Secular trends in innovation and technological change

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0 Summary

This paper deals with the question of changing relations between business R&D (BERD), patents and output measures like value added and productivity (macro level) as well as EBIT and market capitalization (micro level) to analyze long-term/secular effects of technological change at different levels.

The results of the panel data reveal an increase of the patent numbers resulting from R&D expenditures. However, we also find a difference in the elasticities of BERD and patents between patent-intensive and non-patent-intensive sectors. In addition, the association between patents and labor productivity falls when all sectors are taken into account, implying decreasing contributions of technological progress to the productivity. Yet, the drivers are non-patent-intensive sectors, as we observe an increasing association of patents and labor productivity for patent-intensive sectors.

The results of the enterprise panel data reveal similar results. The correlations between R&D and patents increased over the last 20 years, although it seems there is a concentration of R&D and patenting activities to a smaller amount of firms, which can partially be explained by the fact that research and development that is necessary for a single patent has become more and more expensive in the past years.

1 Introduction

Recently, several authors have highlighted that the growth of labor productivity has been gradually declining. Syverson (2016) for example presents figures indicating that labor productivity in growth was 1.3% p.a. for the period 2005 to 2015, after having been more than twice as high (2,7% p.a.) in the preceding decennium 1995 to 2004. Most importantly he shows that the decline cannot be the result of measurement artifacts, which were proposed to explain the tremendous decline. Gordon (2015) provides more long-term figures since the 1920ies and shows that today's labor productivity growth in the US is low also with respect to such long time horizons. Gordon (2015) and Summers (2014) have taken these figures as indications of what they call secular stagnation. While Summers (2014) suggests that a demand side failure would be the cause of the stagnation phenomenon, Gordon (2015) argues that it may be caused rather by supply-oriented long-term technology cycles, specifically pointing out that phases of strong growth in labor productivity have been caused by path-breaking technological revolutions. Distinguishing between the Industrial Revolution (IR) #1 (steam engine), IR #2 (electricity/combustion engine/telephone/chemical engineering), and IR #3 (digitalization/computers), Gordon (2015) argues that IR #3 has factually come to an end by moving into technologically decreasing returns to scale. Implicit in his argument is the notion that the technological opportunities associated with IR #3 become more and more depleted. A resulting expectation of the depletion argument is that the relationship between R&D and labor productivity growth has declined over time, because depletion of technological opportunities would make further R&D investments less likely to lead to great technological advances. A phenomenon related to presumable decline in the association between R&D and labor productivity is the so-called patent surge since the end of the 1990ies, which refers to the observation that out off a fixed a mount of R&D ever more patents have resulted (Blind et al. 2004; Kim and Marschke 2004). While some authors have considered the possibility that R&D has become more productive over time (Janz et al. 2001), most researchers assume that the ‘quality’ of each single patent has declined, because of the growing importance of e.g. strategic patenting (Blind et al. 2006; Neuhäusler 2012). In that respect, the increasing per R&D ratios would be indications of an inflationary use of patents associated with a deterioration of the average ‘quality’ or economic value of the patents.

Thus if Gordon’s (2015) supply-side view on the secular stagnation manifested in the depletion-hypothesis was indeed correct, we would expect that the relationship between R&D, patenting, and productivity has changed overtime. In particular, we would expect that R&D on the input side and patenting on the throughput side of the innovation process become more detached from actual advances in terms of labor productivity. Based on this expectation we will analyze how the relationship between the three variables has changed over the last 20 years. We will make use of two datasets on two different levels. The first dataset is based on time-sectoral-country panel dataset for the OECD countries and thus captures the macroeconomic relationship. The second dataset is based on the firm-level and uses merged data from the IRI R&D scoreboard for the largest R&D performing firms world-wide.

2 Dynamics in the Relationship between Patents and BERD on the Sectoral Level

In this subsection, we analyze on the sectoral level on the hand the relationship between transnational patents and business expenditures on R&D (BERD) and on the other hand the relationship between patents and labor productivity. We pay particular attention to how elasticities with respect to BERD and how labor productivity elasticities with respect to patents have changed over time. The analysis of the relationship between patents and BERD can inform us about the existence and the size of a phenomenon which has been labeled patent surge. In particular, if an association between patents and BERD which would increase over time would be consistent with the observation of a patent surge (Blind et al. 2004, Kim and Marschke 2004). The reasons for the patent surge are however still under debate. Some authors have argued that the patent surge may result from higher productivity of R&D spending (Janz et al. 2001). Others have argued that the motives to patent have changed from a protection of technological assets towards strategic patenting (Blind et al. 2006; Neuhäusler 2012). Strategic patenting tends to imply that an invention is not patented to appropriate its value by warranting its exclusive use, but blocking potential competitors. Accordingly, if the strategic patenting hypothesis was true, the real economic effects (e.g. technological progress) associated with a patent have declined over time, because patents no longer need to proxy technological inventions that are put into use. A changing relationship between R&D and patenting and patenting and labor productivity towards an inflation of patents and a weakening of the relationship between patents and productivity may also give indirect evidence of the supply-side oriented depletion hypothesis by Gordon (2015), because it would indicate that actual technological progress increasingly became decoupled from the inputs (R&D) and throughputs (patents) of the innovation process.

In order to gain insights into the effects of patents on technological progress we also analyze how the relationship between patents and labor productivity has changed over time. In particular, we would expect that if the patent surge was driven by purely higher patenting numbers, the elasticity between patents and productivity to fall. Likewise, if the increased productivity of BERD was the driver of the patent surge, we would expect the relationship between patents and real outputs such as productivity would remain at least stable over time. In order to analyze the question of changing elasticities we have constructed a panel data set from 1993 to 2011, which includes on the level of sector-country-year triplets information on a variety of indicators including transnational patents, BERD, value added, exports.

2.1 Construction of the dataset

The data for our analyses were collected from OECD databases (STAN, Main Science and Technology Indicators), the World Bank (population statistics) and the EPO Worldwide Patent Statistical database (PATSTAT) at the level of ISIC Rev. 4 sectors. In order to include all the data in one dataset, some of the data were aggregated to the level of a smallest common denominator for all variables in terms of ISIC4 sectors. This implies that data for most of the manufacturing sectors is available at the 2-digit level, while the service sectors are only available in a much aggregated form.

To deal with missing data in our ISIC4 dataset, we resorted to ISIC3 data. With the help of the concordance of the United Nations Statistics Division some of the gaps within the data could be filled when the concordance was unanimous at the 2-digit level.

The final challenge relates to patents, which are not available at the level of sectors but are classified technologically via the International Patent Classification (IPC). The solution to this problem lies in the match of PATSTAT to Bureau van Dijk's ORBIS database at the level of companies/patent applicants that is available at Fraunhofer ISI. With the help of this matched database patent applicants in PATSTAT can be assigned an ISIC Rev. 4 class. However, due to incomplete coverage for the earlier years and the fact that the industry structure in the recent years does not resemble the industry structure in the 1990s, we cannot simply aggregate the companies' patent filings at an aggregate sector level. We therefore generated a matrix of patent filings by sector and technology fields (WIPO35 list, Schmoch 2008) in the time period from 2011-2013. From there, we can calculate the share of patents in a given technology field by economic sector. These shares can in a further step be applied to recalculate patents by technology fields to economic sectors across the whole time period. By doing this, we have to assume that the calculated shares are fixed across the whole time-period. However, this allows us to handle the break in series of the sector classification. Additionally, we have compared the matrix in 2011-2013 to a matrix for 2001-2003. The differences are rather small, which backs our assumption that the shares can be applied across the whole time series.

2.2 Methodology

The patent production function approach (Pakes and Griliches1984) suggests that patents are produced by a set of input factors. One of the major inputs is firms R&D spending, on which the focus of this chapter lies. Taking into account that the relationship between patents as an output and the input factors may change over time, the patent production function approach therefore suggests that patents can be described by the following generic representation:

$$patents_{it} = f_{1t}(BERD_{it}; x_{it}) \tag{1}$$

where x_{it} is a $1 \times k$-vector of other inputs and further control variables and f_t is some function not a priori specified. In the patent production function patents represent an output resulting from successful R&D spending. At the same time, Grupp (1997) notes that patents in the whole innovation chain actually are rather an intermediate output. Patents can therefore be considered as being themselves an input for real-term economic effects, such as advances in productivity. Seeing patents as an input into labor productivity suggests a relationship analogous to Eq. (1):

$$value\_added_{it} = f_{2t}(patents_{it}; x_{it}) \tag{2}$$

The goal of this chapter lies in estimating those parts of $f_{jt} \quad j = 1,2$, which determine inasmuch patents depend on BERD and how value added depends on patents in any point in time. The estimation of f_{jt} can be performed in various ways:

One approach to assessing the time-dependence of the relationship between patents and BERD can be implemented by modeling the ratio between patents and BERD as a function of time t:

$$\frac{patents_{it}}{BERD_{it}} = g_1(t; x_{it}) \tag{3}$$

$$\frac{value\_added_{it}}{patents_{it}} = g_2(t; x_{it}) \tag{4}$$

where $g_j \quad j = 1{,}2$ is some function of t and other controls. Eq. (3) and Eq. (4) can be estimated using both parametric and non-parametric methods. To allow for greater flexibility we will use fully-non-parametric spline regression. A spline is a piecewise-defined low-degree polynomial function, which is very smooth at connecting nodes (Wahba 1990; Green and Silverman 1994). Splines have often been used in physics because they have an intuitive interpretation. The connections are determined so that the bending energy corresponding to the intersections of segments is the lowest possible. Splines have however become also very popular in economics (Judd 1998) because the application of local low-degree polynomials leads on the one hand to time efficient and consistent estimation of any sufficiently smooth functional relationship and on the other hand does not produce outliers that would occur in global polynomials of higher degree. To estimate Eq. (3) and (4) we use, in specific, a discontinuity-panelized spline-smoother on the resulting partial residuals against time. If the functions g_j do not depend on time, the partial residuals should follow no trend. A positively sloped trend line in, say, Eq. (3) will indicate that the relationship between BERD and patents has become stronger, i.e. that for any given R&D spending more patents have resulted in later as compared to earlier periods. The resulting spline-graphs also report a test taking the Null-hypothesis of a linear relationship. A rejection of the Null indicates that any observable non-linearity is significant.

The proposed spline-approach has the disadvantage that it informs only about the direction of the change of the relationship between patents and BERD and value added and patents respectively, but it says little about size. Furthermore, a change in the ratio of patents to BERD or of patents and value added may result both from a change in f_{jt} and simply from non-constant returns to scale. For example, suppose that the patent-BERD relationship is subject to increasing returns to scale, growing BERD figures may lead to an upward trend in the spline-graph. But this trend has little to do with a change the function f_{1t} but merely with the fact that f_{1t} is convex and BERD is growing. We can solve the issue of missing size interpretations and non-constant returns to scale by a slightly different approach. In particular, we specify the following two log-log-equations:

$$log\left(\frac{patents_{it}}{value\_added_{it}}\right) = \alpha \cdot log\left(\frac{BERD_{it}}{value\_added_{it}}\right) + x_{it}\beta + c_i + u_{it} \tag{5}$$

$$log\left(\frac{value\_added_{it}}{employment_{it}}\right) = \delta \cdot log\left(\frac{patents_{it}}{employment_{it}}\right) + z_{it}\gamma + k_i + v_{it} \tag{6}$$

where $c_i$and k_i refer to time-constant unobserved heterogeneity, u_{it} and v_{it} are idionsyncratic error terms and x_{it} and z_{it} are vectors of control variables with coefficient vectors β and γ. Because of the log-log-specification α and δ have the interpretation of elasticities. $\alpha \cdot 100$ for example measures the percentage change in patents per value-added induced by a 100%-increase in BERD per value added. We can estimate Eq. (5) either by random effects or by fixed effects models, but we prefer fixed effects models because we can control for correlated unobserved heterogeneity. We can determine whether α and δ have changed over by running Eq. (5) and eq. (6) for different time periods.

In Eq. (3)-Eq. (5) we include control variables. For the patent-BERD relationships, we use a variable capturing the exports per valued-added, the population in the country and the sectoral one-year growth factor. In the value added-patent relationships we exclude the BERD variable because patents are already included as a throughput. Also note that we normalize patents and exports by employment because we use labor productivity as the explained variable. All variables are used in log-form. In the parametric estimations of Eq. (5) and Eq. (6) we additionally include year dummies. Including year dummies also in the spline regressions would be useless, because it models the time trend explicitly.

2.3 Results

Table 1 contains descriptive statistics on the set of variables used throughout this chapter. All monetary units are measured in mln US-$ in power purchasing parities. We see that the average number of transnational patens per US-$ 1 mln is 0.05, while 1 mln. spending on BERD is associated with about 2 transnational patents.

Table 1: Summary statistics[1]

Variable	Obs	Mean	Std. Dev.	Min	Max
Transnational Patents per Value Added in mln. US-$	6371	0.0519	0.1136	0.0000	1.5171
BERD per Value Added	4862	0.0498	0.0852	0.0000	1.0501
Transnational Patents per BERD in mln. US-$	6255	2.0001	8.7822	0.0045	354.7910
Exports per Value Added	6304	1.9612	3.6829	0.0005	64.2124
Population in mln	9408	120.0000	290.0000	3.6000	1400.0000
Sectoral Growth Factor	5988	0.9770	0.0972	0.6902	1.4289
Parkindex	8589	0.8845	0.0797	0.4240	0.9760
BERD financed by Government	9110	7.3224	5.0364	0.8200	33.9300
Indirect relative direct gov. R&D support	3510	1.4533	1.9955	0.0000	9.8571
Patent-intensive sectors	9408	0.4767	0.4995	0.0000	1.0000
Non-Patent-intensive sectors	9408	0.5233	0.4995	0.0000	1.0000

We now turn to results of the spline-regressions, which can be found in the panels of Figure 1. The three figures on the left refer to the patents per BERD ratio, while the panels on the right refer to the value added per patent ratio. As a robustness check both variables are evaluated using different polynomial degrees. The top panels use a degree zero, which produces the best-

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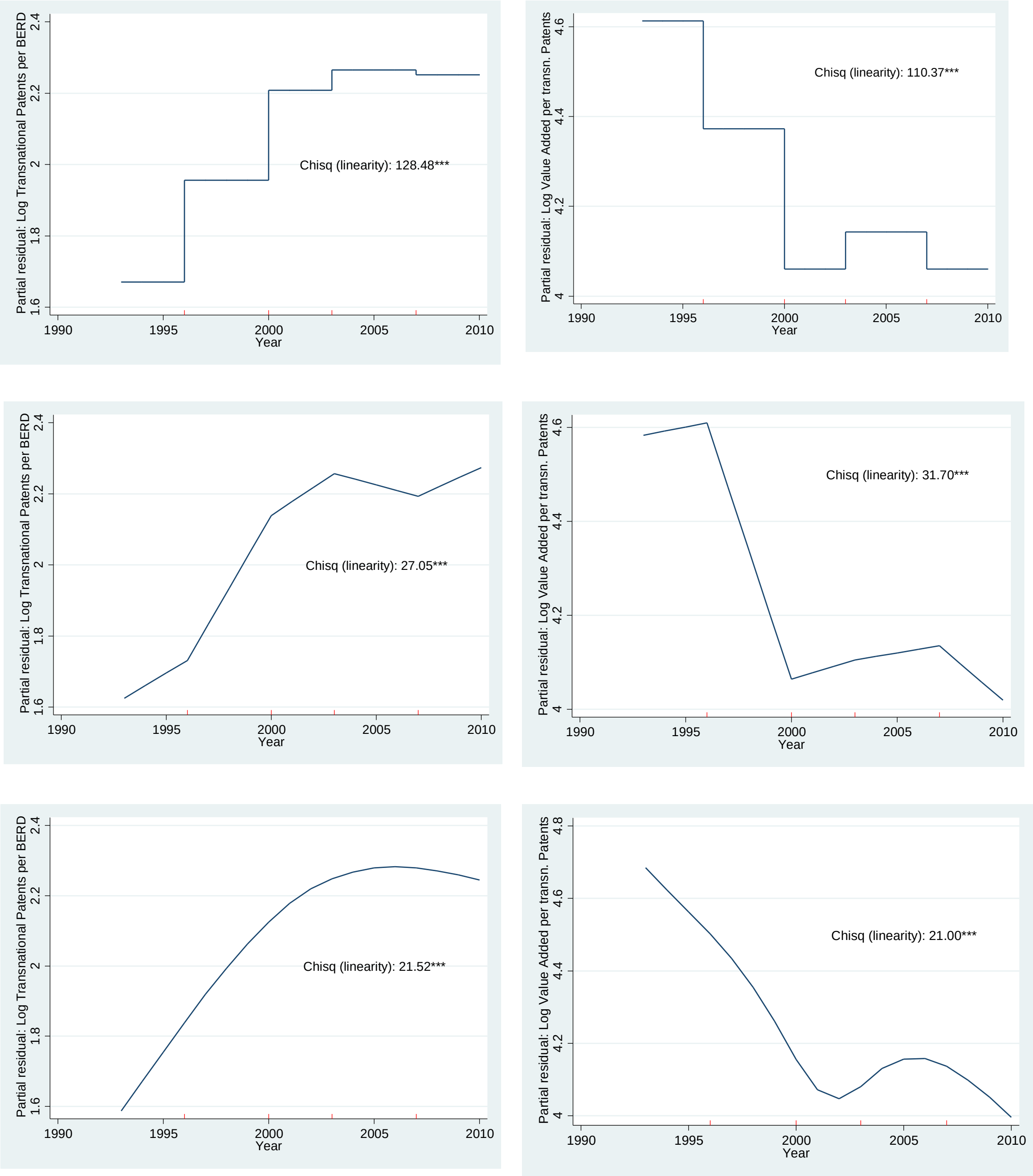
[1] The definition of patent-intensive sectors is loosely inspired by the OECD tech-level classification and combines NACE-sectors 20-30. Because of the sectoral availability of export data, it was not possible to clearly distinguish between any of the sectors 35-99. These sectors and in addition NACE sectors 01-19 and 31-33 are grouped under non-patent-intensive sectors. The approach is despite the high level abstractness still appropriate as the patent per value added indicator amounts to 0.074 in the patent-intensive sectors while it is only 0.023 in the non-patent-intensive sectors

fitting step-function. In the middle panels polynomials of degree 1 are allowed, which leads to locally-linear splines. In the bottom panels, we use a degree 2, which leads to smooth continuous quadratic splines. For both variables the results turn to be fairly robust changes in the polynomial degrees.

Turning to the question of how the patent per BERD ratio changes over time, we see strong increase until about 2002-2005, which largely coincides which coincides with the New Economy crisis. After 2002-2005 the figures differ a little bit depending on whether we use a step-function, linear, or quadratic spline. The step-function and the quadratic spline show a slightly decreasing trend in the effects BERD have on patents after about 2005-2007, while for the linear spline there is only a small dip in 2007 but an increase in the 2005-level afterwards. Contrary to the intensifying patent-BERD relationship we see that the productivity-patent relationship has considerably weakened again until 2002-2005 implying that additional patents had a smaller effect on labor productivity as measured by value added per employment. After 2002-2005 depending somewhat on the degree the weakening stopped (degree 0) or at least considerably slowed down (degree 1 and degree 2). Note that in all cases, the trends in Figure 1 are strongly significant as indicated by the Chi-square tests. In summary, we see that the patent-BERD relationship and the value added-patent relationship followed two opposed trends over time. While the BERD expenditures where continuously associated with an increasing number of patents, the effect that a given number of patents had on labor productivity decreased.

We have indicated that the observable trends in the patent-to-BERD-ratios and the value-added-to-patent-ratios as identified by the spline-regressions need not indicate that indeed the function linking the two variables has changed over time. A confounding mechanism could be that the patent output is subject to increasing returns to scale with respect to BERD. If BERD had increased over time, the positive time trend in the ratio of patents and BERD could be purely driven by the increasing returns to BERD. An analogous argument based on decreasing returns of patents could be made for the relationship between value added and patents. To rule this out we estimate the parametric specification in Eq. (5) and Eq. (6) by fixed effects for an early and a late time period. Based on Figure 1, we choose as cut-off the peaking year in 2002.

Figure 1: Partial Residual Plots: Penalized Spline Regression for the patents per BERD (left panels) and value added per patents at Degree 0 (top panels), 1 (middle panels), and 2 (bottom panels)



The regression results for the patent-to-BERD-ratios can be found in Table 2, where the two left columns do not include any control variables despite year dummies, and the two right columns include the control variables as discussed in the previous subsection. In general, we find a relatively consistent picture in both types of regressions. First, we note elasticities of patents with respect to BERD (both per value added) are highest when no controls are taken into account.

We find an elasticity ranging between 0.030% (before 2002) and 0.093% (after 2002) here. If we include controls, the values drop to 0.022% (before 2002) and 0.059% (after 2002). Irrespective of whether we include additional controls we find strong support for the relationship between patents and BERD which is characterized by decreasing returns to scale. Decreasing returns to scale, however, rule out that the increasing time-trend of patents to BERD is driven by increasing returns to scale. In fact, when comparing elasticities before and after 2002, we find indeed an increasing association between both variables. Focusing on the results including control variables, the number of transnational patents increases by 0.022% if BERD increases by 1% before 2002 while the number of patents increases by 0.059% and is therefore almost three times as large.

Table 2: Fixed Effects Regressions: Patenting Elasticities with respect to BERD

	(1) Log transnational Patents per Value Added	(2) Log transnational Patents per Value Added	(3) Log transnational Patents per Value Added	(4) Log transnational Patents per Value Added
Log BERD per Value Added	0.0300***	0.0934***	0.0222**	0.0596***
	(2.65)	(10.12)	(2.14)	(6.93)
Log Exports per Value Added			0.3492***	0.1968***
			(14.31)	(10.83)
Log Population			-1.1438***	3.7857***
			(-2.84)	(10.36)
Sectoral Growth Rate			-0.3231***	-0.3801***
			(-7.88)	(-13.97)
Constant	-4.7367***	-3.5821***	15.2657**	-68.7642***
	(-92.77)	(-92.37)	(2.20)	(-10.94)
Year dummies	YES	YES	YES	YES
Observations	2660	2293	2637	1973
R^2	0.546	0.127	0.609	0.293
#Groups	309.0000	335.0000	309.0000	330.0000
F-stat	281.8806	31.5621	277.0750	61.4437

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The results on the relationship between productivity as measured by labor productivity and patents per employee can be found in Table 3. The results strongly support the findings from the spline regression and show that the productivity-patenting elasticities have declined both in the case with control variables (two left columns) and without (two right columns). The declining elasticities support the hypothesis that the patent surge had more to do with a multiplication of patent numbers unassociated with increases in technological output.

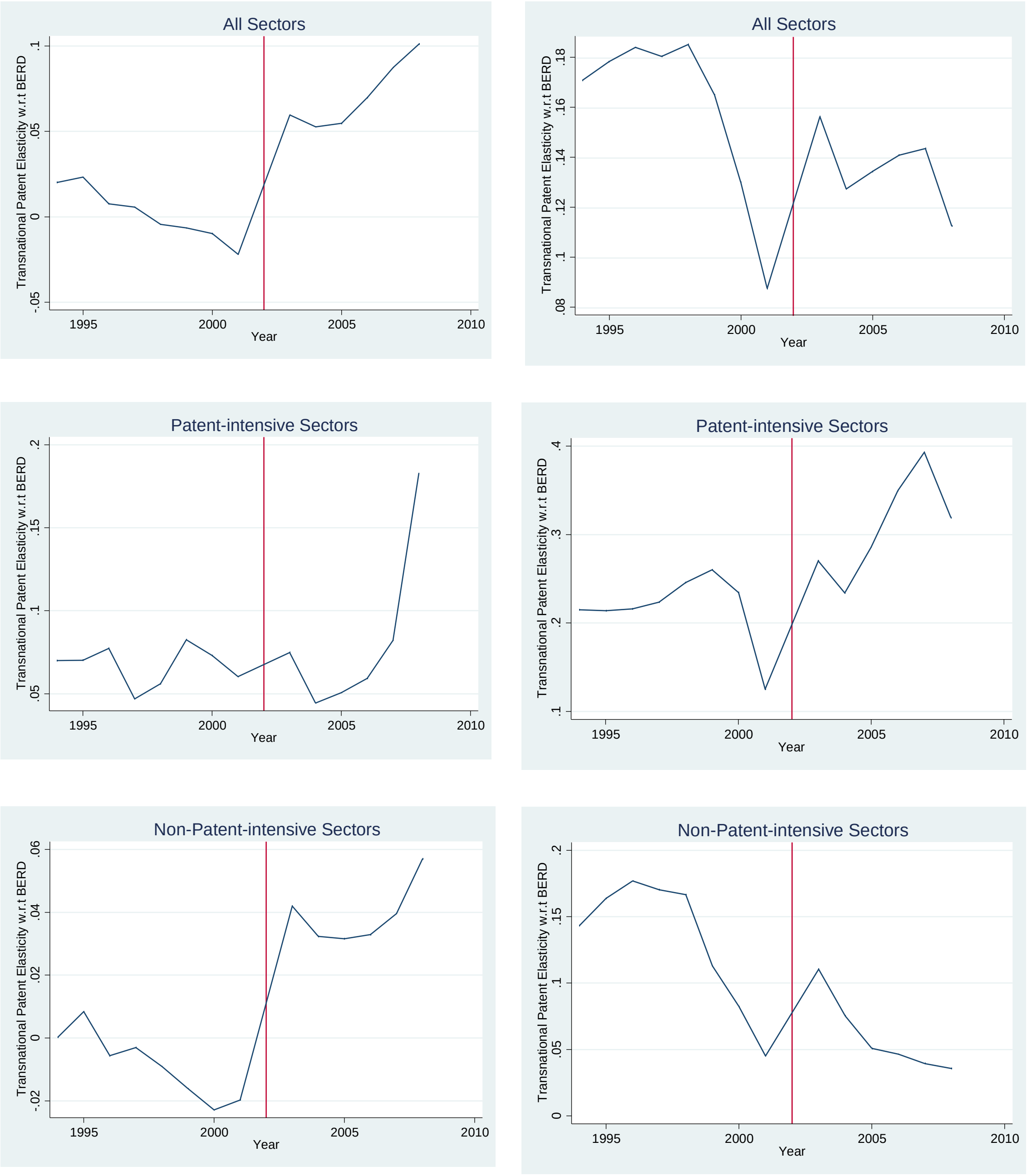
Table 3: Fixed Effects Regressions: Productivity Elasticities with respect to Patents

	(1) Log Value Added per Employee (before 2002)	(2) Log Value Added per Employee (after 2002)	(3) Log Value Added per Employee (before 2002)	(4) Log Value Added per Employee (after 2002)
Log transnational Patents per Employee	0.1352***	0.0429*	0.0735***	0.0418*
	(13.12)	(1.77)	(7.40)	(1.76)
Log Exports per Employee			0.1717***	0.1564***
			(15.25)	(10.84)
Log Population			0.0701	-0.1864
			(0.38)	(-0.70)
Sectoral Growth Rate			0.4107***	0.3749***
			(23.16)	(18.93)
Constant	-2.0494***	-2.1570***	-3.0554	1.3578
	(-25.83)	(-13.91)	(-0.95)	(0.30)
Observations	2948	2326	2896	2042
R^2	0.529	0.316	0.632	0.487
#Groups	316.0000	316.0000	316.0000	316.0000
F-stat	295.0468***	102.4980***	338.5668***	147.8297***

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 2: Patenting-BERD elasticities (left panels) and value added-patenting elasticities (right panels) from moving regression windows by sector (Fixed Effects regression)



To substantiate the results further, in addition to

Table 2 and Table 3 we have distinguishing only between an early and a late period. We run fixed effects using a moving regression window, where we plotted the resulting elasticities in Figure 2 (left panels: patent-BERD -elasticities; right panels: value-added-patent-elasticities).[2] In addition we have made a distinction between sectors. Looking at the upper left panel we make the general observation that the association between R&D and patents has become stronger over time, although before 2001 there seems to be some indication of declining trends. However after 2001 the trends are strongly increasing. If we distinguish the results by patent and non-patent-intensive sectors we find the increasing association between patents and BERD largely corroborated, although there is some indication that the increase in the association came later in patent-intensive sectors (2004 and after) than in non-patent-intensive sectors (2000 and after). As intuitively expected we find that the patenting elasticities with respect to BERD are much higher in patent-intensive sectors (about 0.18% in the last period) than in non-patent-intensive sectors (about 0.06% in the last period).

Looking at the value-added-patents-relationship (right panels) we find a declining trend in the elasticities when not making a sectoral distinction. However, the declining trend seems to be driven completely by non-patent-intensive sectors (bottom right panel). For patent-intensive sectors we can observe the opposite trend. Here the elasticities between of value added with respect to patents have almost doubled from slightly above 0.2% to almost 0.4%.

2.4 Policy effects on the patent-BERD and value-added-patent elasticities

In addition, to the analysis of the patent-BERD and value-added-patent elasticities we have provided some information on whether policy-regimes in the field of innovation and patenting influence the elasticities. To analyze this question we have added information on the policy regimes determining the incentives for patenting and R&D spending. In specific, we have complemented the data with the Park index (Ginarte and Park 1997; Park 2008), the share of BERD financed by Government, and the information on the degree of whether public R&D support is allocated via direct project funding or tax incentives for R&D. We test whether the variables describing the policy/funding regime affect the elasticities between patents on the one hand and BERD on the other. Information on the policy regimes is available only on the country-level implying that these data may differ by time but not by sector.

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[2] Because a fixed-length-moving window led to outlier results in some years, we have used the following length variable windows, where the coefficients in Figure 2 refer to the first included year: 1993-2002, 1994-2002, 1995-2002, 1996-2002, 1997-2002, 1998-2002, 1999-2002, 2001-2002, 2002-2011, 2003-2011, 2004-2011, 2005-2011, 2006-2011, 2007-2011, 2008-2011.

In Table 4 we analyse the effects on the patenting-BERD elasticities. In specific we consider the effect of the Park index measuring the strength of the patent protection, share of BERD financed by government, and the ratio of indirect to direct support. We find that a higher Park index (i.e. greater strength of patent protection) is significantly associated with weaker effects of BERD on patent outputs. One interpretation is that the observable patent surge is largely the result of the increase effort to create patent thickets. Stronger patent systems however decrease the need for patent thickets and therefore reduce the amount of patents resulting from a given R&D expenditures. We also observe that higher government financing of BERD is significantly associated with an increase in the elasticity. No effect is associated with the ratio of indirect to direct R&D support.

Table 4: Fixed Effects Regressions: Effects of Policy/Support Regimes on the patent-BERD-relationship

	(1) Log transnational Patents per Value Added	(2) Log transnational Patents per Value Added	(3) Log transnational Patents per Value Added
Log BERD per Value Added	0.3737***	0.0313***	0.1061***
	(6.08)	(3.06)	(4.87)
Parkindex	3.5035***		
	(8.63)		
(Log BERD per Value Added)*Parkindex	-0.3135***		
	(-4.51)		
BERD financed by Government		0.0268***	
		(7.18)	
(Log BERD per Value Added)*(BERD financed by Government)		0.0049***	
		(6.60)	
Indirect relative direct gov. R&D support			-0.0197
			(-0.55)
(Log BERD per Value Added)*(Indirect relative direct gov. R&D support)			-0.0106
			(-1.34)
Log Exports per Value Added	0.1737***	0.2268***	0.1828***
	(10.72)	(13.85)	(5.69)
Log Population	2.8982***	1.0685***	0.6051
	(13.03)	(4.67)	(0.42)
Sectoral Growth Rate	-0.3891***	-0.3523***	-0.4387***
	(-12.27)	(-10.65)	(-13.30)
Constant	-57.0353***	-22.8093***	-13.7357
	(-14.67)	(-5.80)	(-0.56)
Year dummies	YES	YES	YES
Observations	4207	4587	754
R^2	0.520	0.502	0.557
#Groups	335.0000	335.0000	268.0000
F-stat	198.8766	185.5870	66.5818

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In Table 5 we analyze the elasticity of labor-productivity with respect to patents. Neither the Park index nor the ratio of indirect to direct project funding shows any significant effects. However, we find that the share of governmental R&D funding decreases the effect of patents on value added. The interpretation of this effect remains somewhat speculative without any further analysis but it suggests that in countries with higher level of government financed R&D the effect of BERD on productivity is low. Whether this finding implies that governmental R&D is generally less effective or whether the result is driven by some few less performing countries with high governmental BERD financing (e.g. Eastern European countries) remains unclear.

Table 5: Fixed Effects Regressions: Effects of Policy/Support Regimes on the Value-added-patent relationship

	(1) Log Value Added per Employee	(2) Log Value Added per Employee	(3) Log Value Added per Employee
Log transnational Patents per Employee	0.0431	0.0594***	0.1376***
	(1.64)	(5.13)	(2.67)
Parkindex	0.0695		
	(0.20)		
(Log transnational Patents per Employee)*Parkindex	0.0138		
	(0.43)		
(Log transnational Patents per Employee)*(BERD financed by Government)		-0.0008***	
		(-3.42)	
Indirect relative direct gov. R&D support			-0.0419
			(-0.56)
(Log transnational Patents per Employee)*(Indirect relative direct gov. R&D support)			-0.0064
			(-0.52)
BERD financed by Government		-0.0130***	
		(-5.27)	
Constant	3.1997	-3.2654	-15.3184
	(1.30)	(-1.50)	(-0.79)
Year dummies	YES	YES	YES
Observations	4508	4932	745
R^2	0.633	0.666	0.570
#Groups	316.0000	316.0000	255.0000
F-stat	343.3075***	397.9036***	70.9074***

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

2.5 Summary

We have provided consistent evidence that the strength of the association between patents and BERD has increased over time giving multivariate support of the descriptive accounts of exploding patent numbers. However, it has remained under debate what the reasons for the increasing numbers of patents are. While some authors have argued that the patent surge is the result of real phenomena – Janz et al. (2001) considered the possibility of higher productivity of R&D spending – other authors have attributed the patent surge to changes in the motives to patent implying that patenting numbers and measures of technological progress become increasingly decoupled. Our results show a differentiated picture. While – on average – the relationship between patents and labor productivity has become weaker over time, we can show that the weakening can be attributed exclusively to non-patent-intensive sectors. In the non-patent-intensive sectors BERD has led to an ever-increasing number of patents. However, the additional patents have not implied an increase in labor productivity. On the contrary, the elasticities of labor productivity with respect to patents have gone down while the elasticities of patents with respect to BERD have gone up. The opposed trends can be interpreted to mean that the patent surge does not reflect real technological trends but rather changes in the patenting motives in non-patent-intensive sectors. On the contrary, in patent-intensive sectors we observe that the BERD-elasticity of patents and the patent-elasticity of labor productivity have increased simultaneously. The co-movement of both elasticities suggests an interpretation that differs from the non-patent-intensive sectors. In particular, because the association between labor productivity and patents has become stronger, the reason for the patent surge may well have been rooted in the increasing importance of knowledge and technology as a competitive parameter. In that sense, the patent surge may well reflect a real phenomenon in patent-intensive sectors. As a word of caution concerning the interpretation of our results it should however be mentioned that our analyses observe the evolution of elasticities inside given sectors. Gordon (2015) at the same time considers IR #3 to be a multipurpose technology. It would therefore be interesting as well to analyze cross-sectoral effects of R&D, patents and labor productivity. A worthwhile but time-consuming approach could be implemented by using sectoral input output tables.

3 Dynamics in the Relationship between Patents and BERD at the Firm Level

Within this section, we also analyze the relationship between transnational patent filings and business expenditures on R&D (BERD). However, we switch the angle and go from the sectoral perspective to the firm-level perspective to learn more about the mechanisms behind this relationship and how it evolved over time. In addition to the BERD/patent correlation, we will also take a look at how both measures relate to firm success. To analyze our questions, we have constructed a firm-level panel dataset based on the "EU Industrial R&D Investment Scoreboard" from 1990 to 2012 that has been matched to PATSTAT data. Besides the information included in the *Scoreboard*, i.e. R&D expenditures, profits, sales etc., the dataset also comprises information on the companies' patent filings. Before digging deeper into the results, we will first of all describe our dataset and the variables used for the analysis. In the next step, we will present the descriptive results on the above mentioned relationships as well as multivariate panel regression models providing a more differentiated view.

3.1 Data & Methods

3.1.1 The Data

For the analyses at the micro level, a panel dataset including 435 firms (1990-2012) based on the "EU Industrial R&D Investment Scoreboard" (former DTI-Scoreboard3) has been constructed (compare Neuhäusler et al. 2016b) for a more detailed description on the dataset creation). The Scoreboard is set up by the European Commission and includes companies investing the largest sums in R&D worldwide. The scope of the Scoreboard is expanded progressively, increasing the number of companies and geographic and time coverage. Besides information on R&D expenditures, the Scoreboard contains data on the companies' market capitalization, profit, employees and sales as well as industry classifications, country information etc. Since the Scoreboard is a ranking of companies according to their annual R&D expenditures, large firms are overrepresented in the sample.

For the construction of our dataset, we started with the Scoreboard of the year 2001, where a total of 500 companies were listed for this year. Company data from the previous and following years up to the Scoreboard of the year 2007 were added to this dataset to construct a firm-level panel. To this, we further added company information from the Scoreboard of the year 2013, which contains information dated back to the year 2004. From this source, we also collected the time-invariant information, i.e. sector assignment, country, and dated it back to the earliest firm-year in the dataset. This implies that the break in the NACE classification is not a problem for these analyses.

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[3] The DTI-Scoreboard is an annual ranking of firms alongside their R&D expenditures. Initially, it was published by the UK’s Department of Trade and Industry (DTI). The most recent version of the Scoreboard was published by the UK Department for Business, Innovation and Skills (BIS). However, the service for the DTI-Scoreboard was discontinued in 2012. The versions used to create the dataset for this analysis can be accessed at the UK government’s National Archive: http://webarchive.nationalarchives.gov.uk/20101208170217/http://www.innovation.gov.uk/rd_scoreboard/?p=31

If any company was not listed in the years before or after 2001, the respective observations were treated as missing, i.e. not all information is available for all company-years (unbalanced panel). In the case of mergers and acquisitions (M&A) between listed companies, the data of the respective companies were added for the entire time period. The companies were thus treated as if they were already merged at the beginning of the observation period.[4] Data on M&A with companies not listed in the Scoreboard were not available and thus had to be left uncontrolled.[5] Due to M&A between listed companies, the initial number of 500 firms is reduced to 435 for the whole time period.

The relevant patent data were extracted from the 'EPO Worldwide Patent Statistical Database' (PATSTAT), which provides information about published patent documents collected from over 80 patent authorities worldwide. We restricted the analyses to transnational patent filings, i.e. EPO plus filings at the WIPO (PCT) excluding double counts (Frietsch and Schmoch 2010). All patent data reported are dated by their priorities, i.e. the year of worldwide first filing. To generate the link between the patent data and the Scoreboard, a probability matching of patent applicants with company names from the R&D Scoreboard was performed (a detailed description of the algorithm can be found in Neuhäusler et al. 2016a). With the combined PATSTAT/Scoreboard dataset, we now have the opportunity to relate the innovative outputs of the firms listed in the Scoreboard to its inputs, i.e. we are able to calculate patent intensities (patent filings per million R&D expenditures) for the Scoreboard firms and correlate R&D expenditures and patent filings across a long time period.

Our final sample thus consists of 10,005 company/year observations of 435 firms from 1990 to 2012. The number of observations and firms are lower in the following regression models due to missing values within some of the variables.

3.1.2 Variables

We aim to analyze the development of the relation of R&D expenditures and patent filings from the beginning of the 1990s up to the year 2012, to find out whether there have been significant changes to this relationship over the course of time. The first two important variables for our analyses consequently are the R&D expenditures per company and year (in millions) as well as transnational patent filings. With regard to the R&D expenditures, it has to be mentioned that the R&D expenditures of a company's subsidiaries are included in a company's R&D expenditures, which is due to the matching of R&D and patent data. This should make R&D expendi-

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[4] This preserves comparability over time, as it is no longer possible to separate the individual company information after a merger (compare Frietsch 2006).

[5] In any case, since this contains the most important R&D performers, the enterprises not listed should be smaller and distortions should be limited.

tures and patents more comparable since patents are often filed not by the subsidiary itself but by the parent company.

In order to find out whether and how patent filings are related to economic outcome measures, we further analyze the correlation between patent filings and operating profits as well as the market capitalization of the firms in the sample. Operating profit or earnings before interest and tax (EBIT) is the profit earned from a firm's normal core business, excluding any interest or tax effects. Market capitalization, on the other hand, is the market value a company's shares. It is calculated by multiplying the number of a company's shares by its market price. The difference in the two measures is that a firm's EBIT informs about the actual operative result of a company in a given year, whereas the market capitalization reflects how the market values a company. For all of these variables, the upper and lower 1% values where coded as missing to avoid the problem that massive outliers influence the results.

Besides looking at the bivariate correlations between our variables, we will run several (fixed effects) panel regression models, where we are able to control for company size in terms of employees (in thousands). In addition, we include industry dummies (NACE Rev. 2, 2-digit) to control for industry-specific effects. Finally, we include time-dummies to control for period-specific effects. An overview of the variables including summary statistics can be found in Table 6.

Table 6: Summary Statistics

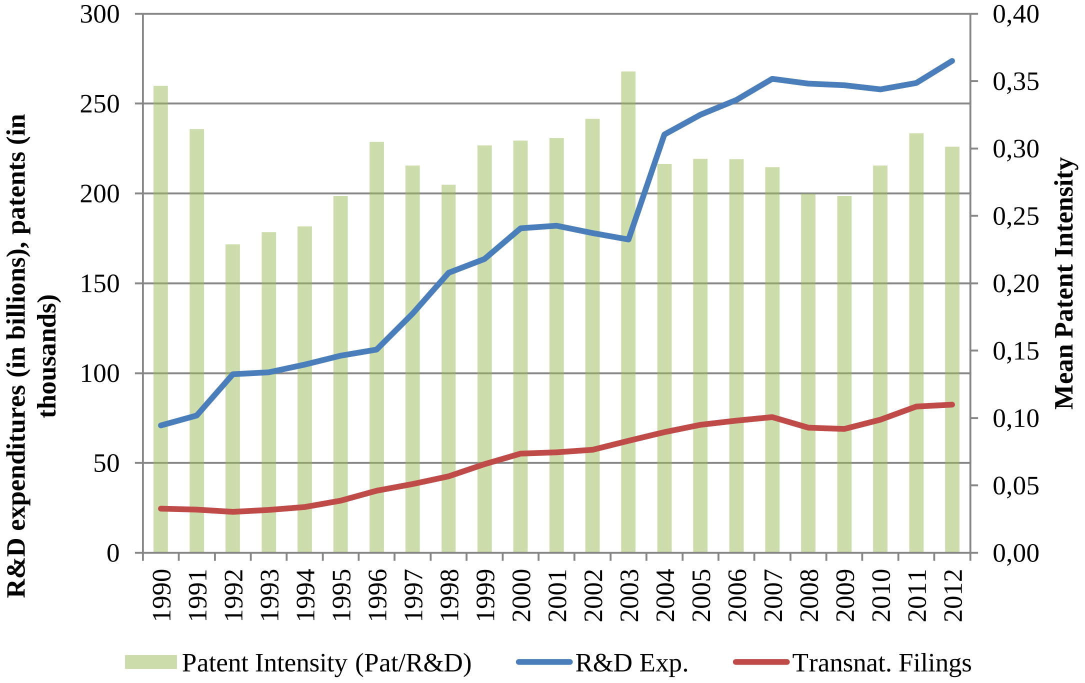
Variable	**Mean**	**Std. Dev.**	**Min**	**Max**	**# Obs.**	**# Firms**
R&D Exp. (in millions)	522.0	822.0	15.9	5090.6	7948	434
Transnat. Filings	120.9	251.3	0.0	3010.0	10005	435
Market Cap. (in millions)	1218.1	2205.8	-1864.7	16238.0	6621	435
Operating Profit (in millions)	13498.5	22184.6	70.0	147922.4	6418	425
Employees	48231.1	58469.6	324.0	344902.0	7838	434
Year	2001.0	6.6	1990.0	2012.0	10005	435
NACE (Rev. 2, 2-digit)	31.6	15.5	10	96	8924	388
Country	17.5	5.6	1	23	8924	388

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

3.2 Results

In a first step, we take a closer look at the development of the patent intensity – i.e. the number of patents per million R&D expenditure (nominal values) – for the firms in the sample. This is plotted in Figure 3. From the graph we first of all observe that the number of transnational patent filings as well as the amount of R&D expenditures have risen over the last 20 years. The growth of both figures is slowed down during times of economic crises, i.e. between 2000 and 2002 during the new economy crisis and between 2008 and 2010 during the recent financial crisis. What we also can see, however, is that the growth of patent filings has been larger in the 1990s than it has been recently. As already stated in the previous chapter, this phenomenon has been described as the patent surge and becomes most visible when directly looking at the patent intensity that is also plotted in the graph.

Figure 3 R&D expenditures, patent filings and patent intensity over time



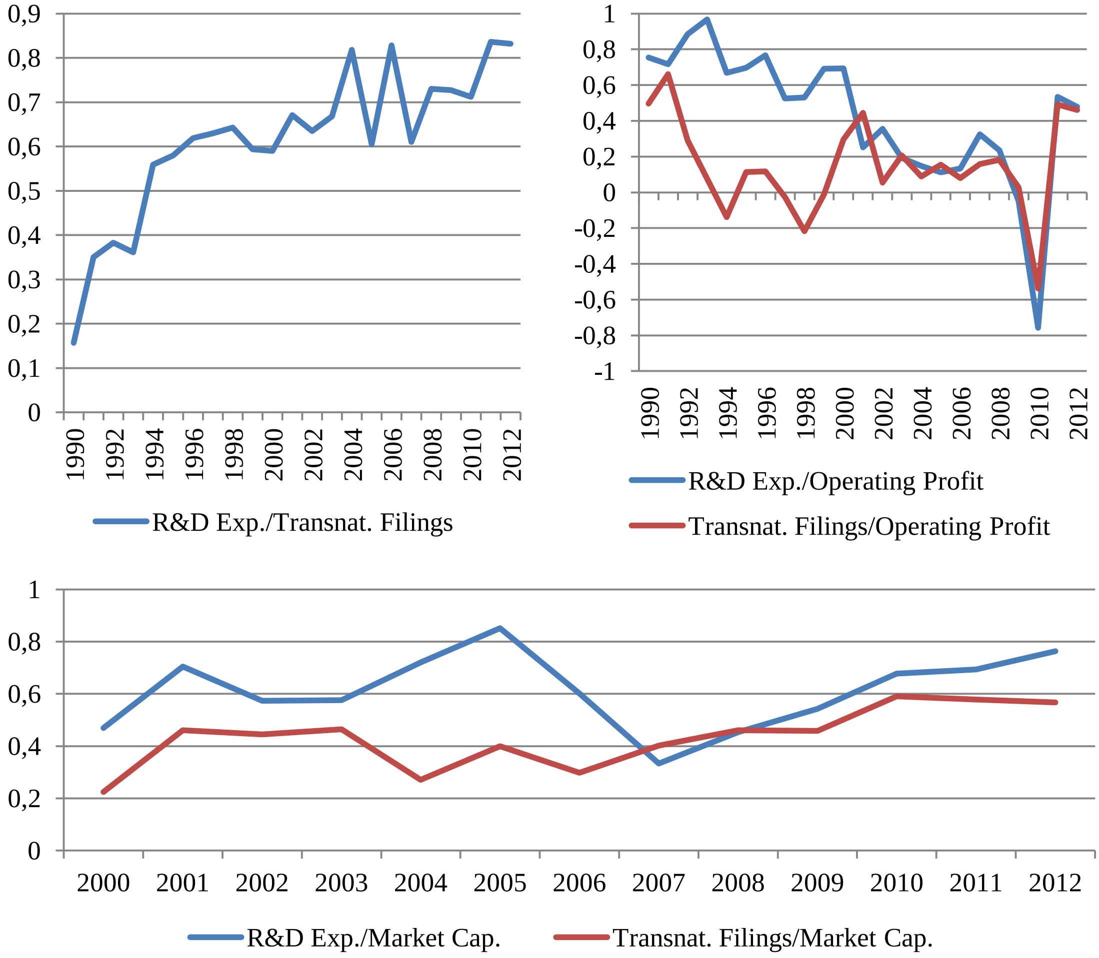
Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

As we can see, the patent intensity has constantly increased in the 1990s. During this period, the number of patent filings was growing fast, whereas the amount of R&D spent only rose moderately (see for example Blind et al. 2006). However, the patent intensity peaked in 2003 and from then has started to decline up to the year 2007. Due to the financial crisis it was lowest in 2008 and 2009 - where the number of filings has decreased while the R&D expenditures have mostly remained at a constant level - but then started to slightly grow again from 2010 onwards. It thus seems that at least for the firms in the Scoreboard, the R&D expenditures in the 2000s were growing at a quicker pace than the patent filings, overall leading to a decrease in the patent intensity over the years. This means that in terms of R&D, generating patentable outcomes becomes more expensive or - vice versa - less patents can be filed per million R&D. This can be due to several reasons. First, companies might file less, which might mean a reduction in strategic patents, i.e. to block competitors etc. (Blind et al. 2006; Neuhäusler 2012). A second explanation could be that complexity and R&D costs increase, so that generating patentable results becomes a more expensive process. Third, an overall structural change might have occurred, towards more R&D intensive or more expensive research fields. Within this study, we will not be able to find a definitive answer to this question. However, we aim to provide some insights into the development of the R&D/patent relationship over time as well as the relation of these indicators to firm success, measured by profits and market capitalization of the analyzed firms.

A first step towards this end is the analysis of bivariate correlations between our variables. This is plotted in Figure 4 (the underlying values and significance levels can be found in the Annex). As can be seen from the upper left of the figure, the correlation between R&D expenditures and transnational patent filings has been rising over the last decade. However, the rather low correlations in the 1990s should largely be driven by the fact that transnational patents (and not national filings) are analyzed, which only form a selected subset of a company's patent filings. However, transnational filings, especially via the WIPO, have gained increased importance for the firms and sometimes have become the "standard" way for firms to file their patents. In general, we thus observe a rather high correlation between R&D and patent filings. What is interesting to note, however, is that this relationship seems to be disturbed in times of financial crises. This has already been found in earlier studies of this series (Neuhäusler et al. 2014). Here, the R&D starts to uncouple from the patent filings as firms follow different cost-saving strategies with regard to research projects as well as patent filings.

With regard to the relationship of R&D expenditures, patents and operating profit of the firms in the sample, a positive correlation can be observed (upper right panel). Yet, for both, R&D expenditures and patents, the correlation has decreased over time. In addition, the relationship especially between patents and profits is not significant in most analyzed years. This, however, is different for the market capitalization. Here, we find a positive and for most years significant correlation to R&D as well as patents. It thus seems that markets do value R&D and patents, although both might not lead to direct profits in the first place. This, however, will be regarded in more detail in the following multivariate models.

Figure 4: Bivariate Correlations between the variables over time



Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

Table 7: Analysis of time lags between the relevant variables

R&D expenditures as explanatory variable

	Transnat. Filings			Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
L0.R&D Exp.	0.082	***	0.011	1.210	***	0.115	7.750	***	0.908
L1.R&D Exp.	0.010		0.014	-0.110		0.155	4.942	***	1.195
L2.R&D Exp.	-0.027	*	0.014	-0.082		0.152	4.202	***	1.143
L3.R&D Exp.	-0.008		0.014	-0.090		0.151	-6.993	***	1.158
L4.R&D Exp.	-0.004		0.015	-0.316	**	0.158	-3.722	***	1.215
L5.R&D Exp.	0.033	***	0.012	0.242	*	0.130	3.564	***	0.984
Constant	1.305		11.833	-57.566		123.584	9749.147	***	317.242
Time Dummies	YES			YES			YES		
Obs.	5236			4801			4469		
Firms	387			386			380		
R² within	0.181			0.223			0.140		
F	46.46			54.93			111.02		
Prob > F	0.000			0.000			0.000		

Patent Filings as explanatory variable

	Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.
L0.Transnat. Filings	0.659	**	0.296	12.727	***	2.393
L1.Transnat. Filings	1.022	**	0.429	-2.883		3.490
L2.Transnat. Filings	-1.327	***	0.471	4.090		3.713
L3.Transnat. Filings	0.294		0.496	7.812	**	3.838
L4.Transnat. Filings	-1.099	**	0.487	-10.738	***	3.903
L5.Transnat. Filings	1.463	***	0.348	20.318	***	2.772
Constant	300.491	***	97.806	10683.380	***	292.850
Time Dummies	YES			YES		
Obs.	5611			5395		
Firms	388			383		
R² within	0.163			0.062		
F	43.92			55.05		
Prob > F	0.000			0.000		

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

Before digging deeper into this issue, we will first take a closer look at the time-lag in the relation of R&D and patents as well as the firm success measures, as this also influences the choice of (time-lagged) variables for our further models.

To analyze the time-lag between R&D and patent filings, we calculated a rather straightforward series of fixed effects (FE) panel regressions. In the first set, we used R&D expenditures in different time-lags as independent variables and regressed it on patent filings, operating profit and market capitalization, controlling for period specific effects via time-dummies. Industry- and country specific effects cannot be identified within an FE-model.

By comparing the coefficients of the model, we can see which time-lag is best able to explain the number of patent filings. The same holds for the models on operating profit and market capitalization. The results of these models can be found in the upper panel of Table 7. Here, it becomes obvious that in all three cases "no time lag" is best able to explain the changes in the outcome variable. Although there are timely-lagged effects that are significant in some of the years, the strongest coefficient can be found for a time lag of zero years. In the case of patents and the relation to operating profit and market capitalization (lower panel of the table), the picture is not that straightforward. Here, rather high coefficients can also be found for a time-lag of five years, which does make sense as it might take some time to turn a patented invention into a marketable product (van Ophem et al. 2002). Yet, for the sake of consistency, we also stick with a time-lag of zero years as there is a significant positive relation between patents, operating profit and market value.

Within the next series of models (Table 8) we will take a closer look at the development of the interrelation between our variables over time. Using the number of transnational patent filings as the dependent variable in an FE model and R&D expenditures, a dummy for the years after 2002 (as compared to the years before) as well as the interaction term between the two variables as explanatory variables controlling for firm size – based on the number of employees - we find that there is a significantly positive relationship between R&D expenditures and patent filings, which is as expected. Also the number of employees is positively related to the number of filings, implying that large firms are more actively patenting than smaller ones. Looking at the dummy variable indicating the years after 2002, we find a highly significant positive effect, which implies that the number of patents is larger after 2002 than it was before. What is interesting, however, is the interaction effect between R&D expenditures and the years after 2002, which also shows a significantly positive effect. This positive effect tells us that in the years after 2002, R&D expenditures are better able to explain the amount of patent filings – i.e. have a larger correlation – than in the years before 2002. This is in line with the results from the correlation analysis, which also showed an increase in the correlation between the two variables over the years.

Table 8: Regression models on the relation between R&D, patent filings and firm success, all industries

R&D expenditures as explanatory variable

	Transnat. Filings			Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Employees	0.0001	*	0.0001	0.012	***	0.001	0.140	***	0.008
R&D Exp.	0.072	***	0.007	0.580	***	0.080	7.725	***	0.708
After 2002	129.987	***	15.996	2073.879	***	174.437	23529.040	***	1675.476
R&D Exp.*After 2002	0.022	***	0.005	0.050		0.058	-0.427		0.501
Constant	0.209		14.855	-1368.206	***	162.495	-18011.170	***	1590.592
Time Dummies	YES			YES			YES		
Obs.	6457			5479			5418		
Firms	387			387			382		
R² within	0.221			0.300			0.344		
F	68.70			86.93			104.89		
Prob > F	0.000			0.000			0.000		

Patent Filings as explanatory variable

	Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.
Employees	0.015	***	0.001	0.172	***	0.008
Transnat. Filings	-0.093		0.200	2.559		1.830
After 2002	2534.007	***	178.648	15547.310	***	1157.879
Transnat. Filings*After 2002	0.899	***	0.154	11.402	***	1.393
Constant	-1531.767	***	166.088	-8060.707	***	1040.433
Time Dummies	YES			YES		
Obs.	5565			5864		
Firms	387			382		
R² within	0.285			0.301		
F	81.95			94.07		
Prob > F	0.000			0.000		

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

When looking at the relationship between R&D expenditures and operating profit as well as market capitalization, we find similar results with respect to R&D expenditures and the number of employees. The interaction effect, however, is not significant in both models. This means that there is no significant difference in the relationship between R&D expenditures and operating profit as well as market capitalization before and after 2002.

For the relation between patent filings and operating profit and market capitalization, however, this is different (lower panel of Table 8). The model specification is the same as in the models with R&D as the independent variables, except that R&D was exchanged with patent filings. We first of all can observe that the number of employees is positively related to both measures. The number of patent filings shows a negative relationship to operating profits, while it is positive – yet not significant – with market capitalization. The interesting effect once again is the interaction effect, here between filings and the dummy indicating the years before and after 2002. In both cases, this effect is positive, showing that the correlation between patent filings and both measures has increased after 2002, compared to the years before.

In sum, it can be stated that after 2002, our measures show a larger relationship between each other than in the 1990s, where the patent surge seems to have had quite a large influence on the relation between R&D, patents and the firm success measures.

Splitting up the models alongside their patent intensity according to the sectoral analyses in the previous chapter reveals some further interesting results. In Table 9, the results for the patent intensive sectors are presented whereas the models for non-patent intensive sectors are presented in Table 10.

Table 9: Regression models on the relation between R&D, patent filings and firm success, patent intensive industries

R&D expenditures as explanatory variable

	Transnat. Filings			Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Employees	0.0004	***	0.0001	0.008	***	0.001	0.089	***	0.010
R&D Exp.	0.060	***	0.010	0.535	***	0.073	10.727	***	0.747
After 2002	147.015	***	22.220	1422.998	***	154.674	20316.130	***	1721.303
R&D Exp.*After 2002	0.023	***	0.007	0.152	***	0.051	-2.100	***	0.511
Constant	14.687		20.539	-1040.344	***	143.312	-16013.670	***	1633.644
Industry Dummies	YES			YES			YES		
Country Dummies	YES			YES			YES		
Obs.	4394			3791			3758		
Firms	262			262			260		
R^2 within	0.208			0.361			0.371		
F	43.14			79.15			82.05		
Prob > F	0.000			0.000			0.000		

Patent Filings as explanatory variable

	Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.
Employees	0.013	***	0.001	0.153	***	0.010
Transnat. Filings	-0.654	***	0.175	0.701		1.809
After 2002	2117.444	***	174.007	15105.950	***	1282.948
Transnat. Filings*After 2002	1.363	***	0.134	12.425	***	1.384
Constant	-1356.969	***	161.291	-8420.227	***	1157.429
Industry Dummies	YES			YES		
Country Dummies	YES			YES		
Obs.	3859			4054		
Firms	262			260		
R^2 within	0.312			0.304		
F	64.85			65.81		
Prob > F	0.000			0.000		

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

Table 10: Regression models on the relation between R&D, patent filings and firm success, non-patent intensive industries

R&D expenditures as explanatory variable

	Transnat. Filings			Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Employees	-0.0002	**	0.000	0.015	***	0.002	0.185	***	0.015
R&D Exp.	0.084	***	0.007	1.031	***	0.194	3.824	**	1.578
After 2002	98.272	***	17.010	3427.873	***	428.709	27897.970	***	3770.667
R&D Exp.*After 2002	0.030	***	0.006	-0.204		0.156	3.520	***	1.220
Constant	-39.731	**	15.956	-2090.694	***	404.621	-19230.550	***	3601.879
Industry Dummies	YES			YES			YES		
Country Dummies	YES			YES			YES		
Obs.	2063			1688			1660		
Firms	125			125			122		
R² within	0.335			0.327			0.363		
F	38.47			29.87			34.48		
Prob > F	0.000			0.000			0.000		

Patent Filings as explanatory variable

	Operating Profit			Market Cap.		
	Coef.		Std. Err.	Coef.		Std. Err.
Employees	0.018	***	0.002	0.197	***	0.013
Transnat. Filings	2.699	***	0.731	10.825	*	6.601
After 2002	3256.139	***	416.637	15008.440	***	2372.539
Transnat. Filings*After 2002	-0.271		0.628	21.307	***	5.048
Constant	-1822.907	***	388.252	-6567.677	***	2110.576
Industry Dummies	YES			YES		
Country Dummies	YES			YES		
Obs.	1706			1810		
Firms	125			122		
R² within	0.319			0.336		
F	29.19			33.63		
Prob > F	0.000			0.000		

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

The results for the patent-intensive sectors mostly corroborate the effects found for the total industries, with the exception that most of the coefficients are larger in size and more highly significant, i.e. it can be stated that the above mentioned arguments hold even more for firms in patent intensive sectors. It is here also worth mentioning again that it does make a difference which firm success measure is chosen when looking at the correlation with patent filings. The number of transnational patents is negatively related to operating profits but positively related to market capitalization. Though the positive effect on market capitalization is not significant, there seems to be the trend that direct monetary measures as EBIT negatively respond to patent filings while the market positively values those filings. Yet, this does not seem to be true for firms in the non-patent intensive sectors, where patent filings show a positive relation to both, operating profit and market capitalization, which is especially true after the year 2002, as the interaction effect shows.

In sum, we can state that the relation between R&D, patents and firm success measures is not so different between patent intensive and non-patent intensive sectors, although the correlations are stronger in the patent intensive sectors. The increase in correlations after the year 2002 also holds in both cases. However, here we even find a stronger effect for non-patent intensive sectors, which can be seen as an indication of a convergence with regard to the R&D/patent relationship.

3.3 Summary

The aim of this section was to shed light on the development of the relationship between R&D expenditures, patent filings and firm success measures at the micro level over a longer time period. Besides the fact of rising R&D expenditures and patent filing figures over time, we have found that the increase in the patent intensity, i.e. patent filings by R&D, has stopped and consolidated at a high level since 2004. In this vein, we have also seen that the correlation between R&D and patent filings has increased over the years, which is especially true for the 2000s in contrast to the 1990s. Yet, this increase in correlation can also be found for the relation between R&D, patents and firm success measures, i.e. operating profit and market capitalization. However, profits and market related measures seem to react differently to patent filings. Profits seem to be negatively related to patents, whereas the market reacts positively to a firm filing a patent. This is especially true in patent intensive sectors, whereas patents positively affect market capitalization and the operating profit of a company.

A final remark is targeted towards financial crises. Here, the correlation analysis revealed that the R&D/patent relationship seems to be disturbed, which manifests itself in a drop of correlations. This is mostly due to different cost-saving strategies of firms during financial crises, but should be kept in mind with regard to further statistical analysis in innovation research.

4 Summarizing conclusion

This paper dealt with the question of changing relations between business R&D (BERD), patents and output measures like value added, productivity, EBIT or market capitalization to analyze long-term/secular effects of technological change. As one additional perspective we tried to find empirical evidence in the context of the Gordon hypothesis (Gordon 2015), which states that the third industrial revolution of the digitalization of the economies is at the end of its cycle resulting in diminishing productivity increases in the recent past. Another particular research question addressed in this paper is the difference of the relationships between R&D and patents on the level of the whole economy, the sectoral level and the level of the individual firms.

These questions were approached from two different angles. First, by using a sectoral panel dataset of BERD, patents, value added and exports, we examined the sectoral trends, mainly of the three factors BERD, patents and value added. Second, an integrated dataset of the largest R&D spending companies in the world was built from several releases of the DTI and the EU R&D Scoreboard, respectively. This dataset was employed to analyze the changes of the relationship on the enterprise level.

The results of the panel data revealed an increase of the patent numbers resulting from R&D expenditures, on average. This means that more R&D leads to more patents. From the literature it is well known that in the second half of the 1990s a decoupling of R&D and patenting was observable that is mainly attributed to what can be characterized as a shift towards more strategic patenting. In the longer perspective that we take here, we find a difference in the elasticities of BERD and patents between patent-intensive and non-patent-intensive sectors. While for the former the relation between R&D expenditures and patents increased, it decreased for the latter type of sectors. We do not find considerably different partial correlations between R&D and patents before and after the year 2002, even though a slightly decreasing trend seems to be present. This means that the pure macro-economic observation of a decoupling of R&D and patents is only modestly visible at the sectoral level.

In addition, the association between patents and labor productivity falls when all sectors are taken into account, implying decreasing contributions of technological progress to the productivity. So we find evidence that is in part consistent with Gordon’s depletion hypothesis (Gordon 2015). However, the drivers are non-patent-intensive sectors, as we observe an increasing association of patents and labor productivity for patent-intensive sectors.

The results of the enterprise panel data revealed increasing correlations between R&D and patents, being congruent to the findings of the sectoral data that patents became more and more important for securing the investments in technological progress. The increasing relationship on the micro level together with the results at the macro level reveal further concentrations of R&D and patenting activities. This is an effect that already started a while ago and can be found in most countries and most sectors. It is also in line with the findings at least based on the German innovation survey that also the innovation activities become more and more concentrated, especially on large multinational companies (Schubert and Rammer 2016).

However, what we find are constant and high-level R&D intensities (R&D per patent) in the recent years after increases in the past decades. To put it in other words, the research and development that is necessary for a single patent has become more and more expensive in the past years. This can at least also partially be an explanation for the increasing concentration of the R&D, patenting and innovation activities: larger companies can afford to conduct R&D and they have – by definition and as a matter of fact – the markets to commercialize these high investments.

A result of the micro data analysis that is also congruent with the findings of the sectoral data analyses is the increasing contribution of R&D and patents to the financial success of companies, especially in patent-intensive sectors. The market capitalization is positively related to R&D and patenting, while profits are negatively related. This latter finding is not surprising as R&D expenditures are costs that reduce the profit. However, in technology-driven sectors this is the way of value performance, while in other the value is generated differently. In our dataset we have the biggest R&D spenders in absolute terms worldwide, but the ratios of R&D to sales are very different (R&D/technology intensity) and also the ratio of profit to sales is very different.

Our findings have at least two policy implications. First, the IR#3 might be close to an end so the investment in the next industrial revolutions is appropriate. For many spectators this is the further digitalization of the economy, but mainly based on network and linking effects. The core of the next industrial cycle might not be technologies alone, which will still be important (or necessary), but which will no longer be sufficient for economic/productivity gains. The combination with new digital business models and services will be the main source of these gains – at least this is what is expected at the moment.

Second, we see a concentration of R&D and patenting on certain sectors and also on multinational companies. To broaden the base, the application and therefore the competences of certain core technologies in sectors of use instead of only sectors of provision/production is advisable. In addition, given the massive investments in R&D that are necessary nowadays, the internationalization especially of medium-sized companies (Mittelstand) seems appropriate. A large array of public support for this need can be named: regulatory frameworks, harmonization of markets, standardization, foreign trade policy, R&D support measures including steps to commercialize the result. An alternative – or parallel support – might address measures to integrate small and medium sized companies in multinational value chains.

5 Annex

Table A1: Bivariate Correlations between the Variables over Time

	R&D Exp./Transnat. Filings		**R&D Exp./Operating Profit**		**R&D Exp./Market Cap.**		**Transnat. Filings/Operating Profit**		**Transnat. Filings/Market Cap.**	
1990	0.157		0.754				0.497			
1991	0.350		0.716	*			0.661			
1992	0.383		0.884	***			0.291			
1993	0.361		0.967	***			0.076			
1994	0.559	**	0.668	**			-0.138			
1995	0.580	**	0.697	**			0.114			
1996	0.619	***	0.767	***			0.118			
1997	0.630	***	0.526	**			-0.025			
1998	0.643	***	0.531	**			-0.217			
1999	0.594	***	0.692	***			-0.011			
2000	0.590	***	0.693	***	0.470	**	0.296		0.224	
2001	0.671	***	0.252		0.705	***	0.444	**	0.461	**
2002	0.635	***	0.356		0.573	**	0.055		0.445	*
2003	0.668	***	0.192		0.576	***	0.207		0.465	**
2004	0.818	***	0.148		0.720	***	0.089		0.271	
2005	0.605	***	0.112		0.851	***	0.154		0.399	
2006	0.828	***	0.133		0.602	***	0.080		0.298	
2007	0.610	***	0.325		0.333		0.159		0.402	**
2008	0.730	***	0.235		0.453	**	0.181		0.461	**
2009	0.727	***	-0.049		0.543	**	0.028		0.458	**
2010	0.712	***	-0.758	***	0.677	***	-0.537	***	0.591	***
2011	0.836	***	0.535	**	0.693	***	0.492	**	0.578	***
2012	0.832	***	0.478	**	0.763	***	0.461	**	0.567	***

Source: EU Industrial R&D Investment Scoreboard, EPO – PATSTAT.

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