

Economic crisis, innovation and organizational responses: evidence from Brazil

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Abstract

The economic crisis of 2008 resulted in a unique context for the empirical experimentation of organizational learning theories and patterns of technological accumulation from Schumpeterian inspiration. This paper investigates the effects of the economic crisis on the innovative performance of firms. We examine an original database with the patent portfolio of 2309 firms based in Brazil, covering a period of eight years preceding the 2008 economic crisis and the five years thereafter. Our finds add to the literature in two ways. First, we exhibit evidence that despite the positive relationships between exploitation and exploration behaviour and innovative performance widely described in the extant literature, in periods of crisis this relationship is curvilinear, in that former exerts diminishing negative effects on the latter. Second, from the literature that perceives a clear division between creative destruction and creative accumulation, our results tend to support the thesis in favour of the existence of a creative accumulation, although consistent with the notion of co-occurrence of both models. The article concludes by highlighting what we have learnt from this experience and suggesting some new avenues for research.

JEL Classification: E32; G01; L25; O31; O32; Q55

Keywords: Economic crisis; Innovation performance; Creative destruction; Exploitation and exploration.

Resumo

A crise econômica de 2008 resultou em um contexto único para a experimentação empírica de teorias de aprendizagem organizacional e padrões de acumulação tecnológica de inspiração Schumpeteriana. Este artigo investiga os efeitos da crise econômica no desempenho inovador das firmas. Examinamos um banco de dados original com o portfólio de patentes de 2309 firmas com sede no Brasil, cobrindo um período de oito anos antes da crise econômica de 2008 e os cinco anos posteriores. Os resultados se somam à literatura de duas maneiras. Em primeiro lugar, apresenta-se evidências de que, apesar das relações positivas entre exploração e exploração e desempenho inovador amplamente descrito na literatura existente, em períodos de crise essa relação é curvilínea, pela qual a primeira exerce efeitos negativos decrescentes sobre a segunda. Segundo, partindo da literatura que percebe uma divisão entre destruição criativa e acumulação criativa, nossos resultados tendem a apoiar a tese em favor da existência de um processo de acumulação criativa, embora consistente com a noção de coexistência de ambos os modelos. O artigo conclui destacando o que aprendemos com essa experiência e sugerindo novas possibilidades de pesquisa.

Classificação JEL: E32; G01; L25; O31; O32; Q55

Palavras-chave: Crise econômica; Desempenho inovativo; Destruição criativa; Exploração e exploração.

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1. Introduction

The 2008 economic crisis has stimulated a series of studies analysing how the innovative activity is affected by a scenario of huge uncertainties about the direction of technological change, demand conditions, and new market opportunities. Evidence suggests the existence of substantive changes in the firm innovation process during the downturn (Amore 2015; Teplykh 2018). One of the most outstanding changes is the sharp reduction of the firm's willingness to undertake innovation investments (OECD 2009; Paunov 2012; Archibugi, Filippetti, and Frenz 2013b, 2013a).

From a perspective of industrial dynamics, economic downturns cannot be interpreted as extended periods of technological stability and continuity. Despite the obstacles imposed by the credit crunch, economic turmoil may result in significant changes in the future trajectory of innovation. The dynamics of innovation during recessions is seized by those firms who aspire to innovate during recessions¹, especially for the possibility to improve its market position in the post-crisis period (Amore 2015).

Following the Schumpeterian tradition, the unfolding of the crisis unleashes a process of low cumulativeness and high technological opportunity, so-called creative destruction². The literature argues that innovation is a result of the novel integration of previously separate bodies of knowledge that has a commercial application. Accordingly, a crisis is a relevant context for firms to *exploit* existing knowledge and in this way to increase their productivity and efficiency, but also to *explore* new fields of knowledge and thus engage in experimentation and variation.

Although our intuition makes us believe that a Great Recession opens the way to generalized disruptions, changes in the environment are also driven by continuity where the bulk of technological transformations is carried out by large and established firms incrementally. Evidence suggests that the 2008 crisis resulted in a great concentration of innovative resources in fewer companies and old innovators have taken advantage of the turbulent environment (Archibugi, Filippetti, and Frenz 2013a).

The recent crisis has resulted in a unique context for empirical experimentation of these approaches, however, there remain gaps in the understanding if in periods of crisis there are significant changes in the organizational responses that affect their innovative performance. At the same time, there is a lack of studies that address how this performance during the crisis is affected by characteristics of the firm and markets (such barriers to entry) and type of knowledge sources. Much of the evidence in this regard is disconnected or unrelated to the effects of economic crises.

The objective of this paper is to provide quantitative evidence on these questions by means of a unique dataset on the patent portfolio of 2309 firms based in Brazil, covering a period of eight years preceding the 2008 economic crisis and the five years thereafter. Brazil is a relevant context for the purposes of this research given its productive heterogeneity and the existence of structural factors which able to mitigate the effects of the economic downturn when compared to its neighbours in Latin America. Nevertheless, the country is perceived as late industrializing economies, where the process of technical change is essentially a learning process, rather than of innovation (Viotti 2002).

The rest of this paper is structured as follows. In the second section, we review the literature and discuss the conceptual framework. The third section describes the data and presents the methodology. Main empirical results, robustness tests and extensions are provided in Section 4. Finally, Section 5 discusses the

¹ The Booz & Company (2009) survey showed that during the recession 90% of executives remarked that investment in innovation is critical to prepare for the upturn.

² This process is related to the insights proposed by the author in *Theory of Economic Development* (Schumpeter 1911). Archibugi (2013a) draws attention that the term was first employed in *Capitalism, Socialism and Democracy* (Schumpeter 1942) in which emphasis is placed on the opposite process of creative accumulation.

organizational responses and the patterns of accumulation and destruction after the crisis and also concludes with the implications of our analysis.

2. Theory and hypotheses

The 2008 economic crisis has encouraged an immediate response by policymakers to avoid a collapse of the financial and banking systems and boundary the economic effects of the credit crunch. The effects on the firm were inevitable and most firms responded to hostile macroeconomic scenario reducing expenditure on investment and innovation and the commitment to engage in long-term activities (Archibugi, Filippetti, and Frenz 2013a, 2013b; Paunov 2012).

Overall, we can say that investments in innovation carried out by the private initiative are largely procyclical and decrease significantly during economic downturns (OECD 2009). Evidence suggests that the negative effect of the global crisis was widely perceived in European firms that reduced innovation expenditure between 2006 and 2008 (Filippetti and Archibugi 2010; Archibugi, Filippetti, and Frenz 2013b). Regarding Latin American, even though the innovation performance remained strong during the crisis with more than one in three firms innovated in processes and about 24% introduced new products, the shock might have had negative effects on firms' innovation paths since on average one in four firms cut back on innovation projects. The main causes reported abandoning innovation investments are the demand shock and financing constraints associated with the crisis (Paunov 2012).

However, this process is heterogeneous and the share of firms stopping innovation projects due to the economic crisis is quite different between countries. The work of Filippetti and Archibugi (2010) reveals that some country structural factors such as competences and quality of the human resources, the specialization in the high technology sector and the extent of the financial system can counterbalance the effect of the economic downturn on innovation investments. In order to illustrate this heterogeneity, we can adopt Latin America as an example. While Argentina and Mexico accounted for the highest percentage of firms stopping innovative investments, respectively 43% and 36%, on the other extreme Uruguay and Brazil realized the lowest share, with 16% and 12% respectively (Paunov 2012).

Similar studies also reveal that non-financial obstacles to innovation such as market structure, demand, knowledge are at least as important as financial barriers for affecting innovation propensity (Pellegrino and Savona 2017). The provision of an efficient credit system in a crisis context is relevant because there is evidence that innovative firms find it harder to access finance than other firms (Lee, Sameen, and Cowling 2015). Estimates suggest that during the crisis, EU manufacturing firms benefiting from research subsidies did not reduce the intensity of their total R&D expenditures but, by taking advantage of public grants, they preserve their innovative capability (Aristei, Sterlacchini, and Venturini 2017).

If we investigate the crisis from a different perspective, we observe the share of firms that “swimming against the stream” and respond to the crisis through the expansion of investments and innovation. The performance of these firms may be the result of two possible scenarios. They can be the most dynamic ones that cannot survive without changing their products and services or are newcomers and not necessarily involved in innovations in the pre-crisis period (Archibugi, Filippetti, and Frenz 2013a). Despite the last scenario, there is evidence that previous experience with innovation during downturns improves the firm's ability to invest in R&D when a new depression hits (Amore 2015). In an econometric study, Sidorkin and Srholec (2014) reveal that pre-crisis innovation affects the firm survival odds and performance thereafter. However, firms that innovate excessively before the crisis turned out to be far more likely to die.

In an innovative dynamics through crises, the organizational responses contrast meaningfully according to firm size. In general, large firms have greater potential to deal with the shortcomings created by the crisis and are most capable to react, although specific situations must be recognized. Evidence indicates that

larger firms reacted to the crisis by making larger investments in both the expansion in international markets and new product development (Colombo et al. 2016). Nevertheless, studies also show that small firms display a relative growth advantage compared to larger firms in both stable and crisis times, and this is due to the flexibility benefit of small size (Bartz and Winkler 2016).

2.1 Innovation performance and limits for the exploitation and exploration

The study of how exploitation and exploration strategies affect innovation performance has become a frequent topic and has evolved from the stream of research that investigates the relationships between exploitation, exploration and innovation performance (Greve 2007; He and Wong 2004; Jansen et al. 2006). Assuming that innovation is a recombination process by which knowledge components are mixed and matched, ones would assume that the crisis can lead to two types of organizational responses. First, the high level of uncertainty may lead firms to undertake the local search within the knowledge that lies around the organization's current knowledge base. In other words, local search means to combine the combining existing solutions to generating new combinations. In the face of a financial crisis, the exploitation of existing knowledge may represent the most efficient mode due to its reliability and relatively low costs. Second, the crisis can also generate opportunities for knowledge combination and recombination and provide completely new solutions. From the non-local search, the firm is enabled to consciously move away from current organizational routines and knowledge bases (Katila and Ahuja 2002).

The pioneering innovation studies perceive organizational routines as an important rule of firm behaviour, which can be defined as a standardized set of embedded rules and heuristics, or even “pieces” of activities that have a repetitive character (Dosi, Nelson, and Winter 2001). At some point, firms “[...] have built into them a set of ways of doing things and ways of determining what to do” (Nelson and Winter 1982, 400). Since the routines are not immutable, firms perform search activities whenever they need to “evaluate the current routines that lead to their modification, changes or replacement” (Nelson and Winter 1982, 400). However, scholars also acknowledge that there are limits to the flexibility of such behaviour and that a changing environment may force firms to risk their own survival in attempts to modify their routines.

Traditionally, this pioneering literature emphasizes that these search processes are performed locally (Dosi 1982; Nelson and Winter 1982; Patel and Pavitt 1997). Firms need to capture the maximum advantage of the set of knowledge they domain, which requires focus, or at least coherence, rather than the random distribution of their efforts. The search process is mostly local since it tends to take place along trajectories established by past experience, routines and heuristics (Nelson 1991; Winter 1984). Thus, it emphasizes the firm's tendency to focus on technological fields that share the same knowledge base and similarity in problem-solving (Dosi 1982; Nelson and Winter 1982; Patel and Pavitt 1997). The main argument for the prevalence of local search is the cost of dominate specialized knowledge in the contemporary world, an example is the large firms that have knowledge in a large number of technological fields (Pavitt 1998; Cantwell and Fai 1999).

While pioneering innovation literature has emphasized the local character of search processes, it is possible to perceive changes in the focus of interpretations on firm behaviour throughout the subsequent literature. Laursen (2012), in an overview of the main empirical contributions on the topic, has identified that the focus on local search processes have increasingly shifted towards the focus of how the firms balance the local search with the non-local search. These later contributions, while recognizing that search processes remain largely local, tend to understand how firms can avoid the “local search trap” and balance local and non-local search.

The exploitation behaviour (local search) can be a dominant strategy in different conjunctures. In contexts where high complexity prevails in solving problems, the tendency to exploit can be justified by two main reasons. The first is the existence of a limited rational behaviour (Simon 1997) which makes the agents

incapable of considering all the possible options for the solution of their technological problems and also unable to accurately assess future performance prospects for potential options. Such factors make the evaluation of alternatives tend to be imperfect (Knudsen and Levinthal 2007). On the other hand, as a consequence of the local search trap, the firm reduces its competence to deal with future paradigms, even though it is developing capabilities that improve its current performance.

At the other extreme of exploitation behaviour, exploration increases the variety of firm's knowledge by supporting strategies to minimize the risk of obsolescence, which may become a reality after an economic stagnation. In particular, exploration behaviour that tends to capture emerging opportunities in crisis scenarios, have been associated with the development of discontinuous solutions and, ultimately, new technological trajectories (March 1991; Gavetti and Levinthal 2000; Fleming 2001). This brief context leads us to our first conjecture:

Hypothesis 1a. *As a result of a crisis, the association between the degree of exploitation and innovation performance is curvilinear, in that former exerts diminishing negative effects on the latter.*

Hypothesis 1b. *As a result of a crisis, the association between the degree of exploration and innovation performance is curvilinear, in that former exerts diminishing negative effects on the latter.*

2.2. Balancing of exploitation and exploration

The ability of firms to balance exploitation and exploration –so-called organizational ambidexterity (see, Lavie et al., (2010), for an expansion) – is a critical element for maintaining its performance over time and deal with fluctuations in the economic landscape (Katila and Ahuja 2002; He and Wong 2004; Wang, Vrande, and Jansen 2017). Put differently, ambidexterity refers to an organization's ability to manage current demands while being adaptable to changes in the environment (Gibson and Birkinshaw 2004; Tushman and O'Reilly 1996).

It is widely accepted in the literature the idea that firms must “engage in enough exploitation to ensure the organization's current viability and engage in enough exploration to ensure its future viability” (Levinthal and March 1993, 105). Even though exploitation and exploration behaviours are complementary actions that tend to reinforce each other as they co-occur over time, they can also generate persistent tensions in the firm context (Koryak et al. 2018).

Firms take advantage of the context of uncertainty about demand conditions create by a crisis to incorporate new knowledge and shape their own market opportunities. Those firms that are able to combine new knowledge with existing knowledge are more likely to offer the market something new and distinctive. When the knowledge that is new to a firm increases technological variation, which is valuable for finding better solutions to technological problems (Katila and Ahuja 2002). In addition, incorporating new knowledge into an innovation is likely to open up previously undiscovered technological opportunities and potential, which may attract more firms or inventors to follow. Therefore, inventions that draw on some new knowledge are likely to be of higher quality than those that only recombine existing knowledge (Wang, Vrande, and Jansen 2017). This leads us to conjecture:

Hypothesis 2. *The interaction of the degree of exploitation and exploration during the crisis is positively related to innovation performance.*

2.3 Crisis and the coexistence of creative destruction and creative accumulation

Innovative activities observed during and after an economic crisis are shaped in different ways across industries and technologies. The literature shows that there are two possible scenarios for this process. In the first, the innovative activities are fashioned by new firms that start to innovate in these periods. These firms may be smaller in size and/or entirely new and contest the technological leadership of incumbents. In the second, these activities are led by incumbents, which tend to be large in economic terms and use their accumulated knowledge to accomplish innovation as a routine and prevent the entrance of newcomers.

The theoretical foundations of this scenario are based on the original distinction between two main works of Schumpeter (1911, 1942) that authors of this theoretical tradition conventionally have labelled Schumpeterian models Mark I and Mark II (Nelson and Winter 1982; Kamien and Schwartz 1982; Freeman, Clark, and Soete 1982). This characterization has been extensively adopted in the literature and continues to have critical implications to interpret the patterns of technological change after an exogenous shock (Archibugi 2017). The empirical relevance is understanding the innovative activities that are characterized by “creative destruction” resulting from the turbulence generated by entry of new innovative firms in the market and those innovative activity characterized by “creative accumulation” as result of incumbent’s activity that use its technological position to innovate persistently and create barriers for newcomers to exploit technological opportunities (Archibugi, Filippetti, and Frenz 2013a).

Those scholars engaged in measuring these patterns and defined the model Mark I by low concentration and asymmetries of innovative activities, the small size of innovators, low stability in the ranking of innovators and high entry of new innovators. Conversely, the model Mark II is defined as high concentrations and asymmetries of innovative activities, the large size of innovators, high stability in the ranking of innovators and low entry of new innovators. The main findings are that these patterns are at the same time systematically different across technological classes and very similar at the country level. The technological regimes, defined in terms of opportunity, appropriability, cumulateness and properties of the knowledge-base play a dominant role in determining the specific pattern of innovative activities of a technological class (Malerba et al. 1995; Malerba and Orsenigo 1996; Malerba, Orsenigo, and Peretto 1997).

An economic crisis may also be associated with a high degree of turbulence in existing industries. In this context, the high technological opportunities and low cumulateness make easier the entry and exit in technological areas. The monopolies generated by innovation are temporary and new innovators constantly replace the technological leadership of the established firms (Anderson and Tushman 1990; Christensen and Rosenbloom 1995; Archibugi, Filippetti, and Frenz 2013a). These firms may be smaller in size and/or entirely new and contest the technological leadership of incumbents. This scenario generates turbulences caused by a change in leading technologies disturb the hierarchy of innovators and the emergence of new technologies (Malerba and Orsenigo 1999; Perez 2009). Note that in some cases, the technological discontinuities are driven entirely by incumbents also may result in dramatic shakeouts in industries. Some incumbents are capable of absorbing new technologies and integrating them with their existing capabilities (Bergek et al. 2013). These ideas lead us to state:

Hypothesis 3. Increase in innovation performance during the crisis is positively associated with firm size, new entrants, and stock of knowledge.

3. Methods

3.1 Data and sample

In order to test our hypotheses, we developed a unique database based on information on patent data from the Brazilian National Institute of Industrial Property (Inpi) from the first version of the Intellectual Property Database for Statistical Purposes (Badepi). The Badepi database was elaborated at the level of 2309 firms based in Brazil, excluding institutions and individual inventors. It was also adopted firm-level micro-data from the Orbis database in order to discriminate these firms for their economic size and main sectors. We emphasize that we do not use granted patents, partly because the Brazilian Patent Office publishes the patent data within a few months after the application, while a grant may last several years. Consequently, if our sample were based on granted patents we would lose relevant observations.

3.2 Measures

3.2.1 Dependent variable

Our dependent variable is the innovation performance of firms (INNOVPER). Innovation performance has been measured in various ways in the literature, such as R&D expenditure, the number of new products, and patents. In line with prior studies, we use the cumulative number of patents applied for by a focal firm within the five years after the 2008 crisis. A five-year time window is perceived as suitable for assessing the firm's performance (Henderson and Cockburn 1996; Nooteboom et al. 2007; Stuart and Podolny 1996). When the firm records a large portfolio of these patents, we have argued that the greater their innovative performance.

This empirical proposal is widely accepted in the literature, despite this fact it is valuable to recognize some limitations. First, patent-based indicators are imperfect proxies of innovative performance. Patents are only one of the ways to protect a knowledge and inventors can avoid patenting for reasons of secrecy, avoiding their public disclosure, or even to not incur the costs of their registration (Cohen, Nelson, and Walsh 2000). On the other hand, there are few cases of economically important inventions that have not been patented (Dernis, Guellec, and Van Pottelsberghe De La Potterie 2001).

Second, there are differences in sectoral propensities to patent that may vary according to technological regimes. These differences are also caused by variations in the rigour with which patent offices apply intellectual property rights. Thus, increased patenting activity may reflect a greater innovative performance but also a greater propensity to grant a patent (Cohen, Nelson, and Walsh 2000). In this article, the adoption of the Brazilian office as the exclusive source of data and the use of appropriate methodologies partially solves this problem.

3.2.2 Independent and control variables

According to the purpose of this work, we focus on two groups of explanatory variables in which we believe to explain the international inventive performance of firms. The first group refers to the degree of exploitation and exploration undertaken by the firm and the second to its capacity of assimilation and stock of knowledge. In the first group of variables, we were inspired by previous studies (Ahuja and Katila 2004) and operationalized the degree of exploitation and exploration by the intensity in which the firm reuses or incorporates new IPCs in its patent portfolio, in the period pre and post 2008 crisis.

The variable degree of exploitation (INEXPLOIT) describes the accumulation of practice with the same knowledge. We state that the more frequently a firm has used knowledge, the more deeply it knows it. Hence, the degree of exploitation was measured as the average number of times a firm repeatedly used the IPC in the patents it applied for. The variable degree of exploitation is operationalized by calculating the

number of times that, on average, each IPC in the five years post-crisis was repeatedly used compared to eight years pre-crisis.

The variable degree of exploration of new knowledge (INEXPLOR) is the proportion of IPC used for the first time in the post-crisis compared to the eight years prior to the crisis. We suggest assessing the share of IPCs during this period that was not on the list of patents applied by that firm in the eight years prior to the crisis. The values for this variable range from 0 to 1.

The measure of the degree of exploitation and exploration can be exemplified by considering a firm with a portfolio of ten patents that are related to ten IPCs. On average, eight of the ten IPCs are new to the firm, in other words, they were used for the first time during the five years. The firm's exploration degree is therefore 0.8. Of the remaining two IPCs that were repeated, the firm used each patent one of them twice and the other three times. Therefore, the degree of exploitation for this firm is 0.5.

The second group of independent variables tests the explanatory potential of the assimilation capacity (ASSIMCAP). We operationalized this variable by measuring firms' patent portfolio dispersion across four-digit IPC. This choice is based on organizational research and innovation management. An example of this theoretical foundation is provided by Lane, Koka and Pathak (2006) when claiming that "the breadth of knowledge that a firm understands determine how far its exploratory learning can venture from its existing knowledge base".

The greater the dispersion of a firm's technological profile, the higher its ability to assimilate external technologies in distant, unacquainted knowledge domains. We estimate this ability by the complement to one of the Herfindahl index applied to firm patent portfolio composition. This index reflects the degree of dispersion of the green patents across different technological (four-digit IPC) classes and varies between 0 and 1: $1 - \sum_{i=1}^n \alpha_i^2$ where α_i is the share of patents in green IPC class i in the firm stock of patents. The higher the index, the broader the scope of the firms' technological expertise and therefore, the more likely it will be able to enter new technologies. Firms with a dispersed green patent portfolio have learned to manage different technologies and therefore should display a better ability to enter into a new technological field compared with firms endowed with a narrow green technological portfolio.

Firms with different portfolio sizes have different inventive performances. We control the stock of knowledge of firms through the number of patents accumulated in pre-crisis periods (KSTOCK). The construction of this variable is originally inspired by the accumulation function of Popp (2012), but excluding the diffusion component, as proposed by Costantini e Mazzanti (2012). In the same way, as agreed by the literature, this variable considers a depreciation rate of 15% (Hall, Jaffe, and Trajtenberg 2005).

We further suggested controls for large firms, in which some would expect to have a greater ability to deal with the crisis environment, from the creation of dummies for medium-sized, large and very large firms. We control for firm size by creating a categorical variable based on the number of employees less than 15 (small firm), between 15 and 150 (medium firm), between 150 and 1,000 (large firm), and greater than 1,000 (very large firm)³. We also control the possible effects that can occur within the sector of performance of the firms, using the 12 NACE Rev.2 sections. Both control variables were constructed from the extraction of the Bureau van Dijk database (Orbis 2013).

³ Considering that Orbis microdata combine several databases, it is possible that this categorical variable is also obtained by total assets or operation revenue.

3.3 Econometric method

Given that our dependent variable is a count variable with non-negative integer values, we employ the negative binomial (NB) model. In patent-based studies, where over-dispersion in the data are often observed, this model is more appropriate than a Poisson regression, where the variance of the random variable must be constrained to equal the average (Greene 2012). Thus, the use of a negative binomial model to analyse count data to control heterogeneity has a long tradition in the literature (Hausman, Hall, and Griliches 1984). The data of this study has demonstrated significant evidence of overdispersion since the variances largely exceed the relative averages (See Table 2).

Furthermore, to control for this overdispersion in the data, we report results with robust standard errors. While the reverse causality problem is not an immediate concern of our model, we recognize that the omitted variable bias is capable of affecting our estimates. In order to partially address this problem, we included a set of control variables that consider the firm size and economic activities.

4. Results

As discussed, the main dependent variable of the model is a count variable with non-negative integer values and able to estimate the innovative performance (INNOVPER). The empirical exercises have as main independent variables the degree of exploitation (INEXPLOIT) and exploration (INEXPLOR), and also the assimilation capacity (ASSIMCAP) and knowledge of stock (KSTOCK). In order to analyse the non-linear relations between innovation performance and degree of exploitation and exploration, we convert both last into a quadratic variable. We predict that search exploitation and exploration leverage each other, yielding a combined positive effect on innovation performance. Therefore, we multiply the former by the later and interpret it as a moderating effect.

The other variables control the firms that are medium (DMEDIUM), large (DLARGE) and very large (DVLARGE), the number of technological classes (NCLASS) in the patent portfolio and their economic sectors based on NACE Rev.2 sections. In order to control the effect of newcomers, the variable (DNEWCO) was proposed. Table 1 describes the variables were chosen to compose the regression models.

Table 1 – Description of variables.

Variable name	Description
INNOVPER	Index of innovative performance – count of patents applications in the five years after the 2008 crisis.
INEXPLOIT	Index of the degree of exploitation – the number of times that, on average, each IPC in the post-crisis was repeatedly used compared to eight years pre-crisis.
INEXPLORA	Index of the degree of exploration – the proportion of IPC used for the first time in the post-crisis compared to the eight years prior to the crisis.
ASSIMCAP	Assimilation capacity – measured by the breadth of the firm portfolio (complement of the HHI).
KSTOCK	Firm knowledge stock – number of patents accumulated by the firm in the eight years prior to the crisis.
NCLASS	Number of technological classes in the firms' patent portfolio.
DNEWCO	Dummy indicating the newcomers who innovate in the post-crisis.

Table 2 provides descriptive statistics and correlations for all variables. We emphasize that are a few values in the correlation table that exceed 0.5. We check the variance inflation factor (VIF) values for all variables and find that VIFs for our models are all less than 7. Therefore, we assume that there does not seem to be a risk of biased estimated due to their multicollinearity.

Table 2 – Descriptive statistics and correlations.

Variable	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7
1. INNOVPER	2.34	9.77	1	405	1.00						
2. INEXPLOIT	0.45	1.97	0	65	0.31	1.00					
3. INEXPLORA	0.90	0.26	0	1	-0.09	-0.48	1.00				
4. ASSIMCAP	0.25	0.29	0	0.98	0.16	0.11	-0.13	1.00			
5. KSTOCK	1.30	9.70	0	404.6	0.58	0.29	-0.23	0.15	1.00		
6. NCLASS	6.93	31.53	1	1252	0.79	0.42	-0.20	0.18	0.91	1.00	
7. DNEWCO	0.74	0.43	0	1	-0.12	-0.39	0.63	-0.39	-0.22	-0.20	1.00

Regarding the econometric estimates of the relationship between innovative performance, organizational responses (exploitation and exploration), Table 3 presents the negative binomial estimates of the coefficients. The econometric exercises begin with the Model 1 which reports estimation results for the baseline model. Models 1-5 we include the explanatory variables of interest one-by-one along with the controls, while Model 6 contain all variables and interactions. For the sake of simplicity, we focus our discussion on the full model in column 6.

The models 1-6 reveal that the variable INEXPLOIT is positive and in the majority significant. Considering the prediction of a curvilinear association between degree of exploitation and innovation performance, the hypothesis 1a is supported. In the Model 6, the variable INEXPLOIT squared is negative and significant ($\beta = -0.003$ and $p < 0.001$). Similar results were also found for the degree of exploration which supports its curvilinear relationship with the innovative performance predicted in hypothesis 2b. In the Model 6, the variable INEXPLOR squared is negative and significant ($\beta = -1.309$ and $p < 0.05$).

The inverted U-shaped relationship reveals that the dependent variable y_i first increases relative to the independent variable x_i at a decreasing rate until it reaches a maximum point, from which y_i decreases at an increasing rate as x_i continues to increase. To provide evidence of a U-shaped relationship, the dependent variable y_i is regressed on the independent variable x_i and its square. The most common specification of this equation in its quadratic form is given by:

$$y_i = \alpha + \beta x_i + \gamma x_i^2 + \xi' z_i + \varepsilon_i \quad (1)$$

Thus, a negative γ with statistical significance indicates an inverted U-shaped relationship and a positive U-shaped γ only. However, a significant γ coefficient is a necessary but not sufficient condition to establish a quadratic relation. In response to this condition, this paper performed the three stages of the tests for the diagnosis of the U-shaped relationship suggested by Lind and Mehlum (2010). In all cases, the tests suggested corroborated the diagnosis of the existence of an inverted U-shaped relationship.

Hypothesis 2 predicts that during the crisis the interaction of the degree of exploitation and exploration exerts a moderating effect and leverage each other. In this case, the results are inconclusive both in terms of the positive or negative relation form and significance. In Models 4 and 6 the relationship with the innovative performance is negative but Model 5 is positive. Moreover, only in models 5 and 6 the variable has significance. Consequently, this hypothesis cannot be supported.

Pertaining to Hypothesis 3, we test the idea that innovation performance during the crisis is positively associated with firm size, new entrants, and stock of knowledge. The dummies for firm size control reveal that there is a positive relationship between innovative performance and medium (DMEDIUM), large (DLARGE) and very large (DVLARGE) firms but there is significance only for firms of large and very large size. Regarding the relationship between innovative performance and the role of newcomers

(DNEWCO), the results are inconclusive. There seems to be a positive relationship between variables, but it is not significant in most models. Still, on this hypothesis, the stock of knowledge (KSTOCK) seems to have a negative relationship with the innovative performance, which contradicts our initial intuition. However, in all models, this variable has no significance at conventional levels.

Table 3 – Negative binomial regressions: determinants of the innovative performance

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
INEXPLOIT		0.155*** (0.04)		0.186*** (0.05)	0.021 (0.04)	0.202*** (0.05)
INEXPLOR			1.930*** (0.42)	0.254* (0.13)	0.968* (0.56)	1.680*** (0.56)
INEXPLOIT x INEXPLOR				-0.030 (0.04)	0.122*** (0.04)	-0.082* (0.04)
INEXPLOIT squared		-0.002*** (0.00)		-0.003*** (0.00)		-0.003*** (0.00)
INEXPLOR squared			-2.022*** (0.47)		-1.117** (0.55)	-1.309** (0.56)
ASSIMCAP	1.081*** (0.09)	1.220*** (0.15)	1.092*** (0.09)	1.200*** (0.16)	1.181*** (0.14)	1.190*** (0.15)
KSTOCK	-0.014 (0.01)	-0.013 (0.01)	-0.013 (0.01)	-0.013 (0.01)	-0.008 (0.01)	-0.012 (0.01)
NCLASS	0.017** (0.01)	0.012 (0.01)	0.014** (0.01)	0.012 (0.01)	0.010 (0.01)	0.011 (0.01)
DNEWCO	-0.129* (0.08)	0.128** (0.06)	0.063 (0.07)	0.066 (0.07)	0.143* (0.08)	0.118 (0.08)
DMEDIUM	0.029 (0.04)	0.020 (0.04)	0.037 (0.04)	0.024 (0.04)	0.035 (0.04)	0.029 (0.04)
DLARGE	0.160*** (0.06)	0.148** (0.06)	0.177*** (0.06)	0.150** (0.06)	0.178*** (0.06)	0.159** (0.06)
DVLARGE	0.407*** (0.10)	0.346*** (0.10)	0.361*** (0.09)	0.353*** (0.10)	0.353*** (0.09)	0.335*** (0.09)
NACE Rev. 2 sections						
B–Mining and quarrying	0.267 (0.32)	0.307 (0.32)	0.334 (0.35)	0.306 (0.32)	0.358 (0.35)	0.337 (0.34)
C – Manufacturing	0.301*** (0.10)	0.267*** (0.09)	0.338*** (0.11)	0.263*** (0.09)	0.310*** (0.11)	0.289*** (0.10)
D – Electricity and gas	0.049 (0.21)	0.098 (0.24)	0.004 (0.22)	0.097 (0.24)	0.048 (0.23)	0.066 (0.24)
E – Water supply	0.159 (0.14)	0.134 (0.14)	0.226 (0.15)	0.124 (0.14)	0.195 (0.15)	0.159 (0.14)
F – Construction	0.275* (0.15)	0.181 (0.15)	0.323* (0.17)	0.176 (0.15)	0.283* (0.16)	0.211 (0.14)
G – Wholesale and retail trade	0.183* (0.10)	0.126 (0.10)	0.222* (0.12)	0.120 (0.09)	0.192* (0.11)	0.144 (0.10)
H – Transportation and storage	0.179 (0.13)	0.183 (0.12)	0.253* (0.14)	0.168 (0.12)	0.233* (0.13)	0.202 (0.12)
I – Acc. And food services	-0.025 (0.15)	-0.080 (0.16)	0.003 (0.17)	-0.085 (0.16)	-0.033 (0.17)	-0.064 (0.16)
J – Information and comm.	0.241** (0.12)	0.180 (0.12)	0.275** (0.14)	0.171 (0.12)	0.236* (0.13)	0.192 (0.13)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
K – Fin. and insurance services	0.073 (0.13)	0.066 (0.14)	0.099 (0.14)	0.077 (0.13)	0.115 (0.14)	0.097 (0.13)
L – Real estate activities	0.151 (0.16)	0.121 (0.16)	0.185 (0.17)	0.112 (0.16)	0.160 (0.17)	0.133 (0.16)
M – Prof. sci. and tech. services	0.340*** (0.10)	0.271*** (0.10)	0.388*** (0.12)	0.267*** (0.10)	0.356*** (0.11)	0.297*** (0.10)
N – Adm. and support serv. act.	0.250** (0.12)	0.209* (0.12)	0.305** (0.14)	0.198* (0.12)	0.265** (0.13)	0.229* (0.12)
P – Education	-0.114 (0.12)	-0.109 (0.13)	-0.081 (0.16)	-0.122 (0.13)	-0.088 (0.15)	-0.112 (0.14)
Q – Human health	0.084 (0.16)	-0.052 (0.17)	0.165 (0.18)	-0.020 (0.17)	0.124 (0.19)	0.051 (0.17)
R – Arts, entertainment and recreation	0.191** (0.10)	0.160* (0.10)	0.219* (0.11)	0.151 (0.09)	0.198* (0.11)	0.168* (0.10)
S – Other service activities	0.131 (0.11)	0.110 (0.10)	0.170 (0.12)	0.100 (0.10)	0.152 (0.11)	0.122 (0.10)
Constant	-0.093 (0.12)	-0.309*** (0.12)	-0.222 (0.17)	-0.494*** (0.14)	-0.218 (0.15)	-0.682*** (0.15)
Inalpha						
Constant	-1.683*** (0.13)	-1.905*** (0.18)	-1.782*** (0.14)	-1.897*** (0.18)	-1.914*** (0.19)	-1.950*** (0.21)
Number of firms	2309	2309	2309	2309	2309	2309

Note: Robust standard errors in parentheses; * $p < 0,10$; ** $p < 0,05$; *** $p < 0,01$.

Our empirical exercise is subject to restrictions that need to be reported. First, we register a large number of newcomer firm, that is, those who innovate for the first time in the post-crisis period. At the same time, hypothesis 3 makes us question about the role of these firms in the innovative performance of the post-crisis. Second, since these firms do not have patent applications in the pre-crisis period, both degree of exploitation and degree of exploration will be dichotomous and will only take two values, zero for exploitation (since all IPC is not repeated) and one for exploration (given that all IPC is new for the firm). We analyse these possible restrictions by performing the same regression routines for a sample of 614 firms (henceforth so-called “persistent innovators”) and applied patents in both periods studied. Therefore, we aim to overcome the possible restrictions reported and make our results even more robust. The negative binomial estimates of these coefficients are reported in Table 4.

Table 4 – Negative binomial regressions: determinants of the innovative performance of persistent innovators.

Variables	Model 7	Model 8	Model 9	Model 10
INEXPLOIT		0.179*** (0.03)		0.215*** (0.04)
INEXPLOR			2.448*** (0.33)	2.041*** (0.34)
INEXPLOIT x INEXPLOR				-0.068* (0.04)
INEXPLOIT squared		-0.002*** (0.00)		-0.003*** (0.00)
INEXPLOR squared			-2.423*** (0.34)	-1.577*** (0.33)
ASSIMCAP	0.859*** (0.15)	1.274*** (0.23)	0.733*** (0.17)	1.039*** (0.25)
KSTOCK	-0.003 (0.01)	0.000 (0.01)	-0.000 (0.01)	0.003 (0.01)
NCLASS	0.013** (0.01)	0.006 (0.00)	0.010*** (0.00)	0.005 (0.00)
DMEDIUM	-0.218* (0.12)	-0.291** (0.12)	-0.188 (0.14)	-0.252* (0.13)
DLARGE	0.032 (0.14)	-0.065 (0.15)	0.058 (0.15)	-0.034 (0.15)
DVLARGE	0.276* (0.16)	0.017 (0.14)	0.165 (0.16)	0.001 (0.14)
B–Mining and quarrying	-0.269 (0.56)	-0.267 (0.52)	-0.175 (0.57)	-0.235 (0.51)
C – Manufacturing	0.446*** (0.13)	0.366*** (0.12)	0.575*** (0.17)	0.434*** (0.11)
D – Electricity and gas	0.393 (0.30)	0.483 (0.32)	0.421 (0.31)	0.488 (0.31)
E – Water supply	-0.429 (0.27)	-0.417 (0.33)	-0.130 (0.27)	-0.345 (0.29)
F – Construction	0.561 (0.56)	0.307 (0.48)	0.868 (0.55)	0.558 (0.52)
G – Wholesale and retail trade	0.334* (0.18)	0.160 (0.16)	0.488** (0.21)	0.229 (0.16)
H – Transportation and storage	-0.156 (0.25)	0.042 (0.21)	0.154 (0.26)	0.066 (0.22)
J – Information and comm.	0.417** (0.20)	0.312 (0.21)	0.551** (0.23)	0.354* (0.20)
K – Fin. and insurance services	0.135 (0.28)	0.162 (0.27)	0.272 (0.27)	0.296 (0.25)
M – Prof. sci. and tech. services	0.485*** (0.17)	0.296* (0.16)	0.653*** (0.20)	0.383** (0.15)
N – Adm. and support serv. act.	0.338 (0.23)	0.258 (0.23)	0.522** (0.26)	0.308 (0.23)
P – Education	0.001 (0.16)	0.041 (0.21)	0.116 (0.25)	0.044 (0.21)
Q – Human health	0.317 (0.34)	-0.001 (0.34)	0.641* (0.37)	0.354 (0.35)
Constant	0.029 (0.17)	-0.197 (0.17)	-0.235 (0.22)	-0.609*** (0.18)
lnalpha Constant	-1.025*** (0.15)	-1.422*** (0.16)	-1.163*** (0.16)	-1.486*** (0.17)
Number of firms	614	614	614	614

Note: Robust standard errors in parentheses; * $p < 0,10$; ** $p < 0,05$; *** $p < 0,01$.

As in the previous routine, the econometric exercises begin with the Model 7 that estimates the results for the baseline model. Models 8 and 9 include the explanatory variables one-by-one along and also controls, and the Model 10 contains all variables and interactions. The results presented in the models 8-10 reinforce

the first hypotheses of the existence of a curvilinear association between the degree of exploitation and exploration with innovation performance. From the Model 10 the variable INEXPLOIT squared is negative and significant ($\beta = -0.003$ and $p < 0.001$) and the variable INEXPLOR squared is negative and significant ($\beta = -1.577$ and $p < 0.001$). The evaluation of these coefficients for the sample of innovative persistent firms ensures robust results and eliminates doubt about the effects of reducing the variability of the explanatory variables of the newcomers. The variable assimilation capacity (ASSIMCAP) remains significant in all models and the variable stock of knowledge remains insignificant (KSTOCK). Dummies for large and very large firms remain positive but lose significance in most cases. Finally, we conclude the results on these two subsets are similar and do not impact on the conclusions that we draw from the results of the full sample.

5. Discussion and Conclusion

This study draws attention to the effects of the economic crisis on the innovative performance of firms. Moving beyond a broad literature dealing with these variables in aggregate terms, this paper proposes a firm-level approach with a focus on organizational responses. This objective requires a careful effort to investigate the links between macroeconomic effects and responses within firms. Therefore, we developed a unique database with the patent portfolio of 2309 firms based in Brazil, covering a period of eight years preceding the 2008 economic crisis and the five years thereafter.

The empirical results are manifold and are presented in two main groups. First, on organizational responses and the second on patterns of accumulation and technological destruction after the crisis. Our results reveal that after a crisis, the innovative performance is positively associated with the adoption of exploitative strategies that aim at the use of knowledge that was already applied by the firm in the period before the crisis. At the same time, this performance is also positively associated with the application of new knowledge and not used by firms before the crisis.

Previous literature has broad evidence of these results in other contexts, but the evidence of the curvilinear relationship is less conclusive. We exhibit evidence that despite these positive relationships, both exploitation and exploration strategies exert diminishing negative effects on innovative performance. We argue that uncertainties about technological trajectories and market conditions that arise after the instauration of a crisis, create obstacles to the continuity of exploitation and exploration strategies, reducing their effects on innovative performance.

Our results also show that in contexts of economic crisis, the balance between exploitation and exploration is not a guarantee of maintaining high innovative performance. This result draws attention to the importance of the contextual conditions that ensure some firms manage ambidextrous activities, that is, the capacity to encompass relatively high levels of both exploitation and exploration. This discussion also recognizes the high imperfection of this measure that it takes no account for the absolute level of exploitative and exploratory activities (Laursen 2012).

The second group of results is framed through two well-established scenarios: the creative destruction and creative accumulation. In order to establish these scenarios, we follow the literature that perceives a clear division between these dimensions and demonstrate that creative accumulation tends to prevail under normal conditions and creative destruction appears in times of crisis.

Our study examines these dimensions from three main characteristics. First, on the characteristics of firms, the innovative performance of firms in the post-crisis period is positively associated with the performance of firms of large and very large size. Second, regarding the high barriers to entry due to the relative importance of appropriation and accumulation of knowledge and high costs of innovation, our findings showed that there is no evidence that innovative performance is associated with newcomers. Finally, on the

relevance of past innovations and accumulated knowledge, the innovative performance does not seem to be positively associated with the stock of knowledge prior to the crisis (measured by cumulative patent applications).

The analysis of these characteristics allows us to conclude that established innovators are the most capable to seize opportunities and take advantage of turbulent environments (Archibugi, Filippetti, and Frenz 2013a). Nevertheless, the absolute number of newcomers in the post-crisis environment is also remarkable draws our attention to the low barriers to entry and the possible technological dynamics in subsequent periods.

Another possible conclusion is that post-crisis innovators are large and very large in economic terms. This result is the most expected because it reinforces a broad literature on the subject. However, the result that tests our intuition is that the previous stock of knowledge does not determine the innovative performance in the post-crisis period. Put differently, despite some level accumulated knowledge is required, ownership of a large stock of knowledge does not ensure the performance in these contexts. Similarly, this result seems to be similar to that found by Sidorkin and Srholec (2014) and Amore (2015).

Finally, although our evidence tends to support the thesis in favour of the existence of a creative accumulation, the scenario portrayed is more complex and consistent with the notion of co-occurrence of both creative destruction and creative accumulation (models Mark I and Mark II). This result is also in line with the idea put forth by Archibugi, Filippetti, and Frenz (2013a).

Our study broadens the extant research in the following directions. First, it contributes to the literature on the effects of economic expansions and depressions on firm-level innovative activity. In this research agenda, our study contributes to broadening our understanding of the relationships between macroenvironmental changes and organizational responses. Second, we contribute to the literature on technological search reporting empirical evidence of how far the relationship between innovative performance and technological search is maintained in different environmental contexts. This contributions also bears some implications for policy. While policy should support persistent innovators who make efforts even in adverse environments, this policy should also provide favourable environments to encourage new innovative firms.

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