of the business cycle.

6. Conclusions

Firms dedicate time and resources to the creation of knowledge that will be applied to the development and introduction of technological innovations. The timing in the use of the cumulated knowledge, with the introduction of new products, processes and organizational designs, is a critical step of the innovation process because it is the time for obtaining private (higher profits for the innovating firm) and social (the spill over in the economy of knowledge incorporated in the innovations introduced by the firm) returns from the innovation efforts. The decline in the number of firms that introduce technological innovations in the crisis rose concerns among national governments and supranational organizations. The decrease in business innovation output not only did not contribute to an earlier recovery from the recession but it could deeper on it and be negative for long-term prospects of economic growth.

In this paper we use the Spanish case to test the general proposition that the business cycle influences the propensity of firms to introduce innovations through three channels: The aggregate demand, the risk and obstacles to innovate channels. The results of the analysis support the following explanation of the fall in the propensity to introduce innovations by Spanish innovating firms in the crisis: First, the fall in aggregate demand reduced the number of firms that initiate innovation projects, as if could be expected from the demand-pull motives for business innovation (aggregate demand channel). Second, the outburst of the crisis was not fully anticipated by firms in the decision to initiate innovation projects and there were surprises (negative shocks) that led firms to cancel and abandon ongoing innovation projects (risk channel). Third, the crisis increased the number of firms that perceived as high obstacles to innovate not having access to external finance and the uncertainty about the demand for the innovations; the evidence indicates that firms that perceive the obstacles as high have lower propensity to initiate innovation projects, which shows up in the data in the form of lower probability to introduce innovations and lower probability of abandons (obstacles to innovation channel).

The results that support the three channels of influence of the business cycle in the innovation output of Spanish firms come from the estimation of a multiprobit with seven nested probits: One for the probability to introduce innovations, one for the probability of abandons and five for the probability of perceiving as high the respective obstacle to innovate of a list of five potential obstacles. There are a priori reasons that justify the multiprobit estimation as a way to account for the interdependency and simultaneity among decisions of introduce innovations and abandons, and these decisions and the perceptions as high of the innovation obstacles. And the empirical evidence corroborates the relevance of taking them into account in the estimation method: the estimation of the single probits as if the interdependencies would not exist, would had let undetected the risk and the obstacles effect channels that were detected by the multiprobit estimation.

There are no reasons to believe that the three channels of influence of the business cycle in business innovation output is a unique feature of the Spanish economy. However, to the best of our knowledge the joint evaluation of the three channels is new in the literature so it would be important to replicate the study with data from other countries. The literature review section includes references to papers with evidence supporting the pro-cyclical propensity to invest in R&D and to introduce innovations with data from other countries, but nothing is known about abandons along the cycle. And the co-movement of propensity to introduce innovations and propensity to abandon as indication of the evolution of the propensity to initiate innovation projects has not been considered so far. There is evidence also from other countries that the financial obstacles reduce the propensity to introduce innovations. But the transmission of the business cycle effects into the propensity to innovate through the effect of the business cycle in the probability that firms perceive the obstacles to innovate as high is new in the literature. Finally, we are unaware of previous analysis of the risk channel effect as defined here (unanticipated surprises along the cycle).

Policy actions intended to minimize the effect of the business cycle in the innovation output of firms should address the singularity of each channel of influence. Monetary and fiscal policies that stabilize the cycle will help to stabilize the innovation output and in turns the stabilization of the innovation output may reinforce the stabilization effects of monetary and fiscal policies. During the Great Recession the Spanish economy went through a severe austerity program of public spending and investment that clearly depressed the aggregate demand. The evidence of this paper in support of the aggregate demand channel effect of the cycle in the innovation output of firms, suggests that the austerity in public spending in Spain in the middle of the crisis could had been responsible, at least in part, that a good number of firms that were introducing innovations in the years previous to 2008, stopped doing so in the years of the crisis. The lower propensity to introduce technological innovations by Spanish firms in the crisis, together with the important "brain drain" that took place during the same time period lowered the stock of knowledge capital of the Spanish economy and with it the prospects of future sustainable growth. Therefore, the results of the paper highlight the importance of public policies that prevent severe contractions in aggregate demand for sustainable innovation and economic growth.

The risk channel is more difficult to tackle but something could be done with public programs of support to innovation activities, flexible to accommodate many different situations and rapid to execute that would help firms to assimilate the unanticipated negative shocks. There is tentative evidence of certain conservativeness in the public subsidies to innovation (firms that receive subsidies abandon more in the conception than in the development so it seems that public subsidies do not stimulate riskier but also more ambitious innovation projects). Maybe if firms knew that they could get some public support to respond to contingences appearing surprisingly in the development stage then they would be willing to take more risks in the conception stage. The financial constraints seem to matter for business innovation output and these constraints are countercyclical (more tightening in recessions). Public programs of financial support to innovation activities should be countercyclical too (increasing the funds available in recessions) in order to soften the constraints when more needed.

The paper has grouped product, process and organization innovations into a single heading of technological innovation. Although it would be of interest to test if the business cycle channels work the same for each type of innovation or not, this research is limited by the fact that information on abandon and on the effect of the obstacles to innovate refers to innovations. That is the Spanish CIS data does not specify if the projects abandoned are innovation in product or in process, neither provides information on whether the financial or other obstacles to innovate condition the same way or not product and process innovations.

The paper restricts the analysis to how the innovation activity of firms responds to external demand shocks and more particularly to the shocks in the transition from years of high economic growth to the years of the Great Depression. One line of extension of the research could be adding supply shocks, idiosyncratic to markets, industries or firms, together with the demand shocks from the evolution of the business cycle common to all firms, in the analysis of how firms' innovation decisions react to the out of equilibrium situation created by these perturbations [51]. The analysis in this paper only considers differences on how firms' innovation outcomes respond to the stages of the business cycle depending on whether the firms perceive the obstacles to innovate as high or not. The extension of the research could contemplate other sources of differences, for example size, age and growth of firms.

Author Contributions: The authors worked together along the research. Per structure: conceptualization and methodology, V.S.-F. and J.O.; software, validation, resources, data curation, investigation J.O.; formal analysis, V.S.-F. and J.O.; original draft preparation, V.S.-F.; writing-review & editing V.S.-F. and J.O.; supervision, project administration and funding acquisition, V.S.-F.

Funding: The research was funded by Government of Aragón, grant number CREVALOR: S42_17R—FEDER 2014–2020 "Construyendo Europa desde Aragón, and by Spanish Ministry of Economic Competitiveness-FEDER, grant number ECO 2017-86305-C4-3-R.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A Comparison of Database of This Study with the Whole PITEC Database

In this appendix we present the comparison of the values of the variables for the whole simple of firms included in the PITEC database with the values of the variables in the balanced panel data of our study. The summary of information is presented in the following table.

The number of firms in the database decreases over time, although the main decrease occurs in the period from 2012–2014 with 30% firms less than in the previous three years period. The 5809 firms in the balanced data panel represent 81.3% of the firms in the PITEC database in 2014.

After 2008 the proportion of firms that introduce innovations and the proportion of firms that abandon innovation projects both decrease. In 2012–2014, 44.77% of the firms introduced innovations, two-thirds of those that did in 2006–2008. The number of firms that abandons innovation projects also decreases with the crisis. Compared with the data in Table 1 of the study, the proportion of firms that introduce innovations and that abandon ongoing innovation projects is lower in the PITEC sample than in the subsample of firms in this study. This is the consequence of the bias towards potential innovators in the database of this study. However, the ratio of abandonment to introductions of innovations at the bottom of the above table shows a very similar pattern over time to the ratio in Table 1. Something similar can be said about the ratio of abandonment in development to that in conception.

	2005	**2008**	**2011**	**2014**
Number of firms	12,179	11,275	10,074	7146
Introduce innovations (%)	69.70	67.09	56.02	44.77
Abandon (%)	21.75	20.68	19.41	15.35
Year average R&D expenditures (Euros)	57,225	59,554	58,912	58,125
Cooperate (%)	28.91	26.46	24.62	23.82
Training (%)	13.39	9.33	11.58	8.84
Subsidies (%)	38.24	30.31	25.84	22.66
Exports (%)	44.29	44.97	52.26	55.71
Employees per firm	294.35	323.49	316.20	393.09
Obstacles high (%)				
Financial	25.51	29.45	35.87	22.86
Personnel	10.48	10.94	8.83	5.47
Technical Uncertainty	7.23	7.36	5.74	3.79
Demand Uncertainty	17.79	21.71	25.11	15.49
Customers do not Demand	11.35	10.22	10.28	6.99
Abandon/Introduce	0.312	0.308	0.346	0.343
Abandon Development/Conception	1.169	0.842	0.887	0.810

The next information in the table above refers to the resource inputs; once again the time pattern of values of these variables are similar to those in Table 4. Once again the message is that the decrease in the resource inputs during the crisis is much less pronounced than the decrease in innovation output, which would reinforce the importance of the aggregate demand effect.

The subsample of firms in the balanced panel that export to a greater degree and on average have more employees than the firms in the PITEC database, although the time trends in the proportion of exporters and average employees per firm are similar in the two samples.

The final block of variables in the table above is the proportion of firms that perceive the respective obstacles as high. It shows values not too different from those in Table 3 with practically identical time trend.

Appendix B

Table A1. Separate probit estimations on the probability that a firm introduces a technological innovation (first column), and on the probability that a firm abandons an ongoing innovation project (second column).

	INNOVATION			ABANDON		
	Coef.		**Std. Err.**	**Coef.**		**Std. Err.**
Innovation resource inputs						
R&D capital stock per employee	0.083	***	0.004	0.020	***	0.006
Cooperation in innovation	0.830	***	0.031	0.384	***	0.031
Training for innovation	0.913	***	0.057	0.309	***	0.038
Subsidies	0.296	***	0.028	−0.049	*	0.026
Economic cycle						
DT-05	−0.083	***	0.025	0.031		0.031
DT-11	−0.167	***	0.025	**−0.003**		**0.023**
DT-14	−0.440	***	0.028	−0.079	***	0.033
High obstacle:						
No access external finance	**0.153**	***	**0.026**	**0.188**	***	**0.030**
Not finding right employees	−0.058		0.049	0.045		0.052
Technological uncertainty	0.020		0.065	0.023		0.061
Demand uncertainty	0.032		0.036	0.160	***	0.028
Customers do not demand	−0.613	***	0.045	−0.228	***	0.045
Control variables						
Employees with university degree	0.421	***	0.087	0.417	***	0.081
Capital per employee	−0.022	**	0.010	−0.002		0.013
Exporter	0.092	***	0.027	0.109	***	0.027
Log number of employees	−0.022		0.014	0.066	***	0.012
Group	−0.042		0.028	0.004		0.028
Constant	−0.344	**	0.161	−1.792	***	0.176

Number of observations: 23,236; number of firms 5809. Wald Chi2 all coefficients of the explanatory variables equal zero 3590 ($p = 0$), column one, and 1445 ($p = 0$) column two. *** $p < 1\%$, ** $p < 5\%$, * $p < 10\%$. Standard errors robust and calculated with observations clustered around firms. The two probit models include sector dummy variables (44). The null hypothesis that the coefficients for the sector dummy variables are equal to zero is rejected with $p < 1\%$. In bold, the independent probit estimated coefficients of explanatory variables that are different from the coefficients of the same explanatory variables in the multiprobit estimation in Table 5 of the main text.

References

1. European Commission. *Monitoring Industrial Research: The 2011 EU Industrial R&D Investment Scoreboard*; Publications Office of the European Union: Luxembourg, 2011.
2. OECD. *OECD Science, Technology and Industry Outlook 2012*; OECD Science, Technology and Industry Outlook; OECD: Paris, France, 2012; ISBN 9789264170322.
3. Archibugi, D.; Filippetti, A.; Frenz, M. Economic crisis and innovation: Is destruction prevailing over accumulation? *Res. Policy* **2013**, *42*, 303–314. [CrossRef]
4. Cirillo, V.; Pianta, M.; Nascia, L. Technology and Occupations in Business Cycles. *Sustainability* **2018**, *10*, 463. [CrossRef]
5. D'Este, P.; Amara, N.; Olmos-Peñuela, J. Fostering novelty while reducing failure: Balancing the twin challenges of product innovation. *Technol. Forecast. Soc. Change* **2016**, *113*, 280–292. [CrossRef]
6. Pakes, A.; Griliches, Z. *Patents and R&D at the Firm Level: A First Look*; Univ. Chic. Press: Chicago, IL, USA, 1984; pp. 55–72.
7. Crepon, B.; Duguet, E.; Mairessec, J. Research, Innovation And Productivity: An Econometric Analysis At The Firm Level. *Econ. Innov. New Technol.* **1998**, *7*, 115–158. [CrossRef]
8. Hall, B. Innovation and Productivity. *Nord. Econ. Policy Rev.* **2011**, *2*, 167–204.
9. Blundell, R.; Griffith, R.; Reenen, J. Van Dynamic Count Data Models of Technological Innovation. *Econ. J.* **1995**, *105*, 333–344. [CrossRef]

10. Crépon, B.; Duguet, E. Estimating the Innovation Function from Patent Numbers: GMM on Count Panel Data. *J. Appl. Econom.* **1997**, *12*, 243–263. [CrossRef]
11. Martinez-Ros, E.; Labeaga, J.M. Modelling Innovation Activities Using Discrete Choice Panel Data Models. In *Innovation and Firm Performance*; Palgrave Macmillan: London, UK, 2002; pp. 150–171.
12. Lööf, H.; Heshmati, A. Knowledge capital and performance heterogeneity: A firm-level innovation study. *Int. J. Prod. Econ.* **2002**, *76*, 61–85. [CrossRef]
13. Parisi, M.L.; Schiantarelli, F.; Sembenelli, A. Productivity, innovation and R&D: Micro evidence for Italy. *Eur. Econ. Rev.* **2006**, *50*, 2037–2061.
14. Criscuolo, C. Innovation and Productivity: Estimating the Core Model Across 18 Countries. In *Innovation in Firms: A Microeconomic Perspective*; OECD, Ed.; OECD: Paris, France, 2009; ISBN 9789264056206.
15. Baldwin, J.; Lin, Z. Impediments to advanced technology adoption for Canadian manufacturers. *Res. Policy* **2002**, *31*, 1–18. [CrossRef]
16. Galia, F.; Legros, D. Complementarities between obstacles to innovation: Evidence from France. *Res. Policy* **2004**, *33*, 1185–1199. [CrossRef]
17. Lööf, H.; Mairesse, J.; Mohnen, P. CDM 20 years after. *Econ. Innov. New Technol.* **2017**, *26*, 1–5. [CrossRef]
18. Mohnen, P.; Palm, F.C.; van der Loeff, S.S.; Tiwari, A. Financial Constraints and Other Obstacles: Are they a Threat to Innovation Activity? *Economist (Leiden)* **2008**, *156*, 201–214. [CrossRef]
19. Madrid-Guijarro, A.; Garcia, D.; Van Auken, H. Barriers to Innovation among Spanish Manufacturing SMEs. *J. Small Bus. Manag.* **2009**, *47*, 465–488. [CrossRef]
20. Silva, M.J.; Leitao, J.; Raposo, M. Barriers to innovation faced by manufacturing firms in Portugal: How to overcome it for fostering business excellence? *Int. J. Bus. Excell.* **2008**, *1*, 92. [CrossRef]
21. García de la Vega, M.L.; López, A. *Cuadernos de Economía y Dirección de la Empresa (CEDE)*; Minerva Ediciones: Madrid, Spain, 2010.
22. Galia, F.; Mancini, S.; Morandi, V. Obstacles to innovation: What hampers innovation in France and Italy? *Res. Policy* **2012**, *41*, 482–488.
23. Blanchard, P.; Huiban, J.-P.; Musolesi, A.; Sevestre, P. Where there is a will, there is a way? *Assessing the impact of obstacles to innovation. Ind. Corp. Chang.* **2013**, *22*, 679–710. [CrossRef]
24. D' Este, P.; Iammarino, S.; Savona, M.; von Tunzelmann, N. What hampers innovation? *Revealed barriers versus deterring barriers. Res. Policy* **2012**, *41*, 482–488.
25. Galí, J.; Hammour, J.L. *Long Run Effects of Business Cycles*; Papers 92-26; Columbia—Graduate School of Business: New York, NY, USA, 1992.
26. Aghion, P.; Saint-Paul, G. *On the Virtue of Bad Times: An Analysis of the Interaction between Economic Fluctuations and Productivity Growth*; Cambridge University Press: Cambridge, UK, 1991; Volume 2.
27. Schumpeter, J. *Capitalism, Socialism and Democracy*; Harper and Brothers: New York, NY, USA, 1942.
28. Hall, B. *Investment and Research and Development at the Firm Level: Does the Source of Financing Matter?* NBER Working Paper No. 4096; The National Bureau of Economic Research: Cambridge, MA, USA, 1992.
29. Hall, B. The Financing of Research and Development. *Oxford Rev. Econ. Policy* **2002**, *18*, 35–51. [CrossRef]
30. Himmelberg, C.P.; Petersen, B.C. R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries. *Rev. Econ. Stat.* **1994**, *76*, 38.
31. Rafferty, M.; Funk, M. Asymmetric effects of the business cycle on firm-financed R&D. *Econ. Innov. New Technol.* **2008**, *17*, 497–510.
32. Czarnitzki, D.; Hottenrott, H. R&D investment and financing constraints of small and medium-sized firms. *Small Bus. Econ.* **2011**, *36*, 65–83.
33. Aghion, P.; Askenazy, P.; Berman, N.; Cette, G.; Eymard, L. Credit constraints and the cyclicality of R&D investment: Evidence from France. *J. Eur. Econ. Assoc.* **2012**, *10*, 1001–1024.
34. Schumpeter, J. *The Theory of Economic Development*; Harvard University Press: Cambridge, MA, USA, 1934.
35. Arrow, K.J. *Economic Welfare and the Allocation of Resources for Invention*; Princeton University Press: Princeton, NJ, USA, 1962.
36. Schmookler, J. *Invention and Economic Growth*; Harvard University Press: Cambridge, MA, USA, 1966.
37. Geroski, P.A.; Walters, C.F. Innovative Activity over the Business Cycle. *Econ. J.* **1995**, *105*, 916. [CrossRef]
38. Martinsson, G.; Lf, H. *Impact of Economic Crises on Innovation Activity: Firm Level Evidence from Patent Data*; Centre of Excellence for Science and Innovation Studies: Stockholm, Sweden, 2009.

39. Hingley, P.; Park, W.G. Do business cycles affect patenting? Evidence from European Patent Office filings. *Technol. Forecast. Soc. Change* **2017**, *116*, 76–86. [CrossRef]
40. Nickell, S.; Nicolitsas, D.; Patterson, M. Does Doing Badly Encourage Management Innovation? *Oxf. Bull. Econ. Stat.* **2001**, *63*, 5–28. [CrossRef]
41. Berchicci, L.; Tucci, C.L.; Zazzara, C. The influence of industry downturns on the propensity of product versus process innovation. *Ind. Corp. Chang.* **2014**, *23*, 429–465. [CrossRef]
42. Iammarino, S.; Sanna-Randaccio, F.; Savona, M. The perception of obstacles to innovation. Foreign multinationals and domestic firms in Italy. *Rev. d'Écon. Ind.* **2009**, *125*, 75–104.
43. Tourigny, D.; Le, C.D. Impediments to innovation faced by Canadian manufacturing firms. *Econ. Innov. New Technol.* **2004**, *13*, 217–250. [CrossRef]
44. Mohnen, P.; Röller, L.-H. Complementarities in innovation policy. *Eur. Econ. Rev.* **2005**, *49*, 1431–1450. [CrossRef]
45. Savignac, F. Impact of financial constraints on innovation: What can be learned from a direct measure? *Econ. Innov. New Technol.* **2008**, *17*, 553–569. [CrossRef]
46. Hottenrott, H.; Peters, B. Innovative Capability and Financing Constraints for Innovation: More Money, More Innovation? *Rev. Econ. Stat.* **2012**, *94*, 1126–1142. [CrossRef]
47. Freel, M.S. Are Small Innovators Credit Rationed? *Small Bus. Econ.* **2007**, *28*, 23–35. [CrossRef]
48. Ivashina, V.; Scharfstein, D. Bank lending during the financial crisis of 2008. *J. Financ. Econ.* **2010**, *97*, 319–338. [CrossRef]
49. Iyer, R.; Peydró, J.-L.; da-Rocha-Lopes, S.; Schoar, A. Interbank Liquidity Crunch and the Firm Credit Crunch: Evidence from the 2007–2009 Crisis. *Rev. Financ. Stud.* **2014**, *27*, 347–372. [CrossRef]
50. Antonelli, C.; Crespi, F.; Scellato, G. Internal and external factors in innovation persistence. *Econ. Innov. New Technol.* **2013**, *22*, 256–280. [CrossRef]
51. Antonelli, C.; Scellato, G. Out-of-equilibrium profit and innovation. *Econ. Innov. New Technol.* **2011**, *20*, 405–421. [CrossRef]