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The impact of the 2008 financial crisis on innovation: A dominant design perspective

Alexander Brem[a], Petra Nylund[b], Eric Viardot[c,*]

[a] Friedrich-Alexander-University Erlangen-Nuremberg, NCT Friedrich-Alexander-University Erlangen, Chair of Technology Management, Dr.-Mack-Str. 81, 90762 Fuerth, Germany
[b] Friedrich-Alexander-University Erlangen-Nuremberg, NCT Chair of Technology Management, Dr.-Mack-Str. 81, 90762 Fuerth Fuerth, Germany
[c] EADA Business School, C/Aragó 204, 08011 Barcelona, Spain

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ABSTRACT

The purpose of this study is to evaluate the impact of the 2008 financial crisis on innovation, as measured by the emergence of dominant designs. A negative impact is substantiated theoretically and empirically, based on longitudinal patent data from the OECD. This study also finds evidence for the moderating impact of globalization on the relationship between innovative performance and the emergence of dominant design. Thus, globalization is more important with regard to the establishment of dominant designs than it was before the financial crisis of 2008. Further, it is found that following the crisis, science-based industries tend to have more dominant designs than other industries.

1. Introduction

The great financial crisis of 2008 is today considered to be one of the longest and most significant economic crises that the world has ever seen (Bordo & Haubrich, 2017). It has driven a dramatic change in the 21st century's business environment, which had already experienced the turbulent waves of the digital revolution, framed against a backdrop of steadily increasing globalization. Many factors contributed to this financial crisis, notably an increase in debt due to the introduction of novel financial instruments, the emergence of a housing (mortgage) bubble, irresponsible risk taking, and lax oversight (Hausman & Johnston, 2014a). The main effects of the crisis were a decrease—or slower economic growth—in industrial countries, persistently high unemployment, continuous private sector deleveraging, large public sector deficits and debts, much greater influence of politics on the economy, a significant lowering of inflation, very low interest rates, and an accelerated migration of growth and wealth dynamics into the emerging world (El-Erian, 2014).

As a result, the financial crisis of 2008 can be interpreted as the "gale of creative destruction", identified by Schumpeter (1942) in his theory of business cycles as the characteristic form of capitalist development, with a succession of upturns creating opportunities for profit and downturns providing scope for restructuring. (Tan & Mathews, 2010).

However, Schumpeter (1934) also considered that innovation was the engine of economic recovery and prosperity in capitalistic systems. Innovation plays a leading role in reigniting growth in economies and delivering new benefits to the world's population and its varied societies (Kim & Huarng, 2011). Today's neo-Schumpeterians emphasize that the unstable nature of the capitalistic system, and innovation, are two sides of the same coin (Archibugi, Filippetti, & Frenz, 2013). In light of this history, this study seeks to evaluate the effect that the ruthless and lengthy financial crisis of 2008 had on the innovation strategies of firms as they had to adapt to a sudden, and deeply turbulent business environment (Makkonen, Pohjol, Olkkonen, & Koponen, 2013).

The paper is organized as follows. First, a review of the literature on the 2008 financial crisis and the funding of new innovation is presented. Next, this paper introduces the concept of dominant design and how it acts as an indicator of innovation, which in turn leads to the development of several hypotheses. Based on this, a methodological approach is proposed and implemented, followed by a discussion of the results. Finally, this paper concludes with an analysis of any relevant limitations, and suggestions for further research.

2. Theoretical background

A key part of Schumpeterian creative destruction is related to the funding of new innovations. Schumpeter (1934) considers finance as

* Corresponding author at: Universität Stuttgart/University of Stuttgart, Institute of Entrepreneurship in Technology and Science, Pfaffenwaldring 19, D-70569 Stuttgart-Vaihingen, Germany.
E-mail addresses: alexander.brem@ets.uni-stuttgart.de (A. Brem), petra.nylund@fau.de (P. Nylund), eviardot@eada.edu (E. Viardot).

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essential to the innovation process, as the credit-driven money provided by financial institutions allows firms and entrepreneurs to invest in innovation.

Since Schumpeter, 1934 work, finance has been seen as an important part of innovation management, but the numerous studies exploring the finance-innovation relationship have so far yielded decidedly inconsistent conclusions.

One aspect of the literature follows Schumpeter's position, arguing that there is a positive relationship between finance and innovation as the financial system provides suitable resources for innovative projects. Furthermore, financing institutions can identify entrepreneurs with the best chance of developing an innovative product or service and they can also supervise them to ensure that the project will succeed (Amore, Schneider, & Zaldokas, 2013; Hsu, Tian, & Xu, 2014; King & Levine, 1993; Shang et al., 2017).

But other studies suggest that financial support may hinder innovation. For example, banks may prevent firms from exploring risky and high return projects such as R&D activities (Weinstein & Yafeh, 1998). Credit markets favor investment in reputable and well-established firms rather than in new or innovative ones because the risk of capital loss is lower (Morales, 2003). Additionally, the availability of credit makes it easier for less efficient firms to remain in the market, while also preventing more efficient innovators from entering said market—which contributes to the forming of a monopoly (Asimakopoulos & Zhu, 2018; Philippe, Peter, & Ross, 2018).

The impact of financing on innovation also depends on the institutional context (Levine, 2002). It is generally accepted that equity compared to debt is more appropriate for governmental R&D investment (Balakrishnan & Fox, 1993; Hill & Snell, 1988). Equity markets are well developed in "market-based" systems, such as in the UK and the US. However, many countries have bank-based systems, as seen in Japan, Germany and any other European countries where banks have a dominant role in the national economy and the financing of innovation (Vitols, 2005). James and McGuire (2016) have found that higher levels of bank loan debt coupled with higher levels of R&D investment increase firm performance in bank-based countries but decrease firm performance in market-based countries.

The effects of finance on innovation may also depend on the sophistication of a country's financial infrastructure development. Meierrieks (2014) for instance, found that higher levels of financial development coincide with stronger innovation activity, which is consistent with Schumpeteŕs view. However, in a more recent paper, Law, Lee, and Singh (2018) detected an inverted U-shaped finance-innovation curve in countries with high institutional quality. The early stages of financial development contribute positively to the innovation sector; however, the later stages of financing hinder innovative development because of an associated increase in the contractual interest rate on loans and the monopolization of financial institutions.

When studying the impact of the 2008 crisis on innovation, researchers have generally considered corporate investment into R&D. They too present mixed or even conflicting evidence. For instance, Paunov (2012) has found that the crisis led many firms in eight Latin American countries to cease ongoing innovation projects between 2008 and 2009. Younger companies and businesses supplying foreign multinationals or suffering export shocks were more likely to abandon innovation investments than companies with access to public funding.

In Europe, Archibugi et al. (2013) have observed a general decrease in the willingness to invest in innovation across European companies as a direct consequence of the 2008 financial crisis. However, many companies have avoided this trend and have kept their levels of investment constant. Furthermore, the research shows local variations between Northern and Southern European countries. In countries such as Sweden, Switzerland, Finland, and Germany the number of companies that have actually maintained or even increased investment in innovation is greater than the number of companies that have reduced it. The main reason for this is that some firms are highly specialized in areas where innovation is a key competitive advantage; they have to keep innovating in order to stay in business. Other research has also reported that some European companies have kept or increased their innovation investments after the shock of 2008 (Archibugi, 2017). They are mostly younger, smaller companies which are searching for new market opportunities, while older, larger companies are found to be less prone to invest in innovation. Further, the financial crisis of 2008 has increased the difficulty for companies of financing innovation.

More specifically, innovative firms have suffered more from the financial crisis than non-innovative firms, primarily due to the difficulty of raising external funds. Research based on a sample of 16,000 firms in Germany shows that innovative companies have reached the same reduction in growth rates in turnover, but a stronger reduction in investment growth than non-innovative firms in the aftermath of 2008 (Giebel & Kraft, 2015).

A similar situation has been observed in the UK where financing worsened for both innovative and non-innovative companies during the great financial crisis: innovative companies were less successful in achieving funding than other firms, and they were more likely to face absolute credit rationing (Lee, Sameen, & Cowling, 2015). In the same vein, a study of Korean companies (Chung, 2017) found a decrease in R &D investments after 2008, which further substantiates the idea that external financing of R&D investments had become more difficult for such companies, so they were required to use their internal financial resources.

2.1. Dominant designs and derivation of hypotheses

In view of the mixed evidence in the existing literature, one cannot conclude that the great financial crisis has a clear effect—positive or negative—on investments in innovation. However, innovation is not only a process but also an outcome (Quintane, Casselman, Reiche, & Nylund, 2011). In academic research, there is a term for describing a turning point in the industrial development of an innovation—dominant design (e.g., Anderson & Tushman, 1990).

A dominant design appears when a single (technological) design emerges with innovation occurring along a defined technological trajectory (Dosi, 2000) and becomes a market standard (Murmann & Frenken, 2006), which is accepted by competitors and innovators at the same time (Utterback, 1994). In terms of product lifecycle thinking, an industry is forced to standardize its core components following the emergence of a dominant design (Gawer & Cusumano, 2014). Earlier research indicates that such a shift from product to process innovation, initiated by a dominant design, can be found across many different industries (Brem, Nylund, & Schuster, 2016). Hence, a dominant design can be seen as an indicator of a key change in market development, since dominant designs are usually the result of (lengthy) competition within the market and help delineate the competitive dynamics of interfirm rivalry (Peng & Liang, 2016).

Such dramatic market changes are induced by open innovation activities (Chesbrough, 2003) and, especially, by related disruptive innovations (Christensen, Raynor, & McDonald, et al., 2015; Reinhardt & Gurtner, 2015). However, the concept of disruption has also received several notable criticisms; including, for example, if it makes sense to setup an external organization for disruptive innovations (Danneels, 2004). Christensen, McDonald, Altman, and Palmer (2018) propose a more detailed concept, including aspects like trajectories in performance, response options, platform economy, and innovation performance management metrics, which is in line with other authors such as Hopp, Antons, Kaminski, and Salge (2018). In this context, Markides (2006, p. 23) notes: "Eventually, the wave of entry subsides and in turn is followed by what is sometimes a sharp, sudden, and very sizeable shakeout leading to the death of most of the early pioneers. The shakeout is associated with the emergence of a dominant design in the market, which signals the beginning of growth in the industry".

Incumbent companies will most likely miss such industry growth, either because they have been too successful in pursuing their old business models (Christensen, 2003), or because the new design is too complex and the costs of adaption are too high (Roy & Sivakumar, 2010).

Hence, these firms are prisoners of their own success, and usually innovative start-ups will take their position in future iterations of the market. As a result, the emergence of a dominant design is a sign that a disruption has occurred: even if in a first run, dominant designs can be seen as a barrier to successful innovations, the new standards are still pitted against the dominant ones, which is not necessarily better (Assink, 2006). Hence, dominant designs can also be perceived as a hindrance to innovation. Specific niches must be found for new innovations, during periods of experimentation, so that they can get started, until new standardizations processes are developed in order to foster their respective technologies (Suarez & Utterback, 1995). Within this conception, dominant designs support an understanding of innovation systems with specific technology transitions, which can be achieved through niche-cumulation, technological add-on, and hybridization (Geels, 2002). Entrepreneurs and start-ups might serve as players who use their respective ecosystems to establish innovation in a niche to gain access to the main market (Brem & Radziwon, 2017). Moreover, it is important to note that dominant designs are not only driven by technologies, but also by markets and complementary assets (Fernández & Valle, 2019).

Srinivasan, Lilien, and Rangaswamt (2006) have shown that the probability of emergence of a dominant design depends on product characteristics—such as the appropriability of rents associated, the intensity of network effects, the degree of radicalness, and the R&D intensity—but also on the economic environment; more precisely, they found that “the presence of a recessionary environment delays the emergence of a dominant design” (page 9). Thereby, they define a recession as two consecutive quarters of decline in real gross domestic product (GDP). In the US, the recession following the financial crisis officially ended in June 2009, according to the National Bureau of Economic Research (2019) (2019), but many economists maintain that the crisis lasted much longer, extending to 2014 (El-Erian, 2014).

Hypothesis 1. The great financial crisis is negatively related to the emergence of dominant designs.

Furthermore, the great financial crisis had a direct effect on the globalization of business. The flow of global trade in goods, services, and finance had grown consistently before the financial crisis, representing 38 percent of global GDP in 1991, compared to 60.8 percent in 2008. However, it tumbled to 52.3 percent in 2009 and stayed below pre-crisis level till 2017 (World Bank. Trade % of GDP. (2018), 2018).

Globalization has a direct effect on innovation, especially for multinational enterprises (MNEs) (Hitt, Hoskisson, & Kim, 1997; Sambharya & Lee, 2014). It enables companies to access cheaper R&D inputs from developing countries, and to draw on valuable knowledge abroad (Lewin, Massini, & Peeters, 2009; Von Zedtwitz & Gassmann, 2002), specifically from international R&D partners with superior technological expertise and better opportunity to facilitate creativity (Nieto & Santamaria, 2007). Globalization also allows MNEs to additionally introduce new, radical products to the market (Roy & Sivakumar, 2010).

Further, globalization has given way to the emergence of global dominant designs (Spencer, 2003). The lead market theory suggests that among different innovation designs that are competing in international markets there is one that will be adopted by leading countries and thus become a dominant design that then diffuses globally (Beise & Cleff, 2004). However, innovative performance, defined as the cumulated results of innovative activities for a technology or product category, has been related to a reduced emergence of dominant designs (Brem et al., 2016). Technologies with high innovative performance thus takes longer to converge towards a dominant design, and when innovation is conducted by a large number of actors in different countries—such as MNEs from emerging countries (Lynch & Jin, 2016)—the convergence is further delayed. The decrease of globalization in the great crisis should have strengthened this relationship. Therefore, the following hypothesis is formulated.

Hypothesis 2. During the great financial crisis, globalization of innovation had a moderating effect on the relationship between innovative performance and dominant design so that innovative performance had greater impact on dominant design for higher values of globalization.

Industries vary in their mode of technical innovation. Pavitt (1984) distinguishes *supplier–dominated* sectors (e.g. agriculture, building, mining, commerce, etc.) where the limited innovations come mostly from suppliers, while in *scale-intensive* (cement, glass, transportation, etc.) and *specialized-suppliers* (e.g., machinery production) industries, innovation is led mostly by larger companies. Finally in *science-based* industries, innovation comes from the R&D activities of all firms.

While science-based industries are not homogeneous, dominant design has a key role; as some industries, including aerospace, electrical equipment, and pharmaceuticals, have already concentrated around one dominant design—which has become a standard. More recent sectors, including computers, software, telecommunication, robotics, biotechnology, etc., engage in sequential competition through new product versions. In these latter industries, dominant designs from leading firms tend to spread rapidly until they are replaced by new dominant designs from competitors with more innovative products (Niosi, 2000).

During the 2008 financial crisis, science-based industries had grown faster than other classes of industry. For instance, in March 2018 the four largest global companies by market capitalization were science-based; namely Apple, Alphabet, Microsoft and Amazon, while in March 2009 they were supplier-dominated companies; namely Exxon, PetroChina, Walmart and ICBC (PwC, 2018).

When assessing the lessons from the financial crisis of 2008, Hausman and Johnston (2014b) establish that economic stability is positively related to discontinuous innovation as they take science-based companies (Apple, Microsoft, as well as biotechnology and health-care innovations) as illustrative that “increased economic pressure often fuels creative solutions” (page 2721). As such, this paper presents a hypothesis as follows.

Hypothesis 3. During the great financial crisis, science-based industries were more related to the emergence of dominant designs than they were previously.

3. Methodology

3.1. Data

The derived hypothesis is tested with longitudinal patent data from the OECD REGPAT and OECD Citations databases, February 2016 edition. Patent data is widely used to study management, and the OECD REGPAT database has recently been used by Belderbos, Du, and Goerzen (2017) to study connectivity and location choice, whereas the OECD Citations database was used by Brem et al. (2016) to study innovation after the establishment of dominant designs. Patent counts are often used to measure innovation (Griliches, 1990; Jaffe, Trajtenberg, & Henderson, 1993; Joshi & Nerkar, 2011), since they correlate highly with alternative measures of innovation; e.g. R&D inputs, patent citations, and new product announcements (Hagedoorn & Cloodt, 2003). This study's data contains a variety of information on each patent, including the patent class that it belongs to and which other patents it relates to through citations of other patents.

Data is used regarding patents filed at the European Patent Office (EPO), which is considered by some to better measure innovative performance than patents filed at the United States Patent and Trademark

Office (USPTO) (Belderbos, Cassiman, Faems, Leten, & Van Looy, 2014; Jaffe & Lerner, 2004), since EPO patent examiners have lower work load and spend more time on each application (Quillen & Webster, 2001). EPO patent data has been used in the study of the internationalization of innovation (Guellec & Van Pottelsberghe de la Potterie, 2001; Picci, 2010).

Patent classes with incomplete data are excluded in order to yield a balanced data set spanning 456 patent classes for the years 1980 to 2013—in total 15,504 patent-class years. The hypotheses are tested on a variety of technologies while simultaneously controlling for diverse technology characteristics.

3.2. Measures

3.2.1. Dependent variable

A technology class has a dominant design when most of the designs share the same underlying technology (Murmann & Frenken, 2006). Dominant design is measured binarily as existing or non-existing in a certain patent class during a specific year. Technologies are considered to share the same underlying technology if they cite the same patent, i.e., refer to the same design. A dominant design exists in a patent class year if the percentage of patents that cite the same patent is above a threshold value of 50 percent. This value is used as it represents a majority of citations—a design is dominant if a majority of innovations in a patent class include the same design (Brem et al., 2016). Citations are included which are not only made by the inventors but also by the patent examiners, since examiners add citations when they find a technology build on a previous patent, even if the author has not cited it. The year used for each patent is the year of the first application for that patent. This way innovations made during the same year are considered and the effects of lengthy patenting processes are avoided. The patent classes are defined at the level of four-digit international patent classification (IPC) codes. Notably, this measure covers disruptive innovations as well as non-disruptive ones; since citing prior innovations is not a requisite for becoming a dominant design, the innovation only has to receive forward citations, or more specifically, be cited by subsequent patents.

3.2.2. Independent variables

Innovative performance is measured as the patenting frequency of each patent class. It is calculated as the number of patent applications in a given year (Ahuja & Katila, 2001, Hall & Ziedonis, 2001; Keil, Maula, Schildt, & Zahra, 2008; Stuart, 2000).

Globalization is measured as the number of countries where the applicants of patents are located for each patent class in a given year. Thus, the number of countries involved in the invention process is measured and not the diffusion of the innovation or global market reach.

Science base is measured binarily as whether a technology is science-based according to Pavitt (1984) taxonomy as described above. The IPC technology codes in the data set are converted to Nomenclature of Economic Activities (NACE) industry codes of the European Community (Schmoch, Laville, Patel, & Frietsch, 2003), and then from NACE codes to the Pavitt taxonomy (Bogliacino & Pianta, 2010).

"Great crisis" is a binary variable, which is 1 if the year is after 2008, and 0 if it is not. "Year of great crisis" is if the year is after 2008, and 0 if it is not. These two variables are used to test whether there is a structural break in the data.

3.2.3. Control variables

Characteristics of the financial system on the country level are controlled for by incorporating data from the Financial Development and Structure Dataset of the World Bank (Čihák, Demirgüç-Kunt, Feyen, & Levine, 2012).

"Market-based financial system" is the logarithm of the total value traded ratio divided by the bank credit ratio, and thus, measures the activity of stock markets relative to that of banks (Levine, 2002). The mean of this variable is used per patent class and year.

"Central bank assets to GDP" is the patent-class mean for each year of claims on the domestic real nonfinancial sector by the Central Bank as a share of GDP (Beck, Demirgüç-Kunt, & Levine, 2000).

All independent and control variables have been lagged by two years, since the establishment of dominant designs usually takes several years. A time-lag analysis is conducted to ensure the correct time-lag has been set, and no hidden effects can be revealed by shorter or longer time lags.

3.2.4. Method

A Probit regression model is used for the data analysis, since the dependent variable "dominant design" is a binary variable (Argyres & Bigelow, 2010). To include both time-variant and patent-class effects, population-averaged Probit-regressions are used with panel-specific first-order autoregressive (AR(1)) autocorrelation (Cameron & Trivedi, 2005). The autoregressive correlations take into account the previous values for each patent class. Since the error structure is specified for each patent class, the specified model is a panel regression model that takes into account the heterogeneity among patent classes. The Probit-regression model can be expressed as follows:

$$Y_{it}^{*} = \beta' X_{it} + u_{it} \quad (1)$$

Y_{it}^{*} is an unobserved latent variable. The observed random variable Y_{it} is defined by:

$$Y_{it} = \begin{cases} 0 & if \quad Y_{it}^{*} \le 0, \\ 1 & if \quad Y_{it}^{*} > 0. \end{cases} \quad (2)$$

X_{it} is a vector of the independent, interaction, and control variables and u_{it} is an autocorrelated fixed effect for the i^{th} patent class as follows:

$$u_{it} = \rho * u_{it-1} + \eta_{it}; \quad \eta \quad is \quad iid(0, \sigma_{\eta}^{2}) \quad (3)$$

4. Results

The mean values, standard deviations, and correlations among the variables used in the analyses are reported in Table 1. The high correlations among the independent variables could be an indicator of multicollinearity. Therefore, related statistics are examined; for

Table 1
Descriptive statistics and correlations.

	Mean	S.D.	1	2	3	4	5
1. Dominant design	0.003	0.052					
2. Innovative performance	337.513	744.649	−0.023**				
3. Globalization	16.349	8.538	−0.067**	0.707**			
4. Science base	0.348	0.476	0.011	0.276**	0.178**		
5. Market-based financial system	−0859	0.913	−0.017**	0.227**	0.403**	0.106**	
6. Central bank assets to GDP	3.830	1.639	0.013	0.193**	0.264**	0.145**	0.419**

n = 14528.
** Correlations significant at the 5% level.

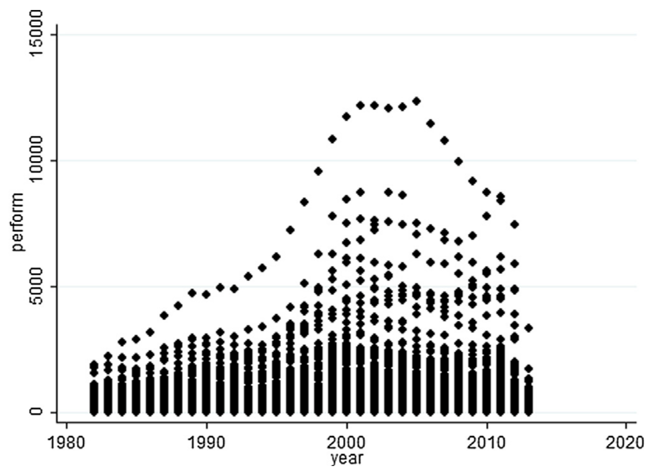

Fig. 1. Scatterplot of innovative performance against year.

example, the variance inflation factors (VIFs) are under 2.10, and the tolerance is over 0.47, and thus do not indicate multicollinearity (Kutner, Nachtsheim, & Neter, 2004).

Fig. 1 shows the innovative performance plotted against the year. All classes are plotted, and overlaps are not differentiated. A sharp rise of innovative performance in the late nineties seemed to peak in the early 2000 s, only to later slope downward.

Globalization is plotted against the year in Fig. 2, and appears to increase steadily until around 2008, after which this variable assumes a downward slope.

Table 2 reports the results of the Probit-regressions. First, whether there is a structural break in the data for dominant design is tested. The significant coefficients for the variables "great crisis" ($\beta = -1678.076$; $p < .05$; Model 1, Table 2) and the "year of great crisis" ($\beta = 0.835$; $p < .05$; Model 1, Table 2) indicate that there is such a break. The coefficient of "great crisis" is negative and significant also when including the independent and control variables ($\beta = -2964.373$; $p < .05$; Model 2, Table 2) and when adding the interaction between globalization and innovative performance ($\beta = -2946.147$; $p < .05$; Model 3, Table 2). The Probit-regression analysis hence supports Hypothesis 1 regarding the negative impact of the great crisis on the emergence of dominant design. There is a positive impact of the variable year of great crisis ($\beta = 1.466$; $p < .05$; Model 3, Table 2), and thus, there is a higher probability of dominant designs when more years have passed since 2008. In addition, model 3 demonstrates the negative impact of innovative performance on dominant design and a moderating effect of globalization as indicated by the significant interaction variable between innovative performance and globalization

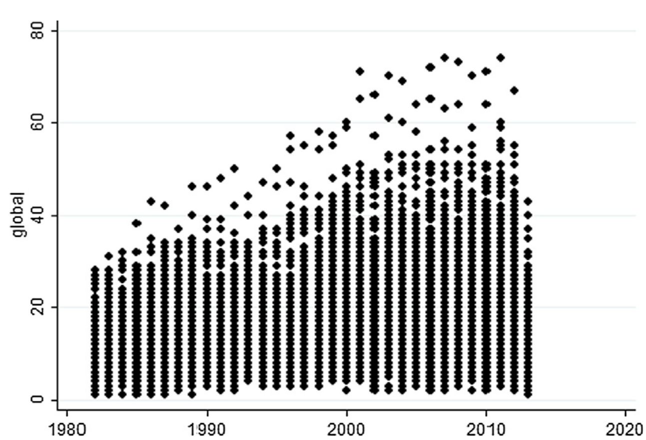

Fig. 2. Scatterplot of globalization against year.

performance ($\beta = 0.001$; $p < .05$; Model 3, Table 2). In Fig. 3, the positive moderating effect is plotted—there is more likely to be a dominant design at lower values of globalization combined with lower values of innovative performance, and when innovative performance is higher, globalization has less impact on the relationship between innovative performance and dominant design.

To study the impact of the independent variables before and during the great crisis, the regressions including only data for the patent class years before 2008 (Model 4, Table 2) and then from 2008 onwards (Model 5, Table 2) are repeated. It is observed that the coefficient for innovative performance is less negative after 2008 ($\beta = -0.067$; $p < .05$; Model 5, Table 2) compared to before the great crisis ($\beta = -0.109$; $p < .05$; Model 4, Table 2). The interaction of innovative performance and globalization is significant both before and during the great crisis ($\beta = 0.001$; $p < .05$; Model 4 and Model 5, Table 2). The moderating effect of globalization is therefore plotted against the relationship between innovative performance and dominant design before and during the great crisis, respectively. In Fig. 4, it is found that for the period before 2008, the globalization of innovation moderates the negative relationship between innovative performance and dominant design so that innovative performance has less impact on dominant design when globalization is high. High values of globalization before the great crisis thus greatly reduce the emergence of dominant designs, particularly for patent classes with low innovative performance. The effect is similar to that of the whole sample, but more pronounced when only the period before the great crisis is observed. In Fig. 5, the period following 2008 is shown, and the moderating effect of globalization is reversed so that higher levels of globalization are more conductive to dominant design, and even more so for lower levels of innovative performance. This supports Hypothesis 2.

In reference to Table 2 and the comparison between the pre- and post-break models, the difference for science-based industries is striking with no significant impact in the years before 2008, and a significant impact during the crisis ($\beta = 0.804$; $p < .05$; Model 5, Table 2). This supports Hypothesis 3. Further investigation is carried out into which these technologies are, and it is found that science-based technologies with dominant designs before the great crisis included chemical substances such as attack gas and working-up tar. In the aftermath of the crisis of 2008, these technologies are joined or replaced by digital technologies such as counting mechanisms (G06M), ciphering apparatus (G09C), and electricity modulation (H03C). There appears to be a tendency favoring more digital technologies with dominant designs.

To test the robustness of the results, a time-lag analysis is conducted: shown in Table 3. An investigation into whether there is an impact of the independent variables on dominant design in the same year is conducted, as the independent variables are measured (model 6), the year after (model 7), two years after (model 3), and three years after (model 8). The results of model 3 are repeated in Table 3 to facilitate comparison between the models with different time lags. When time lag is applied (model 6), the model varies from the original model with a two-year time lag, with a significant negative relationship between globalization and dominant design ($\beta = -0.931$; $p < .05$; Model 6, Table 3). The results of the models with one-year time lag (model 7), two-year time-lag (model 3) and three-year time lag (model 8) are similar, with reference to the sign and significance of coefficients, with the Wald χ^2 of the model with two-year time lag being slightly higher than in the other models. The time-lag analysis thus demonstrates the robustness of the obtained results and further shows that the results endure through time, so that a change in the independent variables of one year has an impact on the emergence of a dominant design during subsequent years.

5. Discussion

The focus of this paper has been to evaluate the effects of the great financial crisis on innovation using the concept of dominant design as

Table 2
Probit-regression results on dominant design.

Model	1	2	3	4 Pre break	5 Post break
Innovative performance		−0.052**	−0.068**	−0.109**	−0.067**
		(0.015)	(0.018)	(0.043)	(0.021)
Globalization		−0.070	−0.062	−0.119	0.061
		(0.049)	(0.048)	(0.089)	(0.053)
Innovative performance × Globalization			0.001**	0.001**	0.001**
			(0.000)	(0.001)	(0.000)
Science base		0.362**	0.368**	−0.014	0.804**
		(0.168)	(0.170)	(0.245)	(0.279)
Great crisis	−1678.076**	−2964.373**	−2946.147**		
	(462.479)	(762.111)	(765.608)		
Year of great crisis	0.835**	1.475**	1.466**		
	(0.230)	(0.379)	(0.381)		
Market-based financial system		−0.127	−0.122	−0.107	−0.147
		(0.086)	(0.087)	(0.092)	(0.353)
Central bank assets to GDP		−0.013	−0.011	−0.024	0.098
		(0.045)	(0.045)	(0.064)	(0.062)
Constant	−2.924**	−1.574**	−1.499**	−0.776**	−1.719**
	(0.075)	(0.320)	(0.321)	(0.388)	(0.534)
Model diagnostics					
Wald χ^2 (df)	72.00**	100.60**	98.56**	33.79**	20.79**
n	14,528	14,528	14,528	13,166	1362
Patent classes	454	454	454	454	454
Years	32	32	32	29	3

*Estimates significant at the 10% level.
** Estimates significant at the 5% level.

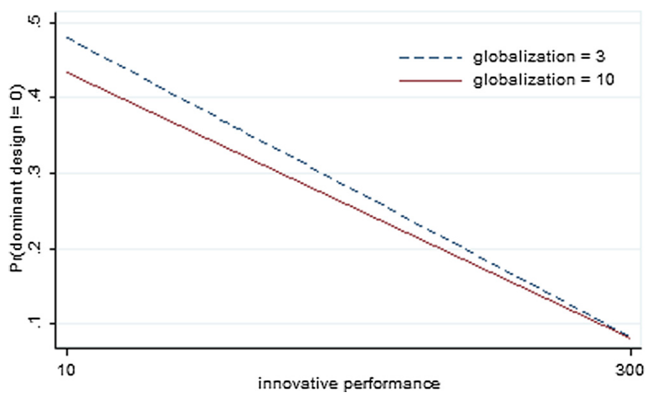

Fig. 3. Interaction between innovative performance and globalization.

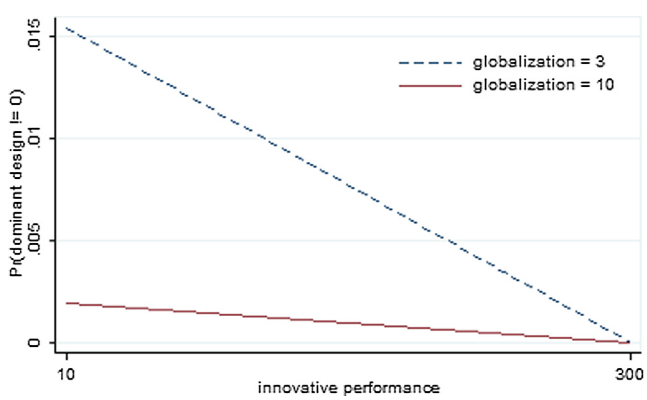

Fig. 4. Interaction between innovative performance and globalization before the Great Crisis.

the primary indicator. Additionally, due to the fact that the financial crisis happened at a time where companies had significantly internationalized their R&D activities, it has been important to examine the consequences of globalization on dominant designs during this period.

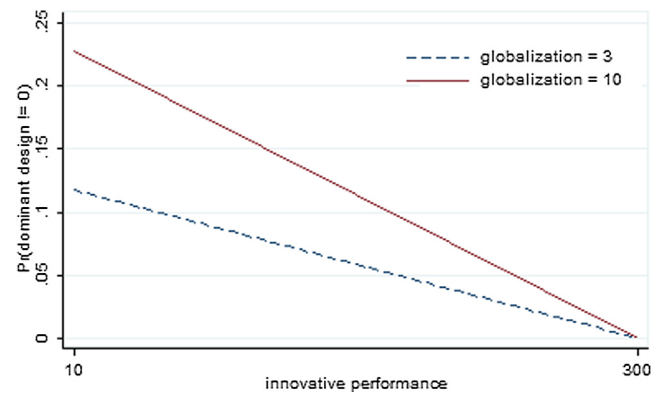

Fig. 5. Interaction between innovative performance and globalization during the Great Crisis.

Finally, this study further evaluated the evolution of dominant designs in science-based industries.

The results validate the first hypothesis about the negative impact of the great financial crisis on the emergence of dominant design. Convergence towards dominant designs is apparently less frequent in long and difficult financial crises: there have been fewer innovations, and especially fewer disruptive ones, than before. It may seem counterintuitive as the world seems to be changing faster than before, but actually it is probable that without a financial crisis as deep as the great financial crisis in 2008 there would have been more radical innovations than today.

These findings further support the established results of existing studies which have shown an interruption or deceleration of innovation investments from companies, mostly for financial reasons, because of the financial crisis of 2008. As indicated by El-Erian (2010), the great financial crisis has also been a time where many companies have shown less willingness to take risks. The same comment can be made about banks which have refrained to invest in innovative firms because of the risk of capital loss, even if the liberalization of financial markets has reduced their market power. As noted by Brogaard, Ngo, and Xia (2019), bank loans are still the most important source of corporate

Table 3
Probit-regression results on dominant design with varying time lags.

Model	6 no lag	7 1-year lag	3 2-year lag	8 3-year lag
Innovative performance	−0.084	−0.098**	−0.068**	−0.073**
	(0.057)	(0.024)	(0.018)	(0.019)
Globalization	−0.931**	−0.022	−0.062	0.005
	(0.155)	(0.054)	(0.048)	(0.049)
Innovative performance × Globalization	0.001	0.001**	0.001**	0.001**
	(0.001)	(0.000)	(0.000)	(0.000)
Science base	0.124	0.291*	0.368**	0.321*
	(0.229)	(0.174)	(0.170)	(0.175)
Great crisis	419.636	−2383.928**	−2946.147**	−2753.847**
	(345.660)	(743.105)	(765.608)	(785.432)
Year of great crisis	−0.208	1.186**	1.466**	1.371**
	(0.172)	(0.369)	(0.381)	(0.391)
Market-based financial system	−0.031	−0.064	−0.122	−0.089
	(0.104)	(0.086)	(0.087)	(0.091)
Central bank assets to GDP	−0.074**	0.065*	−0.011	−0.007
	(0.029)	(0.037)	(0.045)	(0.481)
Constant	1.724**	−1.561**	−1.499**	−1.886**
	(0.425)	(0.315)	(0.321)	(0.338)
Model diagnostics				
Wald χ^2 (df)	83.00**	93.78**	98.56**	93.07**
n	15,436	14,982	14,528	14,074
Patent classes	454	454	454	454
Years	34	33	32	31

** Estimates significant at the 5% level.
* Estimates significant at the 10% level.

finance, far more significant than funds raised in the equity market.

There has been an increased reluctance to engage in risky disruptive innovations that would form entire industries and generate new dominant designs. Still, an increasing probability for emerging dominant designs associated with the year of the crisis, is identified. This could be indicative of a recuperation from the crisis in these years.

A complementary explanation for the diminishing emergence of dominant designs in this period could be the fact that a company may set an industry standard in the sense of a dominant design with only limited intellectual property rights (Brem, Nylund, & Schuster, 2016). An example of the contrary effect comes from the dot-com boom of the 1990s, which was a period characterized by risk-willingness which generated many innovations, as evident by the high innovation performance of this period as per Fig. 1. The following battles for dominant design eliminated competing technologies and led to the bankruptcy of many of those risk-willing firms, thus leaving behind fewer firms and more dominant designs (Day, Fein, & Ruppersberger, 2003; Teece, 2006). In addition, it is important to note that other factors can also influence the probability of a firm to take risks. For instance, the recent period of very low or even negative interest rates might lead to a higher probability of funding risky endeavors.

These findings further support the second hypothesis about the moderating impact of globalization on the relationship between innovative performance and the emergence of dominant design. It is found that globalization is more important to the establishment of dominant designs than it was before the financial crisis of 2008.

One possible explanation for this phenomenon is that companies are increasingly able to connect and take advantage of international knowledge, so that globalization has become an advantage rather than a hindrance. In that case it could contribute to the observed increase in the gap between international companies and local firms which took place during the great financial crisis; the former ones could have experienced a relative acceleration of innovation compared to the latter ones. It is possible that the globalization of innovation is one of the many causes of growing economic inequality—with its socio-political implications more than obvious—that is associated with the great financial crisis (Dabla-Norris, Kochhar, Suphaphiphat, Ricka, & Tsounta, 2015).

Another possible explanation is that companies with more international and open-innovation strategies have a higher tendency of abandoning innovative projects (Tranekjer, 2019). Finally, the rising importance of frugal innovations might also be a key influence: products from emerging markets are not only increasingly sold in Western markets, but also being developed in Western markets by Asian companies (Agarwal, Grottke, Mishra, & Brem, 2016).

The direct negative relationship between globalization and the emergence of dominant designs that appear when no time lag is applied, could be due to reverse causality; for example, the emergence of a dominant design may reduce the geographical spread of innovation regarding a certain technology. Since, with time lags, the dependent variable is measured after the independent variables, and other reverse effects are avoided and the ability to infer causality in the tested relationships is improved. As global innovation also leads to a global competition of standards, it also explains the longer time period until a dominant design can be set.

Finally, regarding the third hypothesis, it is found that science-based industries were more likely to have dominant designs during the financial crisis as there was a reduction of emergence of dominant designs in other industries. For the period before the financial crisis, it is not clear that such a difference between the different types of industries existed.

One possible explanation is that science-based technologies are better at taking advantage of new connectedness—particularly with regard to digital technologies—and to accelerate the diffusion of a radical innovation in order to turn it into a new dominant model. For example, science-based technologies may approach standards through gradually including knowledge and product features in platforms available to partners and customers (Bharadwaj, Sawy, Pavlou, & Venkatraman, 2013) and then turning their innovations into a "de facto" standard with the help of a network effect (Gawer & Cusumano, 2014).

Another explanation for this might be the fact that this study explored patents, which are intellectual property rights for technical inventions. Hence, there is a natural linkage between science-based technologies and dominant designs. Moreover, science-based technologies usually offer a high growth potential, which attracts investors who want to support the commercialization of the technology for their success. Therefore, these investors also have an explicit interest in the fast diffusion of a standard into a dominant design as a basis for new product development. Finally, one can assume generally higher patenting activity of such science-based technologies.

An alternative explanation could be that for technologies that were not science-based, the flexibility and dynamism required for innovation processes in the financial crisis were no longer consistent with technology standardization. Perhaps the advantages of innovation speed and launching into new technologies and areas (Leiponen & Byma, 2009), counteracted the advantages of standardization for technologies that were not science based.

6. Limitations, managerial implications and future research

As with every study, this research process has several limitations. First, a distinctive definition of the financial crisis has been used—-specifically, 'years' were the primary variable—whereas it could be otherwise defined; for example, in terms of growth in turnover, or with the use of some other variable. Future research could consider whether the crisis should be defined differently depending on the industry or country being examined.

Another limitation stems from this paper's definition of independent variables; innovative performance or globalization could also be analyzed with alternative measures. Using patent data excludes those innovations that are not protected by patents but through other measures such as secrecy, or being first to the market (Leiponen & Byma, 2009). With the rise of highly dynamic platform markets, an increasing number of small firms have become involved in complementary innovation. Large firms, such as the platform owners, protect their innovations through patents, as evidenced by their many patent litigations (Trappey et al., 2016). Small firms struggle to benefit from patenting as well as from open innovation (Brem, Nylund, & Hitchen, 2017). They thus rely mainly on versioning, early entry, and other informal mechanisms (Miric, Boudreau, & Jeppesen, 2019). An aspect of the increasing impact of science-based innovations on dominant designs could possibly be explained by other fields increasingly using different forms of intellectual property protection. Future studies might consider if, and how, the protection of intellectual property has changed due to the financial crisis.

Likewise, the use of European data limits the generalizability on a global scale and opens a space for additional research on global interactions and their impact on dominant design. For example, the possible increase of Asian innovation and its effects warrant further studies, such as whether Asian innovation is a substitute or a compliment to European innovation. Another limitation is our view on dominant designs. There are clearly ambiguities in the literature, with dominant design acting as a barrier to 'up and coming' innovation, which was also briefly discussed in literature earlier.

Our research also offers some practical implications for professionals. The first is that whenever a financial crisis occurs, managers should understand that any innovation they have introduced—or plan to introduce—into the market will take longer to be successful than anticipated. In the case of radical innovation, scaling up will be longer and more difficult than in a normal environment. Timing has often been identified as a success factor in the adoption of an innovation (Hoppe, 2000; Klingebiel & Joseph, 2016), and as such it may be wiser to postpone the launching of an innovation if the company lacks the necessary resources to sustain a prolonged effort to turn it into a dominant design. Therefore, managers should keep in mind that delaying is not always an expression of failure, especially with the knowledge that it is also difficult for competitors to innovate radically.

A second implication involves the management of resources when innovating in times of a crisis. Of course, it is impossible to foresee the length and the depth of an economic crisis, but companies have to organize their innovation process to make it more resistant to the duration and the roughness of such a crisis. Schumpeter (1942) has noted that large companies eventually win the competition against entrepreneurial firms as they derive benefits from organization and bureaucracy. King and Tucci (2002) and Chesbrough (2003) have also found that incumbents are more likely to survive in the long term.

Companies must strengthen their financing with strong and effective management of their financial liquidities in order to be able to finance the deployment of their innovation even if external credits are difficult to find. This is demonstrated by the fact that it is not coincidental that the most valued digital companies also have some of the largest cash reserves available. They use it to finance the development of innovations and then to convert such innovations into dominant design. Innovative companies also need to make sure that they have a lean innovation system so that they can experiment and adapt to innovations quickly and inexpensively in the market or in the environment.

Another way to spread costs and to accelerate the adoption of disruptive innovation is to make alliances in the development and diffusion of said innovation. Therefore, another implication of this research is that international alliances can be an effective method of turning innovation into a dominant model when a crisis strikes.

Finally, an implication for technology- and science-based companies is that they should aim to globalize as soon as possible in order to turn their innovation into the dominant standard. Thus, they should consider scaling their innovation in terms of production and commercialization at an early stage in the innovation process rather than considering it before a financial crisis strikes unexpectedly.

This research is the first of its kind to consider the consequences of an economic crisis—and actually one of the most comprehensive studies—on innovation through its consideration of the emergence of dominant design as an indicator for the acceptance of disruptive or radical innovation within the market. While more is now known about the impact of the great financial crisis on dominant designs, the discussion of this study's findings illustrates that more research is indeed needed. Within the potential avenues of further investigation exists a better understanding of intellectual property's role in the emergence of dominant design for radical innovation, a more detailed knowledge of how globalization affects the dominant design strategies of MNEs, and a deeper comprehension—and maybe a reconceptualization—of how digital technologies affect the emergence of a successful dominant design in comparison with other industries.

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Alexander Brem PhD- holds the Chair of Technology Management at FAU which is located at the Nuremberg Campus of Technology a Phd In May 2017, he was appointed Honorary Professor at the University of Southern Denmark. His primary research interest is technology and innovation management with a special focus on interdisciplinary links to creativity and entrepreneurship.

Petra Nylund is a researcher at the University of Vic. She has a Ph.D. in Management from IESE and an M.Sc. in Engineering and Business Management from KTH, Stockholm. Her research and teaching focus on different aspects of innovation and strategy. She is also an expert in the econometric analysis of panel data. Her work has been published in journals such as The Leadership Quarterly, Technovation, and Journal of Knowledge Management.

Eric Viardot is Director of the Global Innovation Management Centre and permanent professor of marketing and strategy at EADA Business School in Barcelona. He has a doctorate in management and he is a graduate of the HEC Business School, Paris, and the Institute of Political Sciences, Paris. Eric Viardot has published various books and articles on strategic management and marketing with a strong focus on Technology Innovation Management.