NATIONAL RESEARCH UNIVERSITY
HIGHER SCHOOL OF ECONOMICS

Grigorii V. Teplykh

INNOVATIONS AND PRODUCTIVITY: THE SHIFT DURING THE 2008 CRISIS

BASIC RESEARCH PROGRAM

WORKING PAPERS

SERIES: SCIENCE, TECHNOLOGY AND INNOVATION

WP BRP 23/STI/2014

Grigorii V. Teplykh[1]

INNOVATIONS AND PRODUCTIVITY: THE SHIFT DURING THE 2008 CRISIS[2]

Innovations and related knowledge are important drivers of corporate success in modern economies. However the crisis of 2008 strongly influenced investment decisions including R&D expenditure. This may be explained by the fact that the crisis has changed a transformation of corporate resources into economic benefit. Innovation activity is found to be a survival factor during the downturn. The aim of this study is to investigate how the crisis has changed relations between innovation and firm performance in western Europe. We apply a structural framework of the CDM model which takes into account endogeneity and selection bias. The study is based on new balanced panel data of 429 western European manufacturing firms.

JEL Classification: O31, O32, D22, D24

Keywords: innovations, economic crisis, CDM model

[1] National Research University Higher School of Economics. Laboratory of Interdisciplinary Empirical Studies and Department of Financial Management. E-mail: teplykhgv@gmail.com.

[2] This study comprises research findings from the project «The Changing Role of Companies' Intangibles over the Crisis» carried out within The National Research University Higher School of Economics' Academic Fund Program in 2013, grant No 13-05-0021.

1. Introduction and literature review

Innovations are an important source of technological progress and economic growth in the modern world. The most part of useful knowledge is created in companies functioning in a competitive environment. The innovative activity of firms allows them to create competitive advantages in the form of new products and processes which provide economic benefit.

There are a lot of studies devoted to the relationships between innovative activity and performance. Some of them analyse the direct contribution of research and development expenses (Griliches, 1979, 1984; Wakelin, 2001; Griffith et al., 2004). However since beginning of 1980s scientists perceive R&D expenditures as the innovative efforts of firms (Griliches, 1979; Pakes & Griliches, 1984). What really influences corporate results is the innovative output created by these innovative efforts. There is a divergence in variables for the measurement of innovative output. It may be the number of patents (Hall et al., 1986), the sales of new products (Janz et al., 2004) or the creation of innovations (Parisi et al., 2006). Whichever variable is measured many studies recognize the gradual transformation of R&D into financial results.

The analysis of innovativeness has some problems. R&D expenses are endogenous because they depend on expectations of firms about future cash-flow (Griliches, 1979; Crépon et al., 1998; Jefferson et al., 2006). Another problem is selectivity. Many studies analyse only those firms formally investing in R&D. However firms that that report zero R&D may also make informal innovations and create new knowledge (Griffith et al., 2006). The analysis of the complicated relations between innovative inputs, outputs and performance requires the appropriate methodology. All these are accounted for in the CDM approach based on Crépon et al. (1998). The structural model of Crépon et al. combines a decision about investment in innovation, the value of the investment, the innovative output and the firm's results. The original model includes four equations. The selection equation (1) defines the firm decision to be involved in formal innovation activity. When latent variable g_i^* exceeds some threshold $\hat{g}$ then the firm invests in R&D.

$$g_i^* = x_{1i}b_1 + u_{1i} \tag{1}$$

Equation (2) describes the latent R&D intensity r_i^* of the firm. For firms doing R&D this variable coincides with actual R&D intensity, i.e. $r_i^* = r_i$ when $g_i^* > \hat{g}$. Authors measure r_i^* as the logarithm of R&D expenditure per employee.

$$r_i^* = x_{2i}b_2 + u_{2i} \tag{2}$$

Equation (3) shows the process of the creation of the innovative output k_i^* which depends on the innovative input r_i^*. Crépon et al. use two measures of this output – the number of patents and innovative sales (the logarithm of sales of new products per employee).

$$k_i^* = a_t r_i^* + x_{3i} b_3 + u_{3i} \tag{3}$$

Equation (4) shows how a firm's performance q_i depends on the innovation output k_i^*. The authors measure q_i by labour productivity (the logarithm of the value added per employee). Equation (4) is derived from a Cobb-Douglas production function.

$$q_i = a_k k_i^* + x_{4i} b_4 + u_{4i} \tag{4}$$

g_i^*, k_i^*, r_i^*, q_i are dependent variables in the model, x_{1i}, x_{2i}, x_{3i}, x_{4i} are vectors of explanatory variables, u_{1i}, u_{2i}, u_{3i} u_{4i} are vectors of errors. The model of Crépon et al. may be visualized in figure 1.

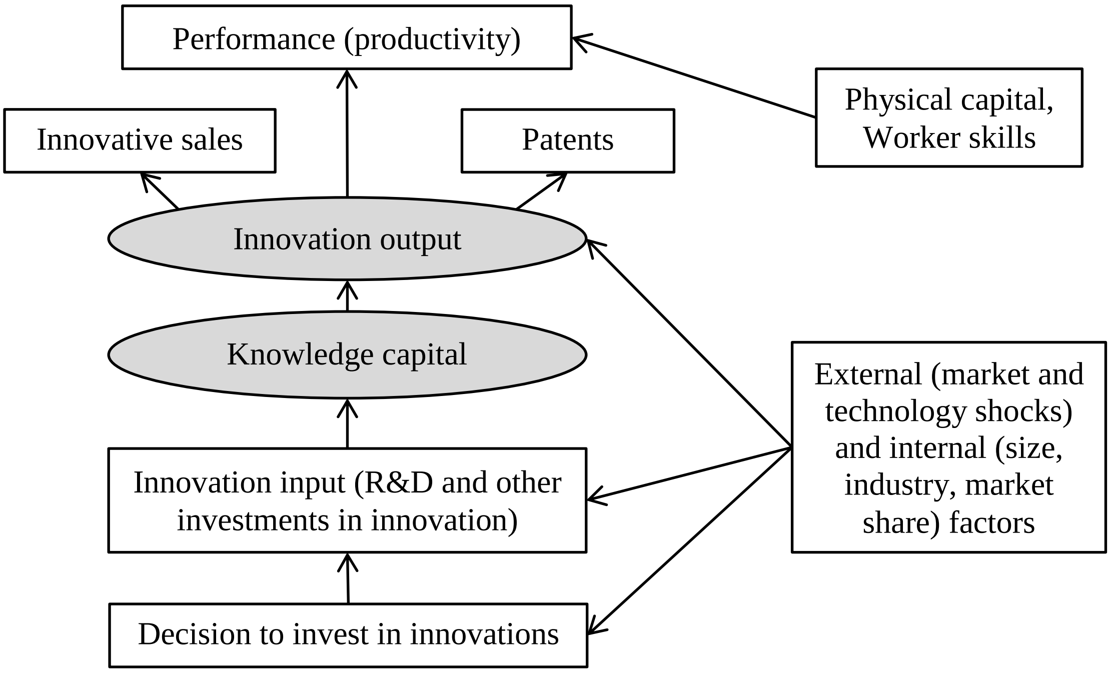

Figure 1. Diagram of the CDM model.

The main academic contributions of their study are (Crépon at al., 1998; Hall, Mairesse, 2006; Lööf, Heshmati, 2006):

1. combining into one model the separate lines of study about innovations;
2. the use of innovation survey data (European CIS);
3. the development of a clear framework for econometric modeling of innovations;
4. the addition of the selection equation into analysis. This reduces selection bias and permits the analyze of firms which do not formally make innovative efforts.

The research of Crépon at al. engendered many studies that share a similar vision of the innovation process (Lööf et al., 2003; Janz et al., 2004; Griffith et al., 2006; Jefferson et al., 2006; Duguet, 2006; Lööf & Heshmati, 2006; Johansson & Lööf, 2008; Heshmati, 2009; Mairesse & Robin, 2009; Musolesi & Huiban, 2010). This structural framework is known as the CDM approach.

Subsequent studies modify the model. Dummies for product and process innovations may be used as innovation output instead of innovative sales or patents (Griffith et al., 2006; Mairesse & Robin, 2009). If performance depends on both product and process innovations then the whole system consists of five equations. Jefferson et al. (2006) exclude the selection equation. Duguet (2006), Musolesi and Huiban (2010) exclude first two steps and analyse a system of equations (3) and (4). On the contrary Johansson and Lööf (2008) investigate a system of innovation using equations (1) and (2). Jefferson et al. (2006) take into account the lag between R&D expenditures, innovative sales and firm profitability. Janz et al., (2004) and Heshmati (2009) include performance in equation (3) to account for a possible feedback effect. Firm performance may be measured in different ways: sales (Janz et al., 2004), profit (Jefferson et al., 2006), productivity growth in dynamics (Lööf & Heshmati, 2006; Heshmati, 2009) etc. These variables are usually measured per employee in logarithm.

Almost all studies within the CDM approach use information from innovation surveys, mainly CIS (Community Innovation Surveys). These surveys provide detailed micro-data about the innovation activity of companies, such as different indicators of innovation input and output, labour quality, the influence of demand and technology. The comparability of CIS methodology makes it possible for researchers to carry out analyses at the intercountry and interindustry level (Lööf et al., 2003; Janz et al., 2004; Griffith et al., 2006). However data from surveys has also some disadvantages such as the subjectivity of self-assessment and imprecise quantitative estimates (Antonelli & Colombelli, 2011).

Studies within the CDM approach find strong relationships between R&D expenditure, innovation output and firm performance. Moreover analyses of different countries and industries give comparable results (Janz et al., 2004; Griffith et al., 2006; Lööf & Heshmati, 2006; Mairesse & Robin, 2009; Musolesi & Huiban, 2010; Hall, 2011). Researchers usually discover that such factors as firm size, demand pull, technology push, labour quality are significant in the model. But almost all these results refer to the pre-crisis period. It is evident that the role of innovations may change noticeably over time. However few studies apply the CDM approach for the analysis of innovative activity after the 2008 crisis. One reason is that CIS data for this period is largely absent as the time between data gathering and data processing is significant. A second reason is that consequent surveys usually embrace different sets of firms, so the samples are not fully comparable. CIS does not provide balanced panel data that would allow dynamic analysis (Hall, 2011).

2. Innovations and the 2008 financial crisis

The financial crisis of 2008 engendered a lot of academic studies. Many of them analyse the causes, and its macro- and microeconomic consequences. However the impact of the crisis on innovations of firms is as yet unexplored field of research. Some recent studies revealed significant changes in firm investment behaviour. The most important evidence is the reduction of firms' willingness to invest in innovation (OECD, 2009; Archibugi et al., 2013).

According to the OECD report financial constraints are the main factor of decreasing private innovation investment. Company cash flows decreased and credit organizations became more risk-averse. Another factor is the international trading that enhanced exposure to external shock. The shift of economies also depends on applied government policy. For example a bold innovation policy in Finland and South Korea had positive impact on structural changes in their economies (OECD, 2009). Acemoglu (2009) notes the importance of institutional frameworks for innovation during the recession.

Economists are interesting in who the post-crisis innovators are. Are they the same as before the crisis or not? Following Schumpeterian ideas researchers single out two processes: creative accumulation and creative destruction. The first implies that innovations are included in organizational routines and firms use them as a competitive advantage against new entrants. On the contrary the creative destruction concept assumes that crises give opportunities for young innovative firms to appear and displace old and less effective companies (Archibugi et al., 2013). Empirical evidence confirms the accumulation hypothesis for the current crisis (Kanerva & Hollanders, 2009; Filippetti & Archibugi, 2011; Archibugi et al., 2013).

Filippetti and Archibugi (2011) found noticeable differences in innovation investments across European countries. National innovation systems were useful for protecting investment in innovation projects during the downturn. The major structural factors were the quality of human resources, specialization in the high-technology sector and a developed financial system. Most innovators did not change investments during the crisis which may be related to lack of flexibility and considerable sunk costs.

Antonioli et al. (2011) investigate relationships between the innovative strategy of Italian firms and their performance during the crisis. They show that past innovative activity assists reactions to the crisis through product, process and organization/HRM dimensions. Firm performance depends on organizational and technological innovation strategies whereas training programs, ICT and environmental innovations are insignificant.

Brencic et al. (2012) show the negative effect of innovations on performance of Slovenian firms during the crisis and positive impact of HRM practices.

Paunov (2012) analyses why companies stopped ongoing innovation projects. The main factors were financial constraints and negative demand push. Younger businesses and firms linked with foreign markets suffered especially. Public funds helped to prevent such discontinuations while size was unimportant.

Archibugi et al. (2013) found that the determinants of innovative behaviour changed during the crisis compared to the pre-crisis period. Firm size and economic performance became less important while the influence of past product innovations and explorative strategies increased. Their results are similar for manufacturing and service industries.

Sidorkin and Srholec (forthcoming) analyse firms in Eastern and Southern Europe and find that pre-crisis innovation activity is the main factor reducing the likelihood of bankruptcy during the crisis, as does manager experience. Also they revealed that having foreign competitors and delayed payments of taxes increase the likelihood of bankruptcy. This is one of the few studies about the crisis and innovations based on the CDM model. However authors only reveal the role of innovative activity in firm survival during the crisis, they do not analyse how the role of innovations changed during the downturn.

Most papers analyse corporate behaviour related to investment in innovation, but few studies investigate how the crisis changed the relationships between innovative efforts, innovative outcomes and firm performance. This paper fills this gap and reveals how the crisis altered innovation activity of large West European enterprises. The analysis is based on the CDM model. It separates out different stages of the transformation of innovation into firm performance and analyses shifts at the each stage.

3. Model of the study

The main purpose of the study is to investigate how the crisis 2008 has changed relations between innovation and performance in large European firms. For this we analyse two models of firm performance for the pre- and post-crisis periods and then compare them. These models are constructed within the CDM approach. Next we reveal shifts at different stages of the transformation of innovative behaviour into economic results.

The main contribution of our study:

1. We apply the CDM model and analyse how the recent crisis affected the shift in relations between innovative behavior and firm performance. We compare every stage of the process of creation and utilization of new knowledge between the pre- and post-crisis periods. As we know it is one of first studies concerning the 2008 crisis made in full structural framework.
2. We take advantages of new unique panel data encompassing more than 1500 large West European enterprises for the period 2004-2011. All information was gathered from common sources which reduces the subjectivity problem common for surveys. The panel data is balanced: it makes possible an intertemporal analysis of fully comparable sets of firms. The size of the dataset permits conclusions which may be generalized for these countries at whole.
3. One additional novelty provided by new data is a new proxy for measuring firm's innovative results. We propose a variable "innovation award" which reflects whether firm received external recognition for their new product and may serve as an indicator of outstanding product innovation on the market.

The model consists of five equations (5)-(9):

$$RD\_doing_i = \begin{cases} 1 \ \text{if} \ \ RD\_doing_i^* = X_{1i}\beta_1 + \varepsilon_{1i} > 0 \\ 0 \ \text{if} \ \ RD\_doing_i^* = X_{1i}\beta_1 + \varepsilon_{1i} < 0 \end{cases} \tag{5}$$

$$RD_i = \begin{cases} RD_i^* = X_{2i}\beta_2 + \varepsilon_{2i} \ \ \text{if} \ \ RD\_doing_i = 1 \\ 0 \qquad\qquad\qquad\qquad \text{if} \ \ RD\_doing_i = 0 \end{cases} \tag{6}$$

$$NewProducts_i^* = a_{R1}RD_i^* + X_{3i}\beta_3 + \varepsilon_{3i} \tag{7}$$

$$Patents_i^* = a_{R2}RD_i^* + X_{4i}\beta_4 + \varepsilon_{4i} \tag{8}$$

$$Q_i = a_{NP}NewProducts_i^* + a_P Patents_i^* + a_{R3}RD_i^* + X_{5i}\beta_5 + \varepsilon_{5i} \tag{9}$$

where X_{1i}, X_{2i}, X_{3i}, X_{4i}, X_{5i}, are explanatory variables, ε_{1i}, ε_{2i}, ε_{3i}, ε_{4i}, ε_{5i}, are errors, β_{1i}, β_{2i}, β_{3i}, β_{4i}, β_{5i} are estimated coefficients.

The latent variable $RD\_doing_i^*$ in (1) determines whether firm will invest in R&D and RD_doing_i is the observable dummy variable of actual investment. Conditional on firm i investing in R&D, we can observe the amount of investments RD_i which equals the latent innovative efforts RD_i^* (6). If a firm does not invest we will not observe expenses $RD_i = 0$. However in this case there may be some innovative efforts RD_i^* which we cannot observe. Following many studies we take the logarithm of R&D expenditures per employee.

Equations (7) and (8) denote innovation functions. We apply two variables for the measurement of innovative output: the number of granted patents $Patents_i^*$ and appearance of noticeable new products $NewProducts_i^*$. The first variable defines a generation of formalized and protected knowledge. The second reflects the creation of new products which are conspicuous at the market. Both give competitive advantages. Innovation functions depend on latent R&D expenditures. It allows the inclusion in the analysis those firms which do not make formal investments in innovations.

Equation (9) shows how the firm performance Q_i (labour productivity in logarithm) depends on latent innovative outputs $Patents_i^*$ and $NewProducts_i^*$. We suppose that R&D may also affect performance. Not all innovative efforts develop into visible innovative output. There are some other channels: development of internal processes, increase of labour quality etc. So we add latent innovative intensity RD_i^* to equation (9).

We estimate two models (5)-(9) for periods before and after crisis. Then we compare them and analyse how each step of transforming of innovativeness into corporate performance has been changed by the current crisis.

Our model is visualized in figure 2.

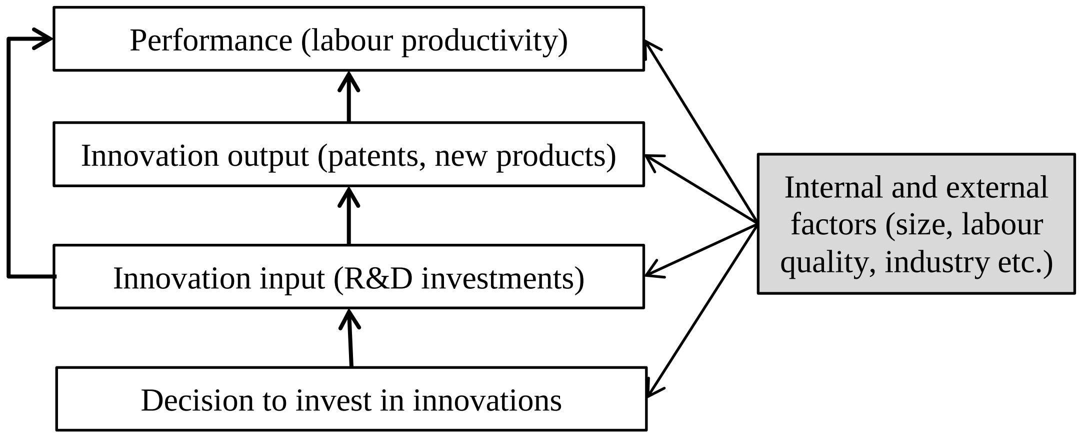

Figure 2. Diagram of the model.

4. Data and methodology

Our extended dataset includes 1693 public companies from 5 largest European countries (The United Kingdom, Germany, France, Spain and Italy). This sample includes all companies from the Amadeus database (Bureau van Dijk). The dataset is balanced panel for 2004-2011. We divide it into two sub-periods for analysis: pre-crisis (2004-2007) and post-crisis (2008-2011). Next we imposed some restrictions on our database to enhance the homogeneity of the sample:

- Firms are only from manufacturing industry.

- All firms were active during the period 2004-2011. We do not analyse possible changes related to “creative destruction” processes in economy which may lead to selection bias in our estimates. Instead we concentrate on an analysis of large companies acting as before as after the crisis.
- Exclusion of outlines and of all firms with missing data.

The final dataset contains 429 manufacturing companies.

All information was collected from open sources. Amadeus and Bloomberg databases give financial data. All financial indicators were converted to comparable prices (Euro 2004). Patent statistics were gathered from the QPAT database. Also we used a broad spectrum of information accessible from corporate sites. Most important was the dummy reflecting whether the firm received innovation awards for new products in each year. This variable is simple for gathering and free from subjectivity. External recognition indicates novelty and high value of new products and reflects competitive advantages of inventor over other firms. Usual proxies for product innovations such as innovative sales or innovations dummy are subjective because taken from surveys. They also do not reflect quality and significance of new products. To the best of our knowledge we first apply the new product award as proxy for innovative output.

Dynamics of main variables in our sample is represented in a table 1. Firms suffered a strong decline in sales in 2009 while innovation activity of firms reduced mainly in 2010. It may be explained by some inertness of investment process. Percentage of firms received awards for new products even grew during the crisis. It’s not strange because this variable just indicates only relative innovative dominance of some firms over others.

Table 1. Descriptive statistics of data in dynamics

Variable	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Firms invested in R&D	54,3%	58,3%	57,6%	58,5%	60,1%	60,4%	59,4%	57,3%
Firms with innovation awards	9,1%	11,2%	13,1%	14,7%	16,6%	18,6%	17,7%	19,6%
Count of patents granted (mean)	N.A.	34,3	34,8	34,5	34,1	34,7	32,0	33,0
R&D expenditures* (mean)	103,5	115,5	112,4	119,8	124,6	120,5	130,1	140,4
Sales* (mean)	2681,0	2848,8	2886,2	2984,3	3057,5	2771,9	3147,1	3442,9

* All financial variables are expressed in thousand Euros in comparable prices of 2004.

The paper is focused on analysis of the most common changes in innovative activity of western European companies. We abstract from a particular specific in national systems of innovations. Some empirical studies have found common patterns in structural innovations models across European countries (Janz et al., 2004; Griffith et. al., 2006). However we are concerned about the possible significance of country peculiar properties. We include a set of country dummies in the analysis to control for possible heterogeneity. Also we include sector dummies and permit heterogeneity within manufacturing industry.

Model (5)-(9) for the pre- and post-crisis periods is estimated by a step-by-step procedure following other researchers (Griffith et al., 2006; Duguet, 2006; Masso, Vahter, 2008). We include the expected values of innovative variables from previous steps as the factors into each next equation. Thereby we take into account the consequent transformation of knowledge into firm efficiency and try to solve the endogeneity problem. There is an assumption that control variables X_{1i}, X_{2i}, X_{3i}, X_{4i}, X_{5i}, are exogenous and errors in all equations are not correlated. The advantage of this step-by-step approach is the possibility of simple testing of any intertemporal shift at each stage of the model.

Equations (5) and (6) are estimated by two-step Heckman model with robust standard errors: probit for (5) and OLS for (6). We include inverse Mills ratio from the probit model in consequent equations to control for selection bias. Second equation is estimated only on the sub-sample of companies doing R&D. The dependent variable in (6) is the logarithm of the average R&D costs per employee for the three years of investigated periods (2005-2007 and 2009-2011). The dummy R&D variable in (5) is defined for the same three year periods. The set of exogenous factors for both equations in the Heckman model is common:

- knowledge protection: a dummy variable for whether the firm has valid patents;
- firm size: measured by the logarithm of the number of employees;
- productivity in the past year: measured as the logarithm of sales per employee. It is the dynamic feedback effect of firm performance on R&D;
- age of company. As we suppose younger firms tend to be more innovative;
- cash-to-assets ratio. This relates to liquidity and financial independence which could influence firm behavior;
- equity-to-book value. As we suppose the capital structure could impact investments in R&D by different ways (cost of capital, flexibility in decisions, financial opportunities etc.);
- R&D Experience: the number of years the company made formal R&D expenditures (for the last 10 years);
- association: a dummy variable for participation in business associations;
- profitability: a dummy variable for positive profit for last year;
- country and sector dummies that control for firm specific factors.

Explanatory variables are taken at the last year before the analyzed periods (2004 and 2008) to reduce endogeneity in estimates.

The dependent variable in (7) is a dummy for whether the firm received an innovation award for a new product during the three years (2005-2007) and (2009-2011). Equation (7) is estimated by probit. The dependent variable in (8) is the number of patents granted for the same three years. We approximate this value by a change in cumulative number of patents that the firm has ever granted. Because patents is a count variable we use maximum likelihood with a negative binomial distribution of errors for the estimation of (8). The set of factors for (7) and (8) is common:

- predicted innovative intensity: the logarithm of R&D per employee;
- labour quality: measured as the logarithm of average personnel costs per employee;
- management quality: an ordinal variable from 0 to 2 depending on the experience and postgraduate education of the Board of Directors;
- corporate university: a dummy whether the firm has its own corporate university;
- association dummy;
- capital intensity: measured as the logarithm of fixed assets per employee;
- firm size;
- inverse Mills ratio;
- country and sector dummies.

All variables in equations (7) and (8) are taken as average for three last years of periods (2005-2007 and 2009-2011). There are some reasons for averaging. The first reason is missing data for some years and possible measurement errors. Secondly we assume a lag between innovative input and output. Lastly many innovative surveys embrace a three-year period of firm activity. So we make our analysis more comparable with other studies in the CDM approach.

The dependent variable in (9) is the logarithm of labour productivity measured by sales per employee. We estimate (9) by OLS with robust covariance matrix. Factors in the (9):

- firm size;
- capital intensity: measured as the logarithm of fixed assets per employee;
- The logarithm of the predicted innovative intensity: we assume that not all knowledge created by R&D investments is formalized;
- the logarithm of the number of predicted granted patents per employee;
- predicted innovation award;
- labour quality;
- management quality;
- inverse Mills ratio;

- country and sector dummies.

It may be noted that productivity equation is a transformed production function of the Cobb-Douglas form. The final equations are estimated for the last year of periods (2007 and 2011). The averaged data on sales, labour and capital is also for these years. Latent values of innovative inputs and outputs are average values for three years (2005-2007) and (2009-2011) which are predicted from equations (6), (7) and (8). We attempt to reduce endogeneity in variables and take into account the lagged influence of knowledge on firm performance.

We estimate separate models (5)-(9) for the pre-crisis (2004-2007) and post-crisis (2008-2011) periods. Also a common model which embraces both periods is estimated. Herein predicted endogenous variables are taken from period-specific models. At the base of common equations we execute tests for intertemporal shift in the model. We construct a set of testing equations which include interaction terms between all factors and dummy for post-crisis period. Then we do statistical testing for the joint insignificance of these terms. Their results will serve as an indicator of intertemporal shifts at different stages of the model.

5. Results

Full results of the estimation of period-specific models, common model and testing equations are represented in Appendices A-D. The key outcomes are shown in tables 1-4.

Table 1. Selection equation

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Constant	-1,513 (0,558)***	-2,049 (0,605)***	-1,579 (0,386)***	-0,536 (0,823)
Knowledge protection	0,578 (0,18)***	0,055 (0,218)	0,349 (0,133)***	-0,522 (0,283)*
Average size	0,086 (0,059)	0,054 (0,067)	0,074 (0,041)*	-0,032 (0,09)
Past productivity	-0,031 (0,115)	0,019 (0,121)	-0,022 (0,086)	0,05 (0,167)
Age of firm	-0,004 (0,002)**	-0,001 (0,002)	-0,004 (0,002)**	0,004 (0,003)
Cash-to-book ratio	0,542 (0,754)	0,482 (0,989)	0,305 (0,581)	-0,06 (1,243)
Equity-to-book ratio	-0,967 (0,453)**	0,702 (0,612)	-0,314 (0,356)	1,669 (0,761)**
Experience in R&D	0,301 (0,032)***	0,449 (0,036)***	0,322 (0,022)***	0,149 (0,049)***
Association	-0,405 (0,22)*	0,251 (0,227)	-0,133 (0,151)	0,656 (0,316)**
Profitability	0,28 (0,239)	-0,231 (0,232)	0 (0,164)	-0,511 (0,334)
Equation statistics				
McFadden R-squared	44,23%	65,00%	49,86%	
Total observations	429	429	858	

First values are coefficients, parentheses contain robust standard errors.
*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.
All equations include a set of country and sector dummies.
The last column contains coefficients by interaction terms between factors and year dummy for post-crisis period from the testing model.

Protected knowledge, external finance resources and experience of innovation activity had positive impact on probability of R&D doing in the pre-crisis period. Younger companies were more inclined to invest in R&D. The interesting result is that participation in association had negative effect. One explanation is that firms may have access to additional sources of knowledge inside the group and do not need their own innovative activity. The crisis has led to notable changes in the selection equation. Experience of R&D is the single significant variable in the post-crisis period. Also we observe an increase of forecasting power of the model. McFadden R-squared is much larger for the later period despite only one significant factor.

Table 2. Innovation intensity

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Constant	-5,325 (1,076)***	-6,143 (1,166)***	-5,613 (0,72)***	-0,819 (1,668)
Knowledge protection	0,324 (0,218)	0,393 (0,189)**	0,374 (0,142)***	0,068 (0,294)
Average size	-0,018 (0,062)	0,003 (0,055)	-0,004 (0,041)	0,021 (0,084)
Past productivity	0,339 (0,193)*	0,693 (0,19)***	0,461 (0,14)***	0,354 (0,278)
Age of firm	-0,006 (0,002)***	-0,005 (0,002)***	-0,006 (0,001)***	0,001 (0,003)
Cash-to-book ratio	1,806 (0,848)**	3,177 (0,927)***	2,664 (0,7)***	1,371 (1,394)
Equity-to-book ratio	0,778 (0,632)	0,29 (0,558)	0,363 (0,44)	-0,488 (0,868)
Experience in R&D	0,018 (0,059)	0,143 (0,076)*	0,053 (0,039)	0,125 (0,1)
Association	0,602 (0,257)**	0,235 (0,205)	0,386 (0,164)**	-0,366 (0,327)
Profitability	-0,66 (0,303)**	-0,502 (0,25)**	-0,546 (0,197)***	0,158 (0,401)
Inverse Mills ratio	-0,467 (0,627)	0,193 (0,472)	-0,223 (0,349)	0,66 (0,82)
Equation statistics				
Adjusted R-squared	27,24%	33,66%	31,09%	
Total observations	282	267	549	

First values are coefficients, parentheses contain robust standard errors.
*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.
All equations include a set of country and sector dummies.
The last column contains coefficients by interaction terms between factors and year dummy for post-crisis period from the testing model.

Coefficients in innovation intensity equation are very similar for both periods. More productive, younger, more liquid and less profitable firms are more intensive before and after the crisis. The negative coefficient for profitability may be explained by the reaction of companies to the earlier bad performance. Participation in associations has a significant positive effect only pre-crisis, knowledge protection and R&D experience only post-crisis. However the testing model does not indicate that shift of coefficients by these factors was significant.

Table 3. Innovation function: awards

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Constant	-0,66 (1,023)	-1,253 (0,867)	-0,876 (0,636)	-0,593 (1,341)
Predicted R&D intensity	0,094 (0,162)	0,297 (0,122)**	0,23 (0,093)**	0,203 (0,203)

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Labour quality	0,202 (0,189)	0,098 (0,187)	0,09 (0,128)	-0,105 (0,266)
Management quality	0,351 (0,115)***	0,158 (0,106)	0,244 (0,077)***	-0,193 (0,157)
Corporate university	0,202 (0,213)	0,045 (0,196)	0,129 (0,143)	-0,156 (0,289)
Association	0,412 (0,208)**	0,45 (0,178)**	0,417 (0,132)***	0,038 (0,274)
Capital intensity	-0,015 (0,088)	-0,145 (0,09)	-0,052 (0,063)	-0,13 (0,126)
Size	0,033 (0,05)	0,212 (0,046)***	0,124 (0,032)***	0,179 (0,068)***
Inverse Mills ratio	-0,266 (0,222)	-0,232 (0,127)*	-0,2 (0,109)*	0,035 (0,256)
Equation statistics				
McFadden R-squared	20,81%	23,67%	20,27%	
Total observations	429	429	858	

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

All equations include a set of country and sector dummies.

The last column contains coefficients by interaction terms between factors and year dummy for post-crisis period from the testing model.

Participation in associations has positive impact on probability of getting awards in both periods. Management quality is significant only before the crisis, firm size only post-crisis. R&D intensity is important only after the crisis. It may reflect the reinforcement of the linkage between innovative input and output over time. On the other hand a weak relationship in the pre-crisis period together with the low explanatory power of models may be evidence that the innovation award is not a good enough proxy for new knowledge. The testing model shows that only the shift of the coefficient by firm size is significant.

Table 4. Innovation function: patents

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Constant	4,939 (2,191)**	2,152 (2,07)	3,323 (1,484)**	-2,787 (3,014)
Predicted R&D intensity	1,743 (0,352)***	1,442 (0,33)***	1,388 (0,219)***	-0,299 (0,483)
Labour quality	0,199 (0,527)	0,257 (0,529)	0,411 (0,366)	0,059 (0,747)
Management quality	0,332 (0,212)	0,125 (0,199)	0,234 (0,144)	-0,207 (0,29)
Corporate university	0,473 (0,395)	0,905 (0,39)**	0,675 (0,281)**	0,43 (0,555)
Association	-0,962 (0,463)**	-0,361 (0,474)	-0,662 (0,322)**	0,598 (0,663)
Capital intensity	0,357 (0,27)	0,143 (0,258)	0,306 (0,183)*	-0,215 (0,373)
Size	1,07 (0,104)***	1,043 (0,092)***	1,029 (0,064)***	-0,026 (0,138)
Inverse Mills ratio	0,213 (0,496)	0,424 (0,259)	0,218 (0,21)	0,21 (0,557)
Equation statistics				
Log likelihood	-1039,85	-1024,58	-2069,64	
Total observations	429	429	858	

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

All equations include a set of country and sector dummies.

The last column contains coefficients by interaction terms between factors and year dummy for post-crisis period from the testing model.

R&D intensity and firm size are important factors for patents before and after the crisis. Participation in associations has a positive influence on new patents before the crisis. Having a corporate university increases the number of patents after the crisis. However overall the intertemporal difference in coefficients is not justified by the testing model.

Table 5. Productivity equations

Variable	2005-2007	2009-2011	Common model (both periods)	Change (from the testing model)
Constant	0,922 (0,503)*	2,127 (0,373)***	1,531 (0,292)***	1,205 (0,636)*
Capital intensity	0,177 (0,034)***	0,245 (0,048)***	0,228 (0,03)***	0,068 (0,058)
Size	0,018 (0,019)	0,071 (0,026)***	0,024 (0,014)*	0,053 (0,031)*
Predicted R&D intensity	-0,08 (0,105)	0,338 (0,087)***	0,101 (0,062)	0,418 (0,144)***
Predicted new patents	0,14 (0,072)*	0,032 (0,046)	0,073 (0,034)**	-0,108 (0,083)
Predicted awards	-0,33 (0,405)	-0,776 (0,297)***	-0,202 (0,156)	-0,446 (0,467)
Labour quality	0,612 (0,123)***	0,4 (0,103)***	0,531 (0,079)***	-0,212 (0,163)
Management quality	-0,027 (0,062)	-0,01 (0,035)	-0,037 (0,03)	0,017 (0,071)
Inverse Mills ratio	0,151 (0,058)***	0,188 (0,036)***	0,149 (0,03)***	0,037 (0,067)
Equation statistics				
Adjusted R-squared	56,70%	63,39%	58,61%	
Total observations	429	429	858	

First values are coefficients, parentheses contain robust standard errors.
*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.
All equations include a set of country and sector dummies.
The last column contains coefficients by interaction terms between factors and year dummy for post-crisis period from the testing model.

The productivity equation is the most important part of the model since it represents final contribution of traditional resources and innovations to corporate results. Capital intensity, labour quality and involvement in R&D activity (Mills' correction) are significant factors in both periods. Nevertheless there are also notable changes in the equation during the crisis. New patents have a positive effect only before the crisis while innovation awards and unformalized knowledge captured by R&D efforts are important factors in the post-crisis period. So we may conclude that a channel of influence of knowledge on firm performance has changed.

One interesting result is the strong negative effect of innovative awards in the post-crisis time. There are some possible explanations. Switching to new products may lead to a short-time decline in efficiency. Or the invention of new products could be a firm response to an expected decrease in sales in stagnant markets. In either case a three year period is not enough lag for the product innovation. The sample of firms receiving awards could be biased or insufficiently large. At last we again note that innovation award may be not good proxy for innovation output.

Another remarkable result is a strong significance of firm size after the crisis. While we analyze transformed production function it is equivalent to an increasing return to scale. This may be evidence of new opportunities for the growth for companies which have survived during the economic recession.

Our previous conclusions about intertemporal changes were based on the analysis of particular coefficients. However they do not give an overall picture of the shifts. In the table 7 we report the results of tests for intertemporal shifts for each equation. We analyze testing equations which embrace two periods and include the set of interaction terms between all factors and a time dummy for the post-crisis period. Two statistical tests are performed: redundant variable and the Wald test. Both check for the joint insignificance of the set of interaction variables. The tests show whether the crisis influenced each equation.

Table 7. Statistical tests for intertemporal shifts

Stage of the model	Redundant variable test		Wald test		Significance of the shift
	Probability (F-statistic)	Probability (LR)	Probability (F-statistic)	Probability (Chi-square)	
Selection equation	-	0.0000	0.0000	0.0000	Strong
Innovation intensity	0.9126	0.8848	0.9741	0.9753	None
Innovation function (awards)	-	0.1164	0.0668	0.0637	Weak
Innovation function (patents)	-	0.9200	0.9152	0.9165	None
Productivity equation	0.0006	0.0003	0.0052	0.0045	Strong

Overall the crisis had a miscellaneous influence on different stages of the transformation of innovative behaviour into firm performance. It strongly affected factors of the probability of firm investment in innovation. However for firms deciding to invest in innovations the amount of investment had similar determinants in both periods. The recession has not shifted the relation between R&D investments and patented knowledge whereas the link between R&D and getting innovative awards changed very slowly. Lastly we observe a strong change in the productivity equation after the crisis. In other words the economic downturn significantly changed the role of innovation and other resources in firm performance.

Conclusion

The current study investigates whether and how the 2008 crisis changed relationships between innovations and productivity within the CDM approach. We constructed and compared the models for pre- and post- crisis periods revealing intertemporal shifts at different stages of firm performance creation. The analysis is based on new balanced panel data covering western European manufacturing firms. All information was gathered from publicly available sources what contrasts with usual applying of surveys. We also offered the innovation award for new products as new proxy for the measurement of innovation output.

The empirical results are manifold. The crisis affected each step of the model differently. It changed the selection equation notably. The factors in decisions to invest in R&D before and after the crisis are diverse. Many variables are significant in pre-crisis period whereas only experience of R&D is essential in post-crisis time. Despite the differences between selection equations, statistical tests did not reveal any significant changes in innovation intensity for firms doing R&D. In both periods investment in R&D depends on past productivity, age, liquidity and past profitability. The crisis slightly influenced the innovation award variable: post-crisis it depends more on R&D, size and association memberships and no more depends on management quality. The patent equation has not changed significantly during the crisis. The count of patents depends on R&D intensity and firm size in both periods. The process of the creation of new formalized knowledge has not been touched by the economic recession.

The most important change in the model relates to the productivity equation. Physical capital, labour quality and involvement in R&D are significant factors in both periods. Innovative factors of firm performance differ strongly. Patented knowledge matters only in the pre-crisis period whereas unformalized knowledge and innovation awards become important only after the crisis. Awards have a negative effect that has no clear single explanation. Overall knowledge has changed its influence on firm performance. The interesting evidence is an increasing return to scale after the crisis: we explain this by the appearance of growth opportunities for survived companies.

This study is a first look at the change of relationships between innovations and firm results pushed by the recent downturn. However this topic needs a further exploration. First of all our sample is too small to draw conclusions for all companies. We do not take into account firms which emerged or disappeared during the periods analyzed and we ignore a possible appropriate selection bias. We do not investigate specific innovations in separate countries and do not take into account national-specific reactions to the crisis. Lastly we are anxious that our variables may be not good substitutes to data from surveys. For example awards may be not enough good proxy for product innovations. We need additional comparisons between publicly accessible information and surveys when data on congruous samples from both sources is accessible. These issues are challenges for future studies.

References

Acemoglu, D., 2009. The crisis of 2008: structural lessons for and from economics. Globalization and Growth, 37.

Antonelli, C., Colombelli, A., 2011. The generation and exploitation of technological change: market value and total factor productivity. The Journal of Technology Transfer 36, 353–382.

Antonioli, D., Bianchi, A., Mazzanti, M., Montresor, S., Pini, P., 2011. Economic crisis, innovation strategies and firm performance. Evidence from Italian firm-level data. In SIE annual meeting.

Archibugi, D., Filippetti, A., Frenz, M., 2013. Economic crisis and innovation: Is destruction prevailing over accumulation? Research Policy, 42(2), 303-314.

Brencic, M. M., Pfajfar, G., Raškovic, M., 2012. Managing in a time of crisis: marketing, HRM and innovation. Journal of Business & Industrial Marketing, 27(6), 436-446.

Crépon, B., Duguet, E., Mairesse, J., 1998. Research Investment, Innovation and Productivity: an Econometric Analysis. Economics of Innovation and New Technology 7, 115–158.

Duguet, E., 2006. Innovation height, spillovers and TFP growth at the firm level: Evidence from French manufacturing. Economics of Innovation and New Technology 15, 415–442.

Filippetti, A., Archibugi, D., 2011. Innovation in times of crisis: National Systems of Innovation, structure, and demand. Research Policy, 40(2), 179-192.

Griffith, R., Huergo, E., Mairesse, J., Peters, B., 2006. Innovation and productivity across four European countries. Oxford Review of Economic Policy 22, 483–498.

Griffith, R., Redding, S., & Van Reenen, J., 2004. Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. Review of Economics and Statistics, 86(4), 883-895.

Griliches, Z., 1979. Issues in Assessing the Contribution of Research and Development to Productivity Growth. The Bell Journal of Economics 10, 92–116.

Griliches, Z., 1990. Patent Statistics as Economic Indicators: A Survey. Journal of Economic Literature, 28(4), 1661-1707.

Hall, B.H., 2011. Innovation and productivity. NBER Working Paper No. 17178.

Hall, B.H., Griliches, Z., Hausman, J.A., 1986. Patents and R and D: Is There a Lag? International Economic Review 27, 265–283.

Hall, B.H., Mairesse, J., 2006. Empirical studies of innovation in the knowledge-driven economy. Economics of Innovation and New Technology 15, 289–299.

Heshmati, A., 2009. A Generalized Knowledge Production Function. The Icfai University Journal of Industrial Economics VI, 7–39.

Janz, N., Lööf, H., Peters, B., 2004. Innovation and Productivity in German and Swedish Manufacturing Firms: Is there a Common Story? Problems & perspectives in management 184–204.

Jefferson, G., Huamao, B., Xiaojing, G., Xiaoyun, Y., 2006. R&D Performance in Chinese Industry. Economics of Innovation and New Technology 15, 345–366.

Kanerva, M., Hollanders, H., 2009. The impact of the economic crisis on innovation. Analysis based on the Innobarometer, 3.

Lööf, H., Heshmati, A., 2006. On the relationship between innovation and performance: A sensitivity analysis. Economics of Innovation and New Technology 15, 317–344.

Lööf, H., Heshmati, A., Asplund, R., Nås, S., 2003. Innovation and performance in manufacturing industries: A comparison of the Nordic countries. International Journal of Management Research 2, 5–36.

Mairesse, J., Robin, S., 2009. Innovation and productivity: a firm-level analysis for French Manufacturing and Services using CIS3 and CIS4 data (1998-2000 and 2002-2004). Working paper.

Masso, J., Vahter, P., 2008. Technological innovation and productivity in late-transition Estonia: econometric evidence from innovation surveys. The European Journal of Development Research 20, 240–261.

Musolesi, A., Huiban, J., 2010. Innovation and Productivity in Knowledge Intensive Business Services. Journal of Productivity Analysis 34, 63–81.

OECD, 2009. Policy Responses to the Economic Crisis: Investing in Innovation for Long-Term Growth. OECD, Paris

Pakes, A., Griliches, Z., 1984. Patents and R&D at the Firm Level: A First Look, in: R & D, Patents, and Productivity. University of Chicago Press, pp. 55–72.

Paunov, C., 2012. The global crisis and firms' investments in innovation. Research Policy, 41(1), 24-35.

Sidorkin, O., Srholec, M. Surviving the times of crisis: Does innovation make a difference? Unpublished paper.

Wakelin, K., 2001. Productivity growth and R&D expenditure in UK manufacturing firms. Research policy 30, 1079–1090.

Appendix A. Selection equation (full results)

	2005-2007	2009-2011	Common model	Testing model
C	-1,513 (0,558)***	-2,049 (0,605)***	-1,579 (0,386)***	-1,513 (0,558)***
Knowledge protection	0,578 (0,18)***	0,055 (0,218)	0,349 (0,133)***	0,578 (0,18)***
Average size	0,086 (0,059)	0,054 (0,067)	0,074 (0,041)*	0,086 (0,059)
Past productivity	-0,031 (0,115)	0,019 (0,121)	-0,022 (0,086)	-0,031 (0,115)
Age of firm	-0,004 (0,002)**	-0,001 (0,002)	-0,004 (0,002)**	-0,004 (0,002)**
Cash-to-book ratio	0,542 (0,754)	0,482 (0,989)	0,305 (0,581)	0,542 (0,754)
Equity-to-book ratio	-0,967 (0,453)**	0,702 (0,612)	-0,314 (0,356)	-0,967 (0,453)**
Experience in R&D	0,301 (0,032)***	0,449 (0,036)***	0,322 (0,022)***	0,301 (0,032)***
Association	-0,405 (0,22)*	0,251 (0,227)	-0,133 (0,151)	-0,405 (0,22)*
Profitability	0,28 (0,239)	-0,231 (0,232)	0 (0,164)	0,28 (0,239)
Sector 2 dummy	0,773 (0,357)**	-0,462 (0,391)	0,374 (0,246)	0,773 (0,357)**
Sector 3 dummy	0,629 (0,406)	-0,094 (0,498)	0,421 (0,292)	0,629 (0,406)
Sector 4 dummy	1,028 (0,424)**	-0,704 (0,496)	0,439 (0,299)	1,028 (0,424)**
Sector 5 dummy	0,817 (0,385)**	-0,391 (0,421)	0,364 (0,266)	0,817 (0,385)**
Sector 6 dummy	0,764 (0,356)**	-0,581 (0,399)	0,313 (0,248)	0,764 (0,356)**
Country dummy (Germany)	0,017 (0,254)	0,485 (0,305)	0,266 (0,187)	0,017 (0,254)
Country dummy (France)	-0,545 (0,24)**	0,562 (0,283)**	-0,123 (0,176)	-0,545 (0,24)**
Country dummy (Spain)	-0,898 (0,335)***	-0,453 (0,441)	-0,71 (0,264)***	-0,898 (0,335)***
Country dummy (Italy)	-0,205 (0,443)	0,956 (0,407)**	0,23 (0,312)	-0,205 (0,443)
T				-0,536 (0,823)
T*Knowledge protection				-0,522 (0,283)*
T*Average size				-0,032 (0,09)
T*Past productivity				0,05 (0,167)
T*Age of firm				0,004 (0,003)
T*Cash-to-book ratio				-0,06 (1,243)
T*Equity-to-book ratio				1,669 (0,761)**
T*Experience in R&D				0,149 (0,049)***
T*Association				0,656 (0,316)**
T*Profitability				-0,511 (0,334)
T*Sector 2 dummy				-1,235 (0,529)**
T*Sector 3 dummy				-0,723 (0,643)
T*Sector 4 dummy				-1,732 (0,653)***
T*Sector 5 dummy				-1,207 (0,571)**
T*Sector 6 dummy				-1,345 (0,535)**
T*Country dummy (Germany)				0,468 (0,397)
T*Country dummy (France)				1,106 (0,372)***
T*Country dummy (Spain)				0,445 (0,554)
T*Country dummy (Italy)				1,161 (0,602)*
Equation statistics				
McFadden R-squared	44,23%	65,00%	49,86%	54,82%
LR statistic	243,94	369,69	559,14	614,77
Log likelihood	-153,78	-99,53	-281,13	-253,32
Total observations	429	429	858	858

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

T denotes a time dummy for the post-crisis period. So the interaction terms allow an estimation of the changes of coefficients over time.

Appendix B. Innovation intensity (full results)

	2005-2007	2009-2011	Common model	Testing model
C	-5,325 (1,076)***	-6,143 (1,166)***	-5,613 (0,72)***	-5,325 (0,986)***
Knowledge protection	0,324 (0,218)	0,393 (0,189)**	0,374 (0,142)***	0,324 (0,21)
Average size	-0,018 (0,062)	0,003 (0,055)	-0,004 (0,041)	-0,018 (0,058)
Past productivity	0,339 (0,193)*	0,693 (0,19)***	0,461 (0,14)***	0,339 (0,174)*
Age of firm	-0,006 (0,002)***	-0,005 (0,002)***	-0,006 (0,001)***	-0,006 (0,002)***
Cash-to-book ratio	1,806 (0,848)**	3,177 (0,927)***	2,664 (0,7)***	1,806 (0,907)**
Equity-to-book ratio	0,778 (0,632)	0,29 (0,558)	0,363 (0,44)	0,778 (0,595)
Experience in R&D	0,018 (0,059)	0,143 (0,076)*	0,053 (0,039)	0,018 (0,058)
Association	0,602 (0,257)**	0,235 (0,205)	0,386 (0,164)**	0,602 (0,244)**
Profitability	-0,66 (0,303)**	-0,502 (0,25)**	-0,546 (0,197)***	-0,66 (0,284)**
Inverse Mills ratio	-0,467 (0,627)	0,193 (0,472)	-0,223 (0,349)	-0,467 (0,593)
Sector 2 dummy	1,095 (0,431)**	1,374 (0,4)***	1,277 (0,289)***	1,095 (0,43)**
Sector 3 dummy	1,572 (0,457)***	1,488 (0,428)***	1,559 (0,311)***	1,572 (0,448)***
Sector 4 dummy	1,33 (0,438)***	1,622 (0,415)***	1,515 (0,293)***	1,33 (0,439)***
Sector 5 dummy	1,005 (0,477)**	1,276 (0,456)***	1,181 (0,32)***	1,005 (0,481)**
Sector 6 dummy	1,157 (0,442)***	1,18 (0,411)***	1,242 (0,296)***	1,157 (0,44)***
Country dummy (Germany)	0,734 (0,239)***	0,385 (0,208)*	0,583 (0,159)***	0,734 (0,223)***
Country dummy (France)	0,211 (0,299)	0,381 (0,263)	0,238 (0,185)	0,211 (0,28)
Country dummy (Spain)	-1,766 (0,619)***	-1,495 (0,736)**	-1,652 (0,461)***	-1,766 (0,584)***
Country dummy (Italy)	1,104 (0,382)***	0,996 (0,398)**	0,98 (0,263)***	1,104 (0,382)***
T				-0,819 (1,668)
T*Knowledge protection				0,068 (0,294)
T*Average size				0,021 (0,084)
T*Past productivity				0,354 (0,278)
T*Age of firm				0,001 (0,003)
T*Cash-to-book ratio				1,371 (1,394)
T*Equity-to-book ratio				-0,488 (0,868)
T*Experience in R&D				0,125 (0,1)
T*Association				-0,366 (0,327)
T*Profitability				0,158 (0,401)
T*Inverse Mills ratio				0,66 (0,82)
T*Sector 2 dummy				0,279 (0,589)
T*Sector 3 dummy				-0,084 (0,627)
T*Sector 4 dummy				0,292 (0,603)
T*Sector 5 dummy				0,271 (0,658)
T*Sector 6 dummy				0,023 (0,606)
T*Country dummy (Germany)				-0,349 (0,32)
T*Country dummy (France)				0,17 (0,403)
T*Country dummy (Spain)				0,271 (0,987)
T*Country dummy (Italy)				-0,108 (0,556)
Equation statistics				
R-squared	32,16%	38,40%	33,48%	35,02%
Adjusted R-squared	27,24%	33,66%	31,09%	30,04%
Log likelihood	-502,35	-435,47	-947,31	-940,90
Total observations	282	267	549	549

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

T denotes a time dummy for the post-crisis period. So the interaction terms allow an estimation of the changes of coefficients over time.

Appendix C. Innovation function: awards (full results)

	2005-2007	2009-2011	Common model	Testing model
C	-0,66 (1,023)	-1,253 (0,867)	-0,876 (0,636)	-0,66 (1,023)
Predicted R&D intensity	0,094 (0,162)	0,297 (0,122)**	0,23 (0,093)**	0,094 (0,162)
Labour quality	0,202 (0,189)	0,098 (0,187)	0,09 (0,128)	0,202 (0,189)
Management quality	0,351 (0,115)***	0,158 (0,106)	0,244 (0,077)***	0,351 (0,115)***
Corporate university	0,202 (0,213)	0,045 (0,196)	0,129 (0,143)	0,202 (0,213)
Association	0,412 (0,208)**	0,45 (0,178)**	0,417 (0,132)***	0,412 (0,208)**
Capital intensity	-0,015 (0,088)	-0,145 (0,09)	-0,052 (0,063)	-0,015 (0,088)
Size	0,033 (0,05)	0,212 (0,046)***	0,124 (0,032)***	0,033 (0,05)
Inverse Mills ratio	-0,266 (0,222)	-0,232 (0,127)*	-0,2 (0,109)*	-0,266 (0,222)
Sector 2 dummy	-0,42 (0,424)	0,086 (0,44)	-0,163 (0,295)	-0,42 (0,424)
Sector 3 dummy	-0,14 (0,513)	-0,156 (0,477)	-0,166 (0,336)	-0,14 (0,513)
Sector 4 dummy	-0,354 (0,486)	0,065 (0,496)	-0,146 (0,337)	-0,354 (0,486)
Sector 5 dummy	-0,606 (0,476)	0,179 (0,467)	-0,208 (0,318)	-0,606 (0,476)
Sector 6 dummy	-0,147 (0,434)	-0,19 (0,44)	-0,184 (0,299)	-0,147 (0,434)
Country dummy (Germany)	0,875 (0,247)***	0,653 (0,227)***	0,716 (0,165)***	0,875 (0,247)***
Country dummy (France)	0,519 (0,261)**	0,363 (0,228)	0,384 (0,168)**	0,519 (0,261)**
Country dummy (Spain)	0,622 (0,487)	0,603 (0,415)	0,635 (0,308)**	0,622 (0,487)
Country dummy (Italy)	1,007 (0,471)**	0,241 (0,457)	0,531 (0,326)	1,007 (0,471)**
T				-0,593 (1,341)
T*Predicted R&D intensity				0,203 (0,203)
T*Labour quality				-0,105 (0,266)
T*Management quality				-0,193 (0,157)
T*Corporate university				-0,156 (0,289)
T*Association				0,038 (0,274)
T*Capital intensity				-0,13 (0,126)
T*Size				0,179 (0,068)***
T*Inverse Mills ratio				0,035 (0,256)
T*Sector 2 dummy				0,506 (0,611)
T*Sector 3 dummy				-0,017 (0,7)
T*Sector 4 dummy				0,418 (0,694)
T*Sector 5 dummy				0,785 (0,667)
T*Sector 6 dummy				-0,043 (0,618)
T*Country dummy (Germany)				-0,223 (0,336)
T*Country dummy (France)				-0,155 (0,347)
T*Country dummy (Spain)				-0,019 (0,64)
T*Country dummy (Italy)				-0,767 (0,656)
Equation statistics				
McFadden R-squared	20,81%	23,67%	20,27%	22,80%
LR statistic	96,94	125,37	203,06	228,38
Log likelihood	-184,47	-202,11	-399,24	-386,58
Total observations	429	429	858	858

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

T denotes a time dummy for the post-crisis period. So the interaction terms allow an estimation of the changes of coefficients over time.

Appendix D. Innovation function: patents (full results)

	2005-2007	2009-2011	Common model	Testing model
C	4,939 (2,191)**	2,152 (2,07)	3,323 (1,484)**	4,94 (2,171)**
Predicted R&D intensity	1,743 (0,352)***	1,442 (0,33)***	1,388 (0,219)***	1,743 (0,349)***
Labour quality	0,199 (0,527)	0,257 (0,529)	0,411 (0,366)	0,199 (0,522)
Management quality	0,332 (0,212)	0,125 (0,199)	0,234 (0,144)	0,332 (0,21)
Corporate university	0,473 (0,395)	0,905 (0,39)**	0,675 (0,281)**	0,474 (0,391)
Association	-0,962 (0,463)**	-0,361 (0,474)	-0,662 (0,322)**	-0,96 (0,458)**
Capital intensity	0,357 (0,27)	0,143 (0,258)	0,306 (0,183)*	0,358 (0,267)
Size	1,07 (0,104)***	1,043 (0,092)***	1,029 (0,064)***	1,069 (0,103)***
Inverse Mills ratio	0,213 (0,496)	0,424 (0,259)	0,218 (0,21)	0,213 (0,492)
Sector 2 dummy	-1,433 (0,797)*	-1,073 (0,755)	-0,993 (0,527)*	-1,434 (0,79)*
Sector 3 dummy	-1,992 (1,029)*	-0,359 (0,835)	-0,77 (0,626)	-1,991 (1,02)*
Sector 4 dummy	-1,799 (0,993)*	-1,506 (0,943)	-1,191 (0,645)*	-1,797 (0,984)*
Sector 5 dummy	-0,495 (0,8)	0,313 (0,757)	0,141 (0,525)	-0,495 (0,793)
Sector 6 dummy	-2,759 (0,839)***	-1,696 (0,746)**	-1,943 (0,535)***	-2,757 (0,831)***
Country dummy (Germany)	-0,691 (0,469)	-0,583 (0,488)	-0,698 (0,334)**	-0,692 (0,465)
Country dummy (France)	2,523 (0,521)***	2,017 (0,511)***	2,332 (0,357)***	2,52 (0,516)***
Country dummy (Spain)	3,358 (0,916)***	2,708 (0,825)***	2,553 (0,573)***	3,353 (0,908)***
Country dummy (Italy)	-2,157 (0,942)**	-1,513 (0,911)*	-1,74 (0,652)***	-2,157 (0,934)**
T				-2,787 (3,014)
T*Predicted R&D intensity				-0,299 (0,483)
T*Labour quality				0,059 (0,747)
T*Management quality				-0,207 (0,29)
T*Corporate university				0,43 (0,555)
T*Association				0,598 (0,663)
T*Capital intensity				-0,215 (0,373)
T*Size				-0,026 (0,138)
T*Inverse Mills ratio				0,21 (0,557)
T*Sector 2 dummy				0,363 (1,097)
T*Sector 3 dummy				1,635 (1,323)
T*Sector 4 dummy				0,292 (1,369)
T*Sector 5 dummy				0,81 (1,101)
T*Sector 6 dummy				1,062 (1,121)
T*Country dummy (Germany)				0,111 (0,677)
T*Country dummy (France)				-0,5 (0,73)
T*Country dummy (Spain)				-0,641 (1,232)
T*Country dummy (Italy)				0,644 (1,311)
Equation statistics				
LR statistic	255516,80	239119,50	494655,90	494666,20
Log likelihood	-1039,85	-1024,58	-2069,64	-2064,47
Total observations	429	429	858	858

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

T denotes a time dummy for the post-crisis period. So the interaction terms allow an estimation of the changes of coefficients over time.

Appendix E. Productivity equation (full results)

	2005-2007	2009-2011	Common model	Testing model
C	0,922 (0,503)*	2,127 (0,373)***	1,531 (0,292)***	0,922 (0,503)*
Capital intensity	0,177 (0,034)***	0,245 (0,048)***	0,228 (0,03)***	0,177 (0,038)***
Predicted R&D intensity	-0,08 (0,105)	0,338 (0,087)***	0,101 (0,062)	-0,08 (0,106)
Size	0,018 (0,019)	0,071 (0,026)***	0,024 (0,014)*	0,018 (0,018)
Predicted new patents	0,14 (0,072)*	0,032 (0,046)	0,073 (0,034)**	0,14 (0,064)**
Predicted awards	-0,33 (0,405)	-0,776 (0,297)***	-0,202 (0,156)	-0,33 (0,365)
Labour quality	0,612 (0,123)***	0,4 (0,103)***	0,531 (0,079)***	0,612 (0,109)***
Management quality	-0,027 (0,062)	-0,01 (0,035)	-0,037 (0,03)	-0,027 (0,059)
Inverse Mills ratio	0,151 (0,058)***	0,188 (0,036)***	0,149 (0,03)***	0,151 (0,052)***
Sector 2 dummy	-0,037 (0,156)	-0,598 (0,114)***	-0,298 (0,09)***	-0,037 (0,151)
Sector 3 dummy	0,049 (0,17)	-0,676 (0,133)***	-0,327 (0,109)***	0,049 (0,186)
Sector 4 dummy	-0,088 (0,184)	-0,75 (0,164)***	-0,391 (0,123)***	-0,088 (0,201)
Sector 5 dummy	-0,215 (0,174)	-0,573 (0,121)***	-0,372 (0,1)***	-0,215 (0,161)
Sector 6 dummy	0,273 (0,203)	-0,527 (0,148)***	-0,124 (0,113)	0,273 (0,205)
Country dummy (Germany)	0,27 (0,114)**	0,271 (0,092)***	0,201 (0,056)***	0,27 (0,106)**
Country dummy (France)	-0,241 (0,206)	-0,065 (0,129)	-0,125 (0,094)	-0,241 (0,187)
Country dummy (Spain)	-0,002 (0,254)	0,406 (0,165)**	0,217 (0,134)	-0,002 (0,255)
Country dummy (Italy)	0,232 (0,165)	-0,176 (0,123)	-0,002 (0,094)	0,232 (0,153)
T				1,205 (0,636)*
T*Capital intensity				0,068 (0,058)
T*Predicted R&D intensity				0,418 (0,144)***
T*Size				0,053 (0,031)*
T*Predicted new patents				-0,108 (0,083)
T*Predicted awards				-0,446 (0,467)
T*Labour quality				-0,212 (0,163)
T*Management quality				0,017 (0,071)
T*Inverse Mills ratio				0,037 (0,067)
T*Sector 2 dummy				-0,561 (0,195)***
T*Sector 3 dummy				-0,725 (0,234)***
T*Sector 4 dummy				-0,662 (0,265)**
T*Sector 5 dummy				-0,357 (0,212)*
T*Sector 6 dummy				-0,799 (0,26)***
T*Country dummy (Germany)				0,001 (0,138)
T*Country dummy (France)				0,176 (0,236)
T*Country dummy (Spain)				0,409 (0,316)
T*Country dummy (Italy)				-0,408 (0,206)**
Equation statistics				
R-squared	58,42%	64,85%	59,43%	61,53%
Adjusted R-squared	56,70%	63,39%	58,61%	59,89%
Log likelihood	-269,95	-220,19	-515,83	-493,02
Total observations	429	429	858	858

First values are coefficients, parentheses contain robust standard errors.

*, **, *** denote a significance of coefficients at the 10%, 5% and 1% level.

T denotes a time dummy for the post-crisis period. So the interaction terms allow an estimation of the changes of coefficients over time.

Grigorii V. Teplykh
National Research University Higher School of Economics
Laboratory of Interdisciplinary Empirical Studies and Department of Financial Management
E-mail: teplykhgv@gmail.com, Tel. +79082426825