HETEROGENEITY OF RETURNS TO BUSINESS R&D: WHAT MAKES A DIFFERENCE?*

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Abstract

Business R&D spending has been shown to exert both direct and indirect positive effects on value added. Nevertheless, the heterogeneity of the returns to R&D has seldom been examined. Using detailed sectoral data from Czechia over the period 1995–2015, this study finds that privately funded business R&D has both direct and spillover effects, but that the publicly funded part of business R&D only leads to spillovers. The results further suggest that both upstream and downstream spillovers matter, regardless of the source of funding, and that during the period studied, R&D returns were heavily affected by the economic crisis. Lastly, private R&D offers significant returns only after reaching a critical mass, while the effects of public R&D spending do not display such non-linearity. This heterogeneity in the returns to business R&D should be reflected in innovation policy design.

Keywords: R&D returns, spillovers, Czechia

JEL Classification: O32, O33, O47, L14

1. Introduction

Research and development (R&D) is a driving factor for economic development. Not only do firms increase their own productivity through R&D investment (Hall *et al.*, 2013), but R&D spending also affects other firms through spillovers (Chen *et al.*, 2013). Because of these spillover effects on other firms, privately funded business R&D tends to be suboptimal from the societal perspective. One of the purposes of public support for business R&D is thus to compensate insufficient private R&D spending (Gil-Moltó *et al.*, 2011).

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For a comprehensive view of business R&D deliverables, it is therefore necessary to consider returns to both private and public R&D as well as direct and spillover effects of R&D (Eberhardt *et al.*, 2013).

Direct returns to R&D have been estimated several times since the first landmark study by Griliches (1979). A firm's knowledge stock has repeatedly been shown to be positively associated with its productivity (Ortega-Argilés *et al.*, 2010). Realizing that direct R&D returns of this kind might only represent a fraction of the total returns to R&D, however, Bloom *et al.* (2013) demonstrated that technology spillovers are also important. Technology spillovers depend not only on the investor but also on the recipient's ability to receive the existing knowledge. For instance, R&D spending enhances absorptive capacity, which stimulates catching-up with the technology frontier (Griffith *et al.*, 2004). It is important to keep this in mind when analysing returns to R&D in less developed economies as the less developed economies often lack the prerequisites for successful technology adoption.

Because private and public funding for business R&D spending are motivated differently, the nature of their effects is also likely to vary. Surprisingly, however, the existing studies have largely focused on either private or public returns to R&D and have only rarely considered both. The main exception is Furman *et al.* (2006), who focus on spillovers and distinguish between public and private R&D effects. Acosta *et al.* (2015) link public R&D support to greater labour productivity but do not compare any equivalent effect of private R&D expenditures. More attention has been devoted to the effects of public R&D support on private R&D spending; most of the studies on this topic have found that public R&D support stimulates private R&D spending rather than crowding it out (Becker, 2015).

The difference between private and public funding is, of course, not the only source of heterogeneity in the returns to business R&D; demand-driven and supply-driven spillovers, for example, must also be considered as distinct technology diffusion channels. It is customary to focus only on spillovers in the downstream direction (Cheng and Nault, 2007; Wilson, 2001) or to use proximity measures that fail to distinguish the kind of linkages (Lucking *et al.*, 2018). Wolff and Nadiri (1993), Forni and Paba (2002) and Plunket (2009) consider both directions separately, but not in the context of public and private R&D. Finally, the effects of R&D investment are likely to be non-linear (De Meyer and Mizushima, 1989) and fluctuate along the economic cycle (Hud and Hussinger, 2015), yet their fluctuation has hardly been investigated in the literature.

Our aim in this study is to address these gaps in an integrated way. For this purpose, we carry out an econometric investigation based on panel data from Czechia at a detailed sectoral level for the period 1995-2015. The results indicate that the direct returns

to privately funded R&D are positive and statistically significant at conventional levels but the returns to publicly funded R&D are neither positive nor statistically significant. That is not to say that public support for business R&D has no effect, however: both privately and publicly funded R&D investments create positive spillovers. Splitting those R&D spillovers along the upstream/downstream distinction shows that although the downstream course is dominant, some benefits are felt in the upstream direction. The results also suggest that private R&D only offers significant returns after reaching a critical mass, whereas we do not see this non-linearity in the effects of the public component. Finally, the returns to privately funded R&D were considerably larger after the great financial crisis of 2008, while the returns to publicly funded R&D support decreased. Meanwhile, the spillovers from both types of investment remained unaffected by the crisis.

These results are of particular importance for latecomer economies that are rapidly catching up with the technology frontier through business R&D expenditures, and for which evidence of returns to R&D is scant, as the existing literature has predominantly focused on developed countries. The Czech economy provides fertile ground for studying these effects. Czechia increased its business R&D expenditures as a fraction of GDP from 0.62% in 1995 to 1.13% in 2017, ending up on par with the Netherlands and the UK and overtaking Spain, Portugal and Italy. The Czech government supported business R&D to the fourth largest extent in the EU between 1995 and 2015 (Eurostat, 2019). Nevertheless, analysis of this spending has so far been limited to two studies by Klímová *et al.* (2019) and Sidorkin and Srholec (2017), both of which focus on the additionality effects of both public subsidies and private R&D spending.

The rest of this paper is structured as follows: Section 2 introduces the theory, explains the key concepts and reviews papers relevant to this study; Section 3 presents the data and methods; Section 4 interprets the empirical results and Section 5 concludes.

2. Theory and Conceptual Framework

Griliches (1979) produced a pioneering analysis of R&D returns using the production function. He introduced R&D capital stock as an additional input in the production function, which made it possible to estimate the effects of R&D on output. This approach has since been used extensively in the literature on this topic¹. Moreover, it has drawn attention to R&D spending as an engine of economic progress. In an age of decelerating productivity, public support for R&D is a prominent part of discussions about economic policy (European Commission, 2010).

1 For a review of the empirical literature, see McMorrow and Röger (2009).

Policymakers are, or should be, interested in the efficiency of public R&D support. In theory, such support is justified: firms invest in R&D with the vision of raising their future profits, but because those profits can be highly uncertain and the benefits of R&D are often not easy to internalize, private R&D investment could be seen to be suboptimal from the societal perspective. Government R&D subsidies and public research programmes are thus designed to compensate firms for the benefits that their R&D provides for other firms and to facilitate research with high social returns where there is no profitable business model.

In practice, state incentives for R&D either take the form of direct subsidies or involve indirect tax deductions for R&D spending. Whereas tax incentives usually cover all sectors engaging in R&D equally, direct subsidies address specific industries and technologies, so the government can then steer its support to projects with the highest social returns, including spillovers. Whether this is done successfully is a different matter. In his review of R&D and productivity growth, Sveikauskas (2007) concludes that only privately financed R&D offers high returns and that publicly financed R&D yields only indirect effects. Coccia (2010) finds that public R&D spending complements private spending only if the former does not exceed the latter. Public R&D support does not seem to crowd out private investment (Czarnitzki and Lopes-Bento, 2013), and there is even some evidence that public R&D support can boost privately funded R&D (Guellec and Potterie, 2003). The review of crowding-out and additionality effects is nonetheless inconclusive (Becker, 2015; David *et al.*, 2000; Marino *et al.*, 2016; Zúñiga-Vicente *et al.*, 2014).

The standard variable used to capture spillovers in the relevant research is the weighted sum of all R&D capital stocks, where the weights reflect the relative proximity between the subjects of interest (Hall *et al.*, 2010). One way of estimating the closeness between countries, industries or firms is to follow Jaffe (1986) and calculate an uncentred correlation matrix of R&D stocks (Bloom *et al.*, 2013). For the purposes of industry analysis, however, trade-based weights that consider trade as a spillover vehicle are more appropriate. Coe and Helpman (1995) used import shares, assuming that close trade relations lead to technology and knowledge diffusion opportunities. In this study, we follow Medda and Piga (2014) in using an input-output structure to estimate the connectedness of the industries.

Based on the input-output matrix, we can calculate both forward and backward trade linkages. This enables us to distinguish between the directions of the technology spillovers. Wolff and Nadiri (1993) consider spillovers in both directions, but they find only the forward direction significant. Forward linkage is usually the only spillover direction considered, since it is assumed that better inputs will increase product quality or process efficiency. Backward spillovers are largely neglected in the literature, with just a few exceptions (Forni and Paba, 2002; Plunket, 2009). Yet the customer's technological

progress may also drive suppliers to innovate, and this is especially likely in tightly knitted value chains where central firms with many sub-suppliers define the production process (Gereffi *et al.*, 2005).

Distinguishing between forward and backward spillovers helps us to differentiate between technology and rent spillovers (Mohnen, 1997). Rent spillovers affect the suppliers in the industry concerned, and thus spread mainly backwards; this makes them likely positively biased in the empirical estimation. Without that bias, backward R&D spillovers may even be negative. Dietzenbacher and Los (2002) state that R&D costs are reflected in output prices, which negatively affects downstream industries. They further show that backward and forward linkages are heterogeneous, which means that using them as weights yields independent measures of shared R&D capital and this dispels fears of collinearity in the estimation.

Forward and backward spillovers may play a special role when it comes to public R&D support. Direct public support is essentially a fiscal stimulus and so, even with no technology gains, it can have a positive effect on the receiving sector. Moreover, such a positive effect should spill upstream to other industries via rent spillovers (Mohnen, 1997). Thus, if we measure knowledge spillovers based on the suppliers' shared knowledge pool, this may produce an overestimation. However, there is little reason to assume that the simple fiscal effect trickles down and benefits downstream industries to any large extent; hence, the bias in the latter direction should be small.

Estimations of R&D returns for whole economies often allow no space for heterogeneity, although there are some exceptions. Based on the rationale of Cohen and Levinthal (1990), Griffith *et al.* (2004) find that industries with lower R&D intensity profess faster productivity growth than the technology forerunners and that technology transfer can be further induced by the receiver's absorptive capacity. Braconier and Sjöholm (1998) provide a comprehensive study on both inter and intra-industry spillovers, showing that both exist. The heterogeneity of R&D effects could also depend on the level of R&D spending itself. Low levels of R&D investment may only have a minuscule effect and substantial returns might materialize only after a critical mass of R&D capital is achieved (De Meyer and Mizushima, 1989).

Another strand of literature has explored the distinction between private and public R&D spending in the estimation of their interplay with productivity. Segerstrom (2000) provides a theoretical framework for the long-term effects of public R&D spending, but with little empirical evidence. Haskel and Wallis (2013) show that public R&D spending (specifically on research councils) spills over to market sector productivity. Other papers have focused rather on direct impacts on firm behaviour (Busom, 2000). Firm-level studies are perfectly fit for the matching approach in the analysis (Almus and Czarnitzki, 2003),

but this technique neglects the magnitude of the public spending – which is crucial for policy evaluation – as it only uses a binary distinction between treated and not treated.

Microdata are suitable for estimating direct effects from R&D as they provide great detail and statistical power, but they are less fit for evaluating spillovers. Despite the fact that R&D spillovers happen between firms at the micro-level, it is not clear how to assess the degree to which firms interact with one another. Spillovers are thus generally neglected in evaluation studies based on microdata (Baumann and Kritikos, 2016). Industry-level data, on the other hand, provide the opportunity to relate one industry to another through input-output tables and, based on this measure, to estimate the indirect spillover effects of R&D spending. The downside of using this approach is that intra-industry spillovers are neglected, but it can still provide some useful insights.

3. Data and Model

The Czech Statistical Office (CZSO) conducts an annual survey on R&D, covering all firms that CZSO believes to have R&D activities. The data on R&D spending can be split according to the source of financing – private or public – and the nature of the expenditure – current or investment. The survey's response rate oscillated around 84 percent over the years 1995–2015, which is high in international comparison. Nevertheless, some data were still missing due to non-response.²

CZSO provides data on value-added, labour, and capital at the detailed NACE 120 level.³ The R&D data have been aggregated to match this classification. Because many of the NACE 120 industries are barely engaged in R&D, we focus on 61 manufacturing and selected service industries, for which the R&D statistics are reliable.⁴ This subset of industries accounts for more than 90 percent of all R&D spending. An overview of the sectors included in the analysis is provided in Appendix. Only data from private companies are used in the analysis, so that we analyse only business R&D returns and

2 We can never be sure whether a missing observation is a non-response or whether the firm ceased its R&D activity. Extrapolation of the missing data is not feasible, because some firms might have ceased operations during the period covered, but it is possible to interpolate the missing data within a time series, because R&D expenditures do not drop to zero for just a few years, especially in large firms. We thus interpolate data on firms with more than 250 employees if the gap between their observations is no more than three years.

3 NACE 120 is a combination of NACE two-digit and three-digit numerical distribution (*i.e.*, divisions and groups).

4 We used the Mahalanobis outlier detection procedure to identify outliers. Using critical values even more conservative than those suggested by Penny (1996) implicated the manufacture of coke and refined petroleum products, mainly because of a highly unstable price index. We have therefore excluded this manufacturing industry from our analysis (as did Eberhardt *et al.*, 2013).

spillovers; we do not mix research at public universities and public research institutions into our analysis. All the monetary variables are transformed into 2010 prices in CZK using sector-specific deflators.

The timing of R&D effects is difficult to pin down (Hall *et al.*, 2010). To deal with this problem, we construct a measure of R&D capital stock for each sector. Using stock instead of flow variables enables us to relate past R&D expenditures to current productivity. Hence:

$$R_t = (1 - \delta) R_{t-1} + r_t \quad (1)$$

where R_t is the R&D capital stock at the time t , r_t is the R&D expenditure at the time t , and δ is the depreciation rate. The depreciation rate is a parameter set to 15%, which is standard in the literature (Hall *et al.*, 2010) but note that its value does not affect the estimates in any significant way. After logarithmic transformation, the rate becomes a constant that only affects the fixed-effects estimation to a limited extent.

For our iterative approach, we need to determine the level of R&D capital at time 1. Following Hall *et al.* (2010), we assume that R&D expenditures have a constant growth rate (which is supported by the empirics) and constant depreciation rate:

$$R_2 = \frac{r_1}{g + \delta} \quad (2)$$

The estimation dataset covers the years 1996–2015. The flexibility of the R&D capital stock model, however, enables us to differentiate between publicly and privately funded R&D stocks in the analysis.

A share of the R&D stock constructed in this way consists of capital stock. We cannot distinguish in the data between a computer purchased for a researcher or one for a reception desk. This leads to double-counting, which can be a source of bias in our estimation of R&D returns. Fortunately, the data contain information on how much R&D spending is of an investment character, so if we assume that investment-related R&D stock is proportional to R&D investment, it is then possible to calculate the precise share of R&D stock that is also included as capital stock. We can then subtract this from the ordinary capital stock to avoid double-counting.

To evaluate the spillovers of R&D spending, we construct an auxiliary variable, shared R&D stock, which weights the R&D stock in other sectors depending on their connectedness. We follow a suggestion from Eberhardt *et al.* (2013) and construct the weights based on the input-output structure of the economy. The knowledge flow can flow either from supplier to customer (forwards) or the other way around (backwards). We thus differentiate between these two directions of knowledge stock sharing, using weights based on supplier or customer input-output linkages.

Consider the forward-shared R&D stock at the industry i 's disposal that stems from the industry j . We take the value of j 's supply to i and divide it by the overall input of the industry i . By repeating this step for all the industries that supply the industry i , we obtain a set of weights, by which we then multiply the respective R&D stocks. The sum is the total forward-shared R&D stock. Backward-shared knowledge stock is calculated similarly. Equation 3 shows the calculation of forward-shared R&D stock with a_{ij} being the element of an input-output matrix in the i^{th} row and j^{th} column.

$$\text{forward.shared R \& D stock}_i = \sum_{j \neq i} w_j^i R_j, \text{ where } w_j^i = a_{ij} / \sum_j a_{ij}, \quad (3)$$

Table 1 presents the summary statistics. The effective unbalanced panel consists of 930 observations from 61 industries over 19 years. There is strong heterogeneity between sectors and over time. Private R&D spending dwarfs public spending by a ratio of four to one, while the levels of forward-shared and backward-shared capital are comparable. Some smaller industries have no R&D spending in a particular year, but these do not drive the results – the results remain similar even when we omit these. Public and private R&D capital are correlated but not to such a degree that this would cause multicollinearity issues. While manufacturing is generally more R&D intense than services, public R&D support is greater, as a share of total R&D capital, in the service sector.

Table 1: Summary statistics

930 observations	Mean	SD	Min	Max
Value added	9,976	13,524	5	113,617
Fixed capital stock	32,377	75,079	76	836,300
Labour (FTE)	20,826	25,128	86	152,388
Private R&D expenditures	124	270	0	2,440
Public R&D expenditures	28	85	0	963
Private R&D capital	648	1,342	1	9,703
Public R&D capital	138	409	1	3,898
Private forward-shared R&D capital	514	379	32	2,278
Public forward-shared R&D capital	79	73	1	394
Private backward-shared R&D capital	423	448	21	4,354
Public backward-shared R&D capital	58	48	1	219

Note: All variables are in CZK million except labour, which is in full time equivalent units.

Source: Czech Statistical Office and author's calculations.

To relate R&D spending to value added, we use the Cobb-Douglas production function augmented with R&D stock as the baseline model for our analysis. We follow the notation presented by Hall *et al.* (2010) and the canonical approach of Zvi Griliches (1979):

$$Y = AL^{\beta_1} C^{\beta_2} K^{\beta_3} [K^S]^{\beta_4} e^u \quad (4)$$

where Y is value-added, A is the shared level of technology, L is labour input, C is capital input, K is R&D stock, and K^S is the shared knowledge pool. The coefficients β_3 and β_4 measure elasticities with respect to internal R&D stock and shared R&D stock. Taking the logarithmic transformation of the equation above, we obtain a linear model with elasticities as coefficients. Lowercase letters represent the variables after the logarithmic transformation. It is further assumed that the trend in technological development can be described by the time effect λ_t and the industry heterogeneity in productivity by the industry effect μ_i .

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 k_{it} + \beta_4 k_{it}^s + \epsilon_{it} \quad (5)$$

We further distinguish between private and public R&D capital and we split the shared capital stock into private/public and backward/forward varieties:

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private_{kit} + \beta_4 public_{kit} + \beta_5 private_k_{it}^s + \beta_6 public_k_{it}^s + \epsilon_{it} \quad (6)$$

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private_{kit} + \beta_4 public_{kit} + \beta_5 forward_k_{it}^s + \beta_6 backward_k_{it}^s + \epsilon_{it} \quad (7)$$

There are several issues with this specification. Successful industries with rising value added may increase their R&D spending, but increased R&D spending may also stimulate their value added; thus, the results lack causal interpretation – the causal effect of R&D spending is likely smaller than our estimates. However, the upward bias may not be too large. Griffith *et al.* (2004) argue that because productivity is pro-cyclical, but the ratio of value added and R&D expenditures is not, the bias remains modest even in simple models without identification specification using exogenous shocks.

4. Econometric Estimates

Our models are estimated using fixed effects within a method for panel data, which controls for the common time trend and industry-specific effects. The elasticities of R&D capital and shared R&D capital reveal the association between a 1% increase

in the respective stock and any change in value added. Although estimating R&D returns and distinguishing between financing sources, recipients and other categories could be difficult due to the collinearity of the key variables, our model does not suffer from these issues: the variance inflation factor reveals that the collinearity of the variables we use is at a permissible level (see Appendix). All the results are reported with robust standard errors, taking into account heteroskedasticity and cross-sectional correlation.

Table 2, column 1 presents the baseline results with aggregate R&D capital and aggregate shared R&D capital and indicates significant direct R&D returns with the elasticity of 0.04. This is in line, for instance, with the past estimates of 0.04 by Bloom *et al.* (2013) and 0.06 by Eberhardt *et al.* (2013). The indirect spillover term is also highly statistically significant with an estimated elasticity of 0.11, and again this is not substantially different from past estimates: 0.07 by Adams and Jaffe (1996), 0.09 by Wolff and Nadiri (1993). Splitting the R&D capital along the private/public axis (column 2) shows that the direct returns are mainly driven by private spending. There is no evidence that public R&D capital has any direct link to sectoral value added. Condemning public R&D support would, however, be premature. After dividing shared R&D capital into public and private capital, it is apparent that public spending is positively associated with value added through spillovers (column 3). Interestingly, the magnitude of these spillover effects is similar for both public and private R&D stock.

Dividing the shared R&D capital stock based on forward and backward linkages of the industries (column 4) shows that spillovers happen in both directions. However, spillovers from supplier to consumer seem to be more prominent. This serves as evidence for the presence of knowledge spillovers, given that rent spillovers are more likely to happen in the backward direction. Splitting the spillover term even further, into public/private in both directions would be even more revealing but, unfortunately, collinearity issues make such an estimation unreliable.

Next, we examine non-linearity in R&D returns. We use threshold regression models to inspect potential discontinuity in R&D returns. It is likely that once R&D capital reaches a certain critical mass, its effect changes. Criscuolo (2005) uses the example of drug development to highlight the need for large amount of human and financial resources in large-scale research activities. We thus hypothesize that when the investment reaches such a critical mass, returns to R&D capital increase. Following Fong *et al.* (2017), we estimate the change points based on the exact method where the estimated change point is chosen from a grid based on the likelihood of the final estimation. Figure 1 shows the likelihood distribution of the change points in private R&D capital stock. The distribution suggests there is indeed a critical value beyond which the returns to R&D tend to be linear. The procedure of Fong *et al.* (2017) showed that the chosen change

point is indeed statistically significant (with a p-value of 0.004), but it did not identify a statistically significant change point in public R&D capital stock.

Table 2: R&D returns and spillovers – benchmark results

<i>Value added as dependent variable</i>	(1)	(2)	(3)	(4)
<i>Fixed capital</i>	0.270*** (0.068)	0.268*** (0.069)	0.306*** (0.052)	0.320*** (0.051)
<i>Labour</i>	0.835*** (0.050)	0.834*** (0.052)	0.857*** (0.036)	0.857*** (0.035)
<i>R&D capital</i>	0.040*** (0.011)	– –	– –	– –
<i>Shared R&D capital, spillover</i>	0.112*** (0.028)	0.120*** (0.004)	– –	– –
<i>Private R&D capital</i>	– –	0.020* (0.009)	0.023** (0.008)	0.022* (0.009)
<i>Public R&D capital</i>	– –	0.003 (0.004)	0.005 (0.004)	0.005 (0.005)
<i>Private shared R&D capital, spillover</i>	– –	– –	0.078** (0.028)	– –
<i>Public shared R&D capital, spillover</i>	– –	– –	0.118*** (0.029)	– –
<i>Backward-shared R&D capital, spillover</i>	– –	– –	– –	0.039* (0.016)
<i>Forward-shared R&D capital, spillover</i>	– –	– –	– –	0.070** (0.024)
Adjusted R²	0.530	0.530	0.540	0.542
Fixed effects (years)	Yes	Yes	Yes	Yes
Fixed effects (industries)	Yes	Yes	Yes	Yes
Number of observations	930	930	930	930

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

Source: Author's calculations.

Figure 1: Maximum likelihood distribution of change points, private R&D capital stock

Source: Author's calculations.

We continue with a segmented threshold regression which estimates a linear relationship between the dependent variable and the threshold variable both below and above the threshold. This is equivalent to the standard estimation if we let the independent variable of interest interact with a dummy which is equal to one when the values of the particular independent variable are greater than the estimated threshold. The interpretation is then analogous to any model with interaction terms.

Table 3 provides threshold regression estimates for both private (columns 1 and 2) and public (columns 3 and 4) returns to R&D capital. The segmented threshold models show that there is a certain critical level of private R&D capital beyond which the returns are substantial. This is in line with the notion of there being a critical mass of R&D capabilities that firms need to generate in order to profit from their R&D activities (De Meyer and Mizushima, 1989). Our estimation does not detect any such critical mass in public R&D capital, which is in line with the statistically insignificant change point. Distinguishing between public and private shared R&D stock or forward and backward shared R&D stock does not affect the results – we find no evidence of non-linearity in those variables.

Lucking *et al.* (2018) inspected whether returns to R&D remain stable in time and found that they hardly changed between 1985 and 2015. Their approach was to let the variables interact with dummies reflecting 5-year periods, so as to inspect the general development of R&D returns in time. We are interested in a more specific time question: whether the returns were affected by the great financial crisis. We therefore allow our measures of R&D capital to interact with a dummy capturing the period from 2009 onwards, as the crisis hit the Czech economy in 2009.

Table 3: R&D returns and spillovers – threshold models

Value added as dependent variable	(1)	(2)	(3)	(4)
<i>Fixed capital</i>	0.254*** (0.070)	0.261*** (0.071)	0.270*** (0.070)	0.277*** (0.071)
<i>Labour</i>	0.841*** (0.068)	0.845*** (0.058)	0.819*** (0.068)	0.822*** (0.066)
<i>Private R&D capital</i>	0.005 (0.014)	0.001 (0.014)	0.028*** (0.012)	0.028** (0.012)
<i>Public R&D capital</i>	0.000 (0.006)	–0.000 (0.006)	–0.013 (0.013)	–0.012 (0.012)
<i>Private shared R&D capital, spillover</i>	–0.001 (0.001)	– –	–0.003 (0.003)	– –
<i>Public shared R&D capital, spillover</i>	0.049*** (0.019)	– –	0.041** (0.019)	– –
<i>Backward-shared R&D capital, spillover</i>	– –	–0.001 (0.001)	– –	–0.003 (0.003)
<i>Forward-shared R&D capital, spillover</i>	– –	0.061*** (0.022)	– –	0.053** (0.023)
<i>Private R&D capital, threshold</i>	0.17*** (0.05)	0.17*** (0.05)	– –	– –
<i>Public R&D capital, threshold</i>	– –	– –	0.019 (0.045)	0.018 (0.044)
Adjusted R²	0.530	0.530	0.530	0.530
Fixed effects (years)	Yes	Yes	Yes	Yes
Fixed effects (industries)	Yes	Yes	Yes	Yes
Number of observations	930	930	930	930

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

Source: Author's calculations.

Table 4 provides the results. As the crisis hit, firms were likely tempted to curb private R&D investment in response to their falling revenues. The results indicate, however, that those who managed to maintain their R&D spending benefitted handsomely as it extended their lead over their competitors (column 1). The returns to private R&D in the years 2009–2015 were more than twice as big as those in 1996–2008.

Table 4: R&D returns and spillovers – effect of economic crisis

Value added as dependent variable	(1)	(2)
<i>Fixed capital</i>	0.306*** (0.052)	0.306*** (0.053)
<i>Labour</i>	0.875*** (0.036)	0.881*** (0.036)
<i>Private R&D capital</i>	0.020** (0.010)	0.020* (0.010)
<i>Public R&D capital</i>	–0.006 (0.009)	0.005 (0.005)
<i>Private shared R&D capital, spillover</i>	0.032 (0.019)	– –
<i>Public shared R&D capital, spillover</i>	0.075*** (0.022)	– –
<i>Private R&D capital x period (2009–2015)</i>	0.043*** (0.013)	0.045*** (0.013)
<i>Public R&D capital x period (2009–2015)</i>	–0.041*** (0.013)	–0.045*** (0.013)
<i>Private shared R&D capital x period (2009–2015)</i>	–0.063 (0.039)	– –
<i>Public shared R&D capital x period (2009–2015)</i>	0.056 (0.031)	– –
<i>Backward-shared R&D capital, spillover</i>	– –	0.039* (0.017)
<i>Forward-shared R&D capital, spillover</i>	– –	0.075*** (0.025)
<i>Backward-shared R&D capital x period (2009–2015)</i>	– –	0.007 (0.020)
<i>Forward-shared R&D capital x period (2009–2015)</i>	– –	–0.078 (0.020)
Adjusted R²	0.555	0.559
Fixed effects (years)	Yes	Yes
Fixed effects (industries)	Yes	Yes
Number of observations	930	930

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

Source: Author's calculations.

Public R&D spending is not positively associated with sectoral performance during the crisis. This can be explained by R&D support having been used as an immediate fiscal stimulus when the crisis hit. With other tools for government support not yet in place,

public R&D spending might have been streamed to the struggling industries in order to keep them afloat. Accordingly, the direct returns to public R&D spending are estimated to be essentially zero in pre-crisis years but turn sharply negative in 2009. This drop in returns to public R&D is in line with Hud and Hussinger (2015), although they did find a small positive effect. The spillovers – divided into public/private (column 1) or forward/backward (column 2) – were, however, not affected by the crisis.

5. Conclusions

In this paper, we have analysed direct and spillover returns to R&D in Czechia. While direct returns only come from private R&D spending, spillover effects are driven by both privately and publicly funded R&D and happen both forwards and backwards in the production process. The great financial crisis increased direct returns to private R&D funding and decreased direct returns to public R&D funding, widening the gap in direct returns.

Our results are mainly explorative: no claim of causality can be made using our specification. Successful industries may invest in R&D with visions of further growth, while struggling industries may rather restrict their R&D investment to improve their cash flow. The cause-effect direction between value added and R&D investment would then be the opposite of that usually suggested. This means that the R&D returns we have presented here are likely overestimated. However, as we have mentioned, this upward bias is likely small (see Griffith *et al.*, 2004). Another source of upward bias in our estimates of direct R&D returns are spillovers between firms within the same industry; these are not considered in our industry analysis and are thus counted as direct returns. While this is a serious matter, it should not be overstated: our results do not differ substantially from those presented in studies that used firm-level data (Hall *et al.*, 2010; Rogers, 2009). Lastly, it is difficult to distinguish between true technology spillovers resulting from public R&D spending and mere rent spillovers. However, by splitting the shared public R&D capital into the forward and backward directions, we show that technology spillovers are likely far more substantial than rent spillovers.

Despite these various shortcomings, our results largely confirm the common intuition as to the benefits of R&D spending, with positive and significant direct and spillover R&D returns (with the exception of direct returns to public spending). The absence of a positive direct return to public R&D support shows that intra-industry spillovers – which would also be captured by the direct effect – are indiscernible. Assessments of public R&D support should thus not be limited to institutions' immediate industry partners: the spillover effects of public investment in R&D are likely far-reaching and may materialize in other industries over longer periods of time.

The direct effects of R&D spending are not linear, and this fact should be taken into account in R&D-enhancing policies. More specific research is needed to establish how policies should be adjusted to these phenomena. Ideally, a proper impact assessment involving different groups of stakeholders must be conducted before any policy is implemented. Such assessments should be based on both industry-level data and micro-data. The results presented in this paper are generalizable only at the industry level. Using firm-level data would provide complementary evidence and map the Czech R&D landscape in greater detail. With increasing data availability, such a study will hopefully be possible in the near future. Granular data could help us identify causal effects, show how returns to public R&D differ based on sources of financing (regional, state, EU funds), and uncover synergies in distinct R&D projects.

Appendix

Variance inflation factors for non-interaction models

Value added as dependent variable	(1)	(2)	(3)	(4)
<i>Fixed capital</i>	1.90	2.03	2.08	2.06
<i>Labour</i>	1.85	2.11	2.28	2.04
<i>R&D capital</i>	1.04	–	–	–
<i>Shared R&D capital, spillover</i>	–	1.28	–	–
<i>Private R&D capital</i>	–	1.73	1.75	1.73
<i>Public R&D capital</i>	–	1.69	1.87	1.87
<i>Private shared R&D capital, spillover</i>	–	–	1.64	–
<i>Public shared R&D capital, spillover</i>	–	–	1.61	–
<i>Backward-shared R&D capital, spillover</i>	–	–	–	2.46
<i>Forward-shared R&D capital, spillover</i>	–	–	–	2.42

Source: Author's calculations.

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