INSTITUTE
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Faculty of Social Sciences
Charles University

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*Petr Pleticha*

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Institute of Economic Studies,
Faculty of Social Sciences,
Charles University in Prague

[UK FSV – IES]

Opletalova 26
CZ-110 00, Prague
E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz

Institut ekonomických studií
Fakulta sociálních věd
Univerzita Karlova v Praze

Opletalova 26
110 00 Praha 1

E-mail : ies@fsv.cuni.cz
http://ies.fsv.cuni.cz



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# Heterogeneity of Returns to Business R&D: What Does Make a Difference?

Petr Pleticha[a,b]

[a]CERGE-EI, a joint workplace of Charles University and the Economics Institute of the Czech Academy of Sciences, Prague, Czech Republic
[b] Institute of Economic Studies, Faculty of Social Sciences, Charles University
Opletalova 26, 110 00, Prague, Czech Republic
Email (corresponding author): ppleticha@gmail.com

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**Abstract:**
Business R&D spending has been showed to exert a positive direct as well as indirect, spillover effects on value added. Nevertheless, heterogeneity of the returns to R&D has been seldom 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 the 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 profess such non-linearity. The heterogeneity of returns to business R&D needs to be reflected in the design of innovation policy.

**JEL:** O32, O33, O47, L14
**Keywords:** R&D returns, spillovers, Czechia

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# 1. Introduction

Research and development (R&D) is a driving factor of economic development. 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 the spillover effects on other firms, privately funded business R&D tends to be suboptimal from the societal perspective. Compensating the insufficient private R&D spending is thus one of the purposes of public support of business R&D (Gil-Moltó et al., 2011). To get a comprehensive view of what drives business R&D, it is thus 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 has been estimated since the landmark study of Griliches (1979). The knowledge stock of a firm was repeatedly shown to be positively associated with its productivity (Ortega-Argilés et al., 2010). Realizing that the direct R&D returns might be only a fraction of the total returns to R&D, however, Bloom et al. (2013) proved that the technology spillovers are indeed important. Technology spillovers are also dependent on the recipient. For instance, R&D spending enhances absorptive capacity which stimulates catching-up with the technology frontier (Griffith et al., 2004). This is important to keep in mind when analyzing returns to R&D in less developed economies.

Because of the different motivations for private and public funding of business R&D spending, the nature of their effects is also likely to vary. Surprisingly, however, the existing studies focus on either private or public returns to R&D but rarely on 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) links public R&D support to greater labour productivity, but they do not compare public R&D support to private R&D expenditures. More attention has been devoted to the effects of public R&D support on private R&D spending. Most of studies on this topic find that public R&D support stimulates rather than crowds out private R&D spending (Becker, 2015).

Yet the difference between private and publicly funded business R&D is not the only source of R&D returns heterogeneity. Demand-driven and supply-driven spillovers also need to be considered as distinct technology diffusion channels. It is customary to focus only on the downstream direction (Cheng & Nault, 2007; Wilson, 2001) or use proximity measures that do not distinguish the kind of linkages (Lucking et al. 2018). Wolff & Nadiri (1993), Forni & Paba (2002) or Plunket (2009) consider both linkages separately but not in the context of public and private R&D. Finally, the variegated R&D effects are likely to be non-linear (De Meyer & Mizushima, 1989) and fluctuate along the economic cycle (Hud & Hussinger, 2015), which has been rarely investigated in the literature.

The aim of this study is to address these gaps in an integrated way. For this purpose we econometrically investigate panel data at detailed sectoral level from Czechia over the period 1995-2015. The results indicate that direct returns to privately funded R&D are positive and statistically significant at conventional levels but to publicly funded R&D are neither. That is not to say public support to business R&D has no effect. Spillovers are positive for both privately and publicly funded R&D capital. Splitting the R&D spillovers along the upstream/downstream distinction shows that although the downstream course is dominant, there are also benefits in the upstream direction. The results also suggest that private R&D offers significant returns only after reaching a critical mass, while there is no non-linearity in the effects of the public component. Finally, 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 went down. The spillovers, no matter which kind, remained unaffected by the crisis.

The results are of special importance for latecomer economies that are rapidly catching up in business R&D expenditures with the technology frontier, for which the evidence is scant, as the existing literature is predominantly focused on developed countries. The Czech economy provides a 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 to become on par with the Netherlands and the UK and overtake Spain, Portugal, and Italy. The Czech government supported business R&D to the fourth largest extent in the EU over 1995-2015 (Eurostat, 2019). Nevertheless, the analysis of this spending is limited to the studies by Klímová et al. (2019) and Sidorkin & Srholec (2017) who point to the additionality effects of public subsidies and private R&D spending.

The rest of the paper is structured in the following way. 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 the paper.

# 2. Theory and conceptual framework

Analysis of R&D returns based on production function was pioneered by Griliches (1979). He introduced R&D capital stock as an additional input in the production function making the estimation of the R&D effects on output possible. Such an approach has become extensively used in the literature on this topic[1]. Moreover, it has drawn the attention to R&D spending as to the engine of economic progress. In the age of decelerating productivity, public support of R&D is a prominent part of the discussion on economic policy (European Commission, 2010).

Policy-makers are, or should be, interested in the efficiency of the public R&D support. In theory, such support is justified. A firm invests in R&D with a vision of future profits. Because these profits can be highly uncertain, and the R&D benefits are often not easy to internalize, the private R&D investment could be suboptimal from the societal perspective. Government's R&D subsidies and public research programs thus often aim at compensating firms for the benefits which R&D provides to other firms and at facilitating research with high social returns where no profitable business model is conceivable.

In practice, the state incentivizes R&D either in the form of direct subsidies or using an indirect tax deduction 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 the spillovers. Whether it can tackle such a quest successfully is a different matter. Sveikauskas (2007) in his review of R&D and productivity growth concludes that only privately financed R&D offers high returns and that publicly financed R&D yield only indirect effects. Coccia (2010) found that public R&D spending complements private one only if the former does not exceed the latter. Generally, public R&D support does not seem to crowd out the private one (Czarnitzki & Lopes-Bento, 2013), and there is some evidence that public R&D support actually boosts the privately funded R&D (Guellec & Potterie, 2003). A review of crowding-out effects is nonetheless inconclusive (Becker, 2015; David et al., 2000; Marino et al., 2016; Zúñiga-Vicente et al., 2014).

[1] For a review of the empirical literature, see McMorrow & Röger (2009)

The standard approach to constructing a variable capturing spillovers is a 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 to estimate the closeness between countries, industries or firms is to follow Jaffe (1986) and calculate an uncentered correlation matrix of R&D stocks (Bloom et al., 2013). For purposes of industry analysis, however, trade-based weights which consider trade as a spillover vehicle are more appropriate. Coe & Helpman (1995) used import shares assuming that close trade relations lead to technology and knowledge diffusion opportunities. In this study, we follow Meda & 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 & Nadiri (1993) consider both directions of the spillovers, but they find only the forward direction significant. Forward linkage is the usually considered spillover direction as better inputs are assumed to increase product quality or increase process efficiency. Backward spillovers are largely neglected in the literature with a few exceptions (Forni & Paba, 2002; Plunket, 2009). Yet technological progress of a customer may also make suppliers innovate, which is especially likely in tightly knitted value chains where central firms with many sub-suppliers define the whole production process (Gereffi et al., 2005).

Distinguishing between spillovers happening in forward and backward direction helps us differentiate between technology and rent spillovers (Mohnen, 1997). Rent spillovers affect suppliers of the respective industry and thus spread mainly backward which makes them likely positively biased in the empirical estimation. Without the bias, backward R&D spillovers are hypothesized to be even negative. Dietzenbacher & 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 which dispels fears of collinearity in the estimation.

Forward and backward spillovers may play a special role in public R&D support. Direct public support is essentially a fiscal stimulus and so even with no technology gains, the support can have a positive effect on the receiving sector. Moreover, via rent spillovers, such a positive effect should spill upstream to other industries (Mohnen, 1997). Measuring knowledge spillovers based on shared knowledge pool of the suppliers is thus prone to overestimation. However, there is little reason to assume that the simple fiscal effect trickles down and benefits to a large extent downstream industries, so along this dimension the bias should be small.

Estimation of the R&D returns for the whole economy often allows no space for heterogeneity. Exceptions, of course, do occur. Based on the rationale of Cohen & Levinthal (1990), Griffith et al. (2004) found that the industries with lower R&D intensity profess faster productivity growth than the technology forerunners and that the technology transfer can be further induced by absorptive capacity of the receiver. Braconier & Sjöholm (1998) provided a comprehensive study on both inter and intra-industry spillovers showing they both exist. The heterogeneity of R&D effects could also depend on the level of R&D spending itself. Small levels of R&D investment may have only a minuscule effect. The returns might materialize only after a critical mass of R&D capital is achieved (De Meyer & Mizushima, 1989).

The distinction between private and public R&D spending in the estimation of their interplay with productivity forms another strand of literature. Segerstrom (2000) provides a theoretical framework for the long-term effects of public R&D spending, but empirical evidence is scarce. Haskel & Wallis (2013) show that public R&D spending (specifically on research councils) spills over to market sector productivity. Other papers focus rather on the direct impact on firm behavior (Busom, 2000). Firm-level studies are perfectly fit for the matching approach in the analysis (Almus & Czarnitzki, 2003), but such technique neglects the magnitude of the public support as it only uses the binary distinction of treated vs. not treated. Yet the magnitudes of public support is crucial for policy evaluation.

Microdata is suitable for estimating the direct R&D effects 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 & Kritikos, 2016). The industry level, on the other, provides 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 the intra-industry spillovers are neglected. Despite such flaws, however, industry-level data still provide us with useful insights into the R&D landscape.

# 3. Data and Model

The Czech Statistical Office (CZSO) conducts an annual survey on R&D covering all firms that CZSO suspects of R&D activities. R&D spending can be further split by the source of financing into private and public and by nature of the expenditure into current and investment. The survey's response rate oscillated around 84 percent over the years 1995-2015, which is high in international comparison. Nevertheless, there were still missing data due to non-response that had to be dealt with in order to obtain robust and representative evidence.[2]

CZSO provides data on value-added, labor, and capital at the detailed NACE 120 level.[3] The R&D data has 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 is reliable.[4] The subset of industries still covers more than 90 percent of total R&D spending. The overview of the sectors included in the analysis is provided in Appendix A1. Only data from private companies are used in the analysis in order to analyze only business R&D returns and spillovers and do not mix public research at universities and public research institutions in the analysis. All the monetary variables are transformed into 2010 prices in CZK using sector-specific deflators.

[2] We can never be sure whether a missing observation is a non-response or the firm ceased R&D activity. Extrapolation of the missing data is not feasible, because some firms might have ceased operations during the covered period, but it is possible to interpolate the missing data within 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 the 250 employees, if the gap between observations is up to three years.

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

[4] Mahalanobis outlier detection procedure has been used 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, and thus this manufacturing industry has been (similarly to Eberhardt et al. 2013) eliminated from the analysis.

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 relating past R&D expenditures to current productivity. Hence:

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

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

For this iterative approach, one still needs to determine the level of R&D capital at time 1. Following Hall et al. (2010), we assume constant growth rate of the R&D expenditures (which is not unfounded by the empirics) and the constant depreciation rate:

$$R_2 = \frac{r_1}{g + \delta} \tag{2}$$

The estimation dataset thus covers only 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 is contained in the capital stock. Indeed, buying a computer for a researcher is indistinguishable from a computer for a reception desk. This leads to double-counting which can be a source of bias in the estimation of R&D returns. Fortunately, the data contains information on how much R&D spending is of an investment character, so under the assumption of the investment-related R&D stock being proportional to R&D investment, it is possible to calculate the precise fraction of R&D stock which is also included in the capital stock. We can then subtract this part of the R&D capital stock from the ordinary capital stock to avoid double-counting in the analysis.

To evaluate the spillovers of R&D spending, we construct an auxiliary variable, a shared R&D stock, which weights the R&D stock in other sectors depending on their connectedness. We follow the suggestion of 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 its customer (forward) or the other way around (backward). We thus differentiate between knowledge stock shared in one and the other direction using weights based on supplier or customer input-output linkages.

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

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

Table 1 presents the summary statistics. The effective unbalanced panel consists of 930 observations coming from 61 industries and spanning over 19 years. There is a strong heterogeneity between sectors and in time. Private R&D spending dwarfs the public one with one to four ratio while the levels of forward-shared and backward-shared capital are comparable. There are also some industries with no R&D spending in a particular year, but they do not drive the results – the results stay intact even when we omit these small and from R&D perspective insignificant sectors. Public and private R&D capital is correlated but not to the degree that it would cause multicollinearity issues. While manufacturing is generally more R&D intense than services, public R&D support as a share of total R&D capital is greater 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 |
| **Labor (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 |

*Except for labour which uses full-time equivalent units, all variables are in CZK million*

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 the analysis. Following the notation of Hall et al. (2010) and the canonical approach of Zvi Griliches (1979):

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

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 $\beta_3$ and $\beta_4$ measure elasticities with respect to internal R&D stock and shared R&D stock. Taking the logarithmic transformation of the equation above, one obtains 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 time effect $\lambda_t$ and the industry heterogeneity in productivity by the industry effect $\mu_i$.

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

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

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private_{k_{it}} + \beta_4 public_{k_{it}} + \beta_5 private\_k_{it}^s + \beta_6 public\_k_{it}^s + \epsilon_{it} \quad (5)$$

$$y_{it} = \mu_i + \lambda_t + \beta_1 l_{it} + \beta_2 c_{it} + \beta_3 private_{k_{it}} + \beta_4 public_{k_{it}} + \beta_5 forward\_k_{it}^s + \beta_6 backward\_k_{it}^s + \epsilon_{it} \quad (6)$$

There are several issues with this specification. Because successful industries with rising value added may increase its R&D spending, as well as R&D spending may stimulate their value added, the results lack causal interpretation – the actual causal effect 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 method for panel data, thus controlling for common time trend and industry-specific effects. The elasticities of R&D capital and shared R&D capital thus tells us the association between 1% increase in the respective stock and change in value added. Although estimating R&D returns and distinguishing between financing sources, recipients and other categories could be difficult due to collinearity of the key variables, the presented model does not suffer from such issues. Using the variance inflation factor reveals that the collinearity of all the variables is permissible (see the Appendix A.1). All the results come with robust standard errors taking into account heteroscedasticity and cross-sectional correlation.

Table 2 column 1 presents the baseline results with only aggregate R&D capital and aggregate shared R&D capital 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 of 0.06 by Eberhardt et al. (2013). The indirect, spillover term is also highly statistically significant with the estimated elasticity of 0.11 and again not substantially different from past estimates; e.g., 0.07 of Adams & Jaffe (1996), or 0.09 of Wolff & Nadiri (1993). Splitting the R&D capital along the private/public axis (column 2) shows that the direct returns is 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 the public and the private one, it is apparent that public spending is positively associated with value added after all through spillovers (column 3). Interestingly, the magnitude of the spillover effects is similar between 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 the spillovers happen in both directions. However, the spillovers seem to be more prominent in the direction from supplier to consumer. This serves as evidence for the presence of knowledge spillovers as rent spillovers are more likely to happen via the backward direction. Splitting the spillover term even further into public forward-shared R&D stock etc. would be even more revealing. Unfortunately, collinearity issues make such an estimation unreliable.

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

| *Value added as dependent variable* | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| Fixed capital | 0.270*** | 0.268*** | 0.306*** | 0.320*** |
| | (0.068) | (0.069) | (0.052) | (0.051) |
| Labor | 0.835*** | 0.834*** | 0.857*** | 0.857*** |
| | (0.050) | (0.052) | (0.036) | (0.035) |
| R&D capital | 0.040*** | - | - | - |
| | (0.011) | - | - | - |
| Shared R&D capital, spillover | 0.112*** | 0.120*** | - | - |
| | (0.028) | (0.004) | - | - |
| Private R&D capital | - | 0.020* | 0.023** | 0.022* |
| | - | (0.009) | (0.008) | (0.009) |
| Public R&D capital | - | 0.003 | 0.005 | 0.005 |
| | - | (0.004) | (0.004) | (0.005) |
| Private shared R&D capital, spillover | - | - | 0.078** | - |
| | - | - | (0.028) | - |
| Public shared R&D capital, spillover | - | - | 0.118*** | - |
| | - | - | (0.029) | - |
| Backward-shared R&D capital, spillover | - | - | - | 0.039* |
| | - | - | - | (0.016) |
| Forward-shared R&D capital, spillover | - | - | - | 0.070** |
| | - | - | - | (0.024) |
| Adjusted $R^2$ | 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 |

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

Next, we examine the non-linearity in R&D returns. We use threshold regression models to inspect potential discontinuity of the R&D returns. It is likely that once R&D capital reaches certain critical mass, its effect changes. We hypothesize that when large enough, returns to R&D capital increase. For this reason, we implement segmented threshold regression which estimates a linear relationship between the dependent variable and the threshold variable below and above the threshold. This is equivalent to the standard estimation where the independent variable of interest is let to interact with a dummy which is equal to one when the values of the particular independent variable is greater than the estimated threshold. 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. The interpretation is then analogical to any model with interaction terms.

Table 3 below provides threshold regression estimates of both private (columns 1 and 2) and public returns to R&D capital (columns 3 and 4). The segmented threshold models show that there is a certain critical level of the private R&D capital beyond which the returns begin to matter. This is in line with the notion of critical mass of R&D capabilities which firms need to generate in order to profit from their R&D activities (De Meyer & Mizushima, 1989). Our estimation has not detected any critical mass in public R&D capital. Distinguishing between public and private shared R&D stock or forward and backward shared R&D stock does not affect the results.

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

| *Value added as dependent variable* | *(1)* | *(2)* | *(3)* | *(4)* |
|---|---|---|---|---|
| Fixed capital | 0.254*** | 0.261*** | 0.270*** | 0.277*** |
| | (0.070) | (0.071) | (0.070) | (0.071) |
| Labor | 0.841*** | 0.845*** | 0.819*** | 0.822*** |
| | (0.068) | (0.058) | (0.068) | (0.066) |
| Private R&D capital | 0.005 | 0.001 | 0.028*** | 0.028** |
| | (0.014) | (0.014) | (0.012) | (0.012) |
| Public R&D capital | 0.000 | -0.000 | -0.013 | -0.012 |
| | (0.006) | (0.006) | (0.013) | (0.012) |
| Private shared R&D capital, spillover | -0.001 | - | -0.003 | - |
| | (0.001) | - | (0.003) | - |
| Public shared R&D capital, spillover | 0.049*** | - | 0.041** | - |
| | (0.019) | - | (0.019) | - |
| Backward-shared R&D capital, spillover | - | -0.001 | - | -0.003 |
| | - | (0.001) | - | (0.003) |
| Forward-shared R&D capital, spillover | - | 0.061*** | - | 0.053** |
| | - | (0.022) | - | (0.023) |
| Private R&D capital, threshold | 0.17** | 0.17** | - | - |
| | (0.05) | (0.05) | - | - |
| Public R&D capital, threshold | - | - | 0.019 | 0.018 |
| | - | - | (0.045) | (0.044) |
| Adjusted $R^2$ | 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 |

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

Lucking et al. (2018) have inspected whether returns to R&D remain stable in time to find that they indeed hardly change between 1985 and 2015. Their approach is to let the variables interact with dummies reflecting 5-year periods to inspect the general development of R&D returns in time. Contrarily, we are interested specifically in whether the returns were affected by the great financial crisis. The measures of R&D capital thus interacts with a dummy capturing the period from 2009 onward as the crisis hit the Czech economy in this year.

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

Public R&D spending is not positively associated with sectoral performance during the crisis. On the contrary, R&D support might have 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. The direct returns to public R&D spending are estimated to be essentially zero in pre-crisis years but turn sharply negative in 2009. The drop in returns to public R&D is in line with Hud & Hussinger (2015), although the authors still find a positive effect. The spillovers divided into public/private (column 1) or forward/backward (column 2) ones were not affected by the crisis.

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

| *Value added as dependent variable* | *(1)* | *(2)* |
|---|---|---|
| Fixed capital | 0.306*** | 0.306*** |
| | (0.052) | (0.053) |
| Labor | 0.875*** | 0.881*** |
| | (0.036) | (0.036) |
| Private R&D capital | 0.020** | 0.020* |
| | (0.010) | (0.010) |
| Public R&D capital | -0.006 | 0.005 |
| | (0.009) | (0.005) |
| Private shared R&D capital, spillover | 0.032 | - |
| | (0.019) | - |
| Public shared R&D capital, spillover | 0.075*** | - |
| | (0.022) | - |
| Private R&D capital **x** period (2009-2015) | 0.043*** | 0.045*** |
| | (0.013) | (0.013) |
| Public R&D capital **x** period (2009-2015) | -0.041*** | -0.045*** |
| | (0.013) | (0.013) |
| Private shared R&D capital **x** period (2009-2015) | -0.063 | - |
| | (0.039) | - |
| Public shared R&D capital **x** period (2009-2015) | 0.056 | - |
| | (0.031) | - |
| Backward-shared R&D capital, spillover | - | 0.039* |
| | - | (0.017) |
| Forward-shared R&D capital, spillover | - | 0.075*** |
| | - | (0.025) |
| Backward-shared R&D capital **x** period (2009-2015) | - | 0.007 |
| | - | (0.020) |
| | - | -0.078 |

| | | |
|---|---|---|
| Forward-shared R&D capital **x** period (2009-2015) | - | (0.020) |
| Adjusted $R^2$ | 0.555 | 0.559 |
| Fixed effects (years) | Yes | Yes |
| Fixed effects (industries) | Yes | Yes |
| Number of observations | 930 | 930 |

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

# 5. Conclusions

The paper has analyzed direct and spillover returns to R&D in Czechia. Whereas the direct returns are limited to the private R&D spending, the spillover effects attribute to both privately and publicly funded R&D and happen both in the forward and backward direction of the production process. The great financial crisis increased the wedge between direct returns to privately and publicly funded R&D by increasing the private and decreasing the public ones.

The results are mainly explorative as no claim of causality can be made using this specification. Successful industries may invest in R&D with the vision of further growth while struggling industries may rather restrict their investment to enhance their cash flow. The cause-effect direction between value added and R&D investment would then be the opposite than it is usually suggested. R&D returns presented here are thus likely overestimated. However, as it was mentioned above, this upward bias is likely small (Griffith et al., 2004). Another source of upward bias in the direct R&D returns estimates are spillovers between firms within one industry. Those are not considered in the industry analysis and thus count as the direct return. Although this issue should be taken seriously, it should not be overstated as this study's results do not differ much from studies that used firm-level data (Hall et al. 2010; Rogers, 2009). Lastly, the estimated technology spillovers of public R&D spending are difficult to distinguish from mere rent spillovers. However, by splitting the shared public R&D capital into forward and backward shared, we show that technology spillovers are far more important than rent spillovers.

Despite these shortcomings, the results mainly confirm the intuition behind the benefits of R&D spending with positive and (with the exception of the direct return to public spending) significant direct and spillover R&D returns. The absence of a positive direct return to public R&D support shows that intra-industry spillovers which are captured by the direct effect are indiscernible. Assessment of public R&D support should thus not limit itself on immediate partner of the participating institution. The spillover effects are likely far-reaching and can materialize in other industries over longer periods of time.

The direct effects of R&D spending are not linear and R&D enhancing policies should take that into account. More specific research is, however, needed to adjust policies to these phenomena. Ideally, a proper impact assessment is conducted before any policy is implemented with a particular accent of different groups of stakeholders affected by the policy. Such assessments should be based both on industry and microdata. 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 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.

# References

Adams, J., & Jaffe, A. (1996). Bounding the Effects of R&D: An Investigation Using Matched Establishment-Firm Data. *The RAND Journal of Economics, 27*(4), 700-721.

Almus, M., & Czarnitzki, D. (2003). The Effects of Public R&D Subsidies on Firms' Innovation Activities: The Case of Eastern Germany. *Journal of Business & Economic Statistics*, *21*(2), 226–236.

Baumann, J., & Kritikos, A. S. (2016). The Link Between R&D, Innovation and Productivity: Are Micro Firms Different? *Research Policy*, *45*(6), 1263–1274.

Becker, B. (2015). Public R&D Policies and Private R&d Investment: A Survey of the Empirical Evidence. *Journal of Economic Surveys*, *29*(5), 917–942.

Bloom, N., Schankerman, M., & Reenen, J. V. (2013). Identifying Technology Spillovers and Product Market Rivalry. *Econometrica*, *81*(4), 1347–1393.

Braconier, H., & Sjöholm, F. (1998). National and International Spillovers from R&D: Comparing a Neoclassical and an Endogenous Growth Approach. *Weltwirtschaftliches Archiv, 134*(4), 638-663.

Busom, I. (2000). An Empirical Evaluation of the Effects of R&D Subsidies. *Economics of Innovation and New Technology*, *9*(2), 111-148.

Coccia, M. (2010). Public and Private R&D Investments as Complementary Inputs for Productivity Growth. *International Journal of Technology, Policy and Management*, *10*(1–2), 73–91.

Coe, D. T., & Helpman, E. (1995). International R&D Spillovers. *European Economic Review*, *39*(5), 859–887.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly, 35*(1), 128-152.

Czarnitzki, D., & Lopes-Bento, C. (2013). Value for Money? New Microeconometric Evidence on Public R&D Grants in Flanders. *Research Policy*, *42*(1), 76–89.

ČSÚ. (2019). Ukazatele výzkumu a vývoje—2016. Retrieved August 27, 2019, from Ukazatele výzkumu a vývoje—2016 website: https://www.czso.cz/csu/czso/ukazatele-vyzkumu-a-vyvoje-2016

David, P. A., Hall, B. H., & Toole, A. A. (2000). Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence. *Research Policy*, *29*(4), 497–529.

De Meyer, A., & Mizushima, A. (1989). Global R&D Management. *R&D Management, 19*(2), 135-146.

Dietzenbacher, E., & Los, B. (2002). Externalities of R&D Expenditures. *Economic Systems Research, 14(4)*, 407-425.

Eberhardt, M., Helmers, C., & Strauss, H. (2013). Do Spillovers Matter When Estimating Private Returns to R&D? *The Review of Economics and Statistics*, *95*(2), 436–448.

European Commission. (2010). Europe 2020 Strategy. Retrieved September 30, 2019, from https://ec.europa.eu/eurostat/web/europe-2020-indicators

Eurostat. (2019). General Government Expenditure by Function (COFOG, Gov_10a_exp). Accessed September 6, 2019. https://ec.europa.eu/eurostat/data/database?node_code=gov_10a_exp.

Fong, Y., Huang, Y., Gilbert, P.B. and Permar, S.R. (2017). Chngpt: Threshold Regression Model Estimation and Inference. *BMC Bioinformatics*, 18(1), p.454.

Furman, J. L., Kyle, M. K., Cockburn, I., & Henderson, R. M. (2005). Public & Private Spillovers, Location and the Productivity of Pharmaceutical Research. *Annales d'Économie et de Statistique*, (79/80), 165–188.

Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The Governance of Global Value Chains. *Review of International Political Economy, 12(1)*, 78-104.

González, X., & Pazó, C. (2008). Do Public Subsidies Stimulate Private R&D Spending? *Research Policy*, *37*(3), 371–389.

Griffith, R., Redding, S., & Reenen, J. V. (2004). Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. *The Review of Economics and Statistics*, *86*(4), 883–895.

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics*, *10*(1), 92–116.

Guellec, D., & Potterie, B. V. P. D. L. (2003). The Impact of Public R&D Expenditure on Business R&D. *Economics of Innovation and New Technology*, *12*(3), 225–243.

Hall, B. H., Mairesse, J., & Mohnen, P. (2010). Chapter 24 - Measuring the Returns to R&D. In B. H. Hall & N. Rosenberg (Eds.), *Handbook of the Economics of Innovation* (pp. 1033–1082).

Haskel, J., & Wallis, G. (2013). Public Support for Innovation, Intangible Investment and Productivity Growth in the UK Market Sector. *Economics Letters*, *119*(2), 195–198.

Hud, M., & Hussinger, K. (2015). The Impact of R&D Subsidies During the Crisis. *Research policy, 44(10)*, 1844-1855.

Jaffe, A. B. (1986). Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value. *American Economic Review, 76(5)*. 984-1001

Klímová, V., Žítek, V., & Králová, M. (2019). How Public R&D Support Affects Research Activity of Enterprises: Evidence from the Czech Republic. *Journal of the Knowledge Economy*.

Los, B., & Verspagen, B. (2000). R&D Spillovers and Productivity: Evidence from U.S. Manufacturing Microdata. *Empirical Economics*, *25*(1), 127–148.

Lucking, B., Bloom, N., & Van Reenen, J. (2018). Have R&D Spillovers Changed? (No. w24622). *National Bureau of Economic Research.*

Marino, M., Lhuillery, S., Parrotta, P., & Sala, D. (2016). Additionality or Crowding-out? An Overall Evaluation of Public R&D Subsidy on Private R&D Expenditure. *Research Policy*, *45*(9), 1715–1730.

McMorrow, K., & Röger, W. (2009). R&D Capital and Economic Growth: The Empirical Evidence. *EIB* Papers, 14(1), 94–118.

Medda, G. & Piga C.A. (2014), Technological Spillovers and Productivity in Italian Manufacturing Firms, *Journal of Productivity Analysis, 41*

Mohnen, P. (1997). Introduction: Input–Output Analysis of Interindustry R&D Spillovers. *Economic Systems Research, 9*(1), 3-8.

Penny, K. I. (1996). Appropriate Critical Values When Testing for a Single Multivariate Outlier by Using the Mahalanobis Distance. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, *45*(1)

Rogers, M. (2009). R&D and Producitivity: Using UK Firm-Level Data to Inform Policy. *Empirica, 37(3),* 329-359.

Segerstrom, P. S. (2000). The Long-run Growth Effects of R&D Subsidies. *Journal of Economic Growth, 5*(3), 277-305.

Sveikauskas, L. (2007). R&D and Productivity Growth: A Review of the Literature. *U.S. Bureau of Labor Statistics Working Paper*, *408*.

Wolff, E. N., & Nadiri, M. I. (1993). Spillover Effects, Linkage Structure, and Research and Development. *Structural Change and Economic Dynamics, 4(2)*, 315-331.

Zúñiga-Vicente, J. Á., Alonso-Borrego, C., Forcadell, F. J., & Galán, J. I. (2014). Assessing the Effect of Public Subsidies on Firm R&D Investment: A Survey. *Journal of Economic Surveys*, *28*(1), 36–67.

# Appendix

## A.1

Variance inflation factors for the non-interaction models

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

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E-mail : ies@fsv.cuni.cz http://ies.fsv.cuni.cz