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Document status and date:
Published: 01/01/2010

Document Version:
Publisher's PDF, also known as Version of record

Please check the document version of this publication:

Working Paper Series

#2010-040

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July 22, 2010

Abstract

This paper examines the impact of the R&D fiscal incentive program on R&D by Dutch firms. Taking a factor-demand approach we measure the elasticity of firm R&D capital accumulation to its user cost. Econometric models are estimated using a rich unbalanced panel of firm data covering the period 1996-2004 with firm-specific R&D user costs varying with tax incentives. Using the estimated user cost elasticity, we perform a cost-benefit analysis of the R&D incentive program. We find some evidence of additionality suggesting that the level-based program of R&D incentives in the Netherlands is effective in stimulating firms' investment in R&D. However, the hypothesis of crowding out can be rejected only for small firms. The analysis also indicates that the level-based nature of the fiscal incentive scheme leads to a substantial social dead-weight loss.

1. Introduction

Many governments rely on fiscal incentives to lower the user cost of R&D and thereby stimulate business investment in research and development. The market failures due to R&D externalities and asymmetric information between lenders and borrowers for the financing of R&D projects are often cited to justify the existence of such government programs, which often involve substantial budgets (OECD, 2007). The effectiveness of R&D fiscal incentives programs, however, continues to be the object of intense debate among economists.

We know from economic theory that investment in R&D can be modeled in the same way as investment in physical capital, and that therefore the user cost of R&D is a primary determinant of a firm's decision to invest in research and development. The elasticity of R&D with respect to its price is the main parameter of interest when assessing the effectiveness of such programs. Few studies have estimated this elasticity on firm-level data.[1] Notable exceptions are early contributions by Hall (1993) on the effectiveness of US Research and Experimental Credit; Bernstein (1986) on R&D support program in Canada and a more recent study by Mairesse and Mulkay (2004) on French data.

In this paper we take a fresh look at the sensitivity of the R&D capital accumulation to the user cost and assess the additionality of the R&D tax incentive program, such as the WBSO Act[2]. The focus of previous received contributions was primarily on estimating precisely the magnitude of the elasticity of R&D to its price. The emphasis in this paper is on the cost-benefit trade-off of the government support of R&D. Fiscal programs, especially when they are level-based, are costly and in contrast to the previous literature that merely acknowledged the possibility of some significant waste from the social planner perspective (e.g. Russo, 2004), we actually attempt to quantify the magnitude of the dead-weight-loss due to present and future R&D and tax receipts forgone.

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[1] Several studies produced evidence using the user cost, or structural, approach in the estimation of the effectiveness of R&D tax incentives on industry data (e.g. Mamuneas, Nadiri, 1996; Bloom, Griffith, van Reenen, 2002) or aggregate data (e.g. Jaumotte and Pain, 2005). A critical discussion of the state of the art in this literature is provided by Hall and van Reenen (2000). Many other studies evaluate the effects of tax incentives using counterfactuals, i.e. matching estimators, difference-in-difference estimators or regression discontinuity designs (see Czarnitzki, Hanel and Rosa, 2004, Cornet and Vroomen, 2005, Hægeland and Møen, 2007, Duguet, 2007, Corchuelo and Martínez-Ros, 2009). The quasi-experimental approach does not allow to perform policy experiments unlike the user-cost based structural model.

[2] WBSO is an acronym for The Wage Tax and Social Insurance Act (Wet bevordering speur - en ontwikkelingswerk) introduced in 1994 to stimulate research and development in the Netherlands. In 2005 the Dutch government spent about 400 million Euros on WBSO.

The model considers each firm's demand for R&D capital, among other things, as a negative function of its price (user cost). Government lowers the price of R&D by implementing tax deductions on R&D labor, which triggers a partial adjustment process to a higher desired R&D stock. Our dynamic factor demand model accounts for this partial adjustment mechanism and is based on a CES technology (cf. Chirinko, Fazzari, Meyer, 1999; Mairesse and Mulkay, 2004; Hall and van Reenen, 2000). We estimate the model using a firm-level unbalanced panel dataset covering 1996-2004, constructed from the annual R&D surveys, production statistics from the Central Bureau of Statistics and R&D tax incentives data. The richness of the merged dataset allows us to construct R&D price indexes and year- as well as firm-specific R&D user costs as a function of R&D tax incentives. Our firm-specific data allow a good measurement of the user cost by providing sufficient variation in the indexes in both the cross-section and time dimensions to improve the estimation of the effects of the R&D fiscal incentives program. To account for the endogeneity of the user cost of R&D we apply a generalized instrumental variables method to estimate a significant short-run elasticity of -0.4 and a long-run elasticity of -0.8 of firm R&D capital formation to its user cost.

We apply the estimated user cost elasticity of R&D capital stock to assess the effectiveness of the fiscal incentives program by comparing the additional R&D spurred by the fiscal incentives program to the cost for the government of supporting the R&D with the tax scheme. Our measure of the so-called bang-for the-buck differs from the measures adopted in most other papers (Czarnitzki et al., 2007; Parsons and Phillips, 2007) in that we compare the costs and benefits incurred until the firm reaches a new steady state in its R&D capital stock. When the adjustment to the new optimal stock is spread out over time, it is appropriate to compare the costs and benefits in a dynamic perspective allowing for a rate of time preference.

We find evidence that the program of R&D incentives in the Netherlands has been effective in stimulating firms' investment in R&D. However, the hypothesis of crowding out can be rejected only for small firms. The results of our simulations also indicate that the level-based nature of the fiscal incentive scheme leads to the government supporting R&D which firms would do even without the tax incentives, resulting in a substantial deadweight loss (as much as 85% of the total revenue loss) from the social planner's perspective.

The rest of the paper is organized as follows. Section 2 lays out our modeling approach. Section 3 describes the way we have assembled our data set and explains how we have constructed the variables used in the empirical analysis. Section 4 presents our empirical results. We discuss several regression specifications, leading to our preferred specification. We also discuss a number of alternative specifications and the robustness checks that we have performed. In section 5 we measure the effectiveness of the tax credits in stimulating R&D in the Netherlands. Section 6 concludes.

2. **Empirical model**

We derive a modeling framework that allows estimating the elasticity of firm R&D capital accumulation to its user cost. We start from a CES approximation to the true production function for firm i at time t (following Chirinko et al., 1999; Hall and van Reenen, 2000; Mairesse and Mulkay, 2004):

$$Q_{i,t} = F(K_{i,t}, X_{i,t}) = \gamma [\beta K_{i,t}^{-\rho} + (1-\beta) X_{i,t}^{-\rho}]^{-\nu/\rho} \tag{1}$$

where $Q_{i,t}$ is the output, $K_{i,t}$ is the end-of-period R&D stock, $X_{i,t}$ represents the other inputs, and γ (a scale factor), β (the distribution parameter), and ν (a measure of the returns to scale) are parameters to be estimated that characterize the technology, as well as ρ that enters the expression for the elasticity of substitution (σ) between the R&D stock and the other inputs and is given by $\sigma = 1/(1+\rho) \geq 0$. If we assume that the R&D stock becomes immediately productive and there are no adjustment costs or other sources of lagged adjustment, and static expectations on prices and output, we obtain the first-order condition of the profit maximization, stating that the marginal product of R&D must equal the user cost of R&D $U_{i,t}^R$ divided by the output price of the firm $P_{i,t}^Q$

$$\nu \beta Q_{i,t}^{(1+\rho/\nu)} \gamma^{-\rho/\nu} K_{i,t}^{-(\rho+1)} = U_{i,t}^R / P_{i,t}^Q \tag{2}$$

Solving this equation for the optimal long-term R&D stock yields:

$$K_{i,t}^* = AQ_{i,t}^{\zeta}(U_{i,t}^R / P_{i,t}^Q)^{-\sigma} \tag{3}$$

where A is a constant and $\zeta = \sigma + \dfrac{\sigma}{v}(\dfrac{1}{\sigma} - 1)$. The exponent of output is equal to 1 if returns to scale are constant or if the elasticity of substitution is equal to 1 (a Cobb-Douglas technology). Equation (3) expresses the optimal demand for R&D capital in terms of its price (the user cost) relative to the price of output, and the volume of output. By taking the logarithm of both sides of (3) and denoting the log of variables by small letters we obtain:

$$k_{i,t}^* = a + (\sigma + (1-\sigma)/v)q_{i,t} - \sigma(u_{i,t}^R - p_{i,t}^Q). \tag{4}$$

The volume of output and the output price are difficult to measure at the micro level. What is generally done is to use industry-level prices. To eliminate the need to observe individual output prices, we introduce an output demand equation with constant price elasticity, so as to obtain a formulation involving nominal output, following the example of Klette and Griliches (1996). We assume that the enterprise faces a demand curve given by

$$Q_{i,t} = Q_{I,t}\left(\frac{P_{i,t}^Q}{P_{I,t}}\right)^{-\varepsilon} \tag{5}$$

where $Q_{I,t}$ is the industry demand and $P_{I,t}$ the industry price in period t, and ε is the price elasticity in absolute value ($\varepsilon > 0$). If we invert the demand function (5) we can write

$$P_{i,t}^Q = Q_{i,t}^{-1/\varepsilon}Q_{I,t}^{1/\varepsilon}P_{I,t} \tag{6}$$

The resulting industry-price deflated output is

$$V_{i,t} = P_{i,t}^Q Q_{i,t} / P_{I,t} = Q_{I,t}^{1/\varepsilon}Q_{i,t}^{1-1/\varepsilon},$$

and the demand function can also be written as

$$Q_{i,t} = V_{i,t}^{\zeta}Q_{I,t}^{1/(1-\varepsilon)} \tag{7}$$

8

where $\zeta = (1 - 1/\varepsilon)^{-1}$ is the price markup over marginal cost in monopolistic competition. If, after taking logs, we plug (6) and (7) into (4), we get

$$k_{i,t}^* = a + \phi v_{i,t} - \sigma(u_{i,t}^R - p_{I,t}) + \gamma q_{I,t} \tag{8}$$

where $\phi = \sigma + \zeta(1 - \sigma)/v$, and $\gamma = (1 - \zeta)(1 - \sigma)/v$. The resulting expression gives the steady-state relationship (in logarithms) between a firm's optimal R&D stock, its real output, its user cost relative to the industry price, and the industry output[3].

Equation (8) depicts a long-run relationship. Many empirical studies have shown that there are adjustment costs associated with the accumulation of the stock of R&D (having to do with setting up and organizing the research team, financing the project, or elaborating a research program). It is costly to adjust the stock of knowledge too quickly and therefore the optimal investment outlays depend on the shape of the adjustment cost function. Other theoretical models justify a dynamic formulation (i.e. with lagged terms) of the investment equation on the basis of the existence of various lags in perception, decision-making, and implementation of investment projects. The exact expression for the optimal path of R&D expenditures, derived from an inter-temporal optimization problem depends then on the assumptions made regarding the adjustment cost function, the "time to build", and the process underlying the expectation formations. Such structural models are theoretically appealing but practically not very rewarding. To quote Hall and van Reenen (2000, p. 460) "Structural investment models for physical capital had a poor record of success in empirical testing whether of q-models, Euler equations or Abel-Blanchard variety. Although various attempts have been made to estimate these more structural forms none have been conspicuously successful." An alternative, more flexible, strategy is to start from a more ad hoc dynamic formulation or to let the data reveal the dynamic formulation without specifying the essence of the dynamics.

To introduce a parsimonious specification that allows distinguishing between short-term and long-term effects of the user cost of R&D and indirectly of tax credits on R&D, several

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[3] The industry output disappears from equation (8) when either $\sigma = 1$ (Cobb-Douglas technology) or $\zeta = 1$ (perfect competition). Parameter ϕ equals 1 if either $\sigma = 1$ or $\zeta = 1$ and $v = 1$ (constant returns to scale).

approaches have been used in the literature. A partial adjustment mechanism could be appended to equation (8) resulting in the addition of a lagged dependent variable term. The error term could be decomposed into an individual and an idiosyncratic effect. Bloom, Griffith and van Reenen (2002) have estimated such a specification, which is in terms of levels of R&D stocks.

An alternative approach would be to estimate an investment equation of R&D. Investment is composed of a replacement investment ($R_{i,t}^r$) and a net investment ($R_{i,t}^n$). The former is proportional to the R&D stock at the beginning of the period: $R_{i,t}^r = \delta K_{i,t-1}$. The latter represents the change in the R&D stock: $R_{i,t}^n = K_{i,t} - K_{i,t-1}$. Hence we can write

$$\frac{R_{i,t}}{K_{i,t-1}} = \frac{R_{i,t}^r + R_{i,t}^n}{K_{i,t-1}} = \delta + \frac{\Delta K_{i,t}}{K_{i,t-1}} = \delta + \Delta k_{i,t}. \tag{9}$$

We approximate the discrete growth rate in the R&D stock by a log difference and assume that the growth rate in the R&D stock follows a partial adjustment mechanism, which could be formalized by an adjustment cost model (Chirinko et al., 1999; Nadiri and Rosen, 1969),

$$k_{i,t} - k_{i,t-1} = \lambda(k_{i,t}^* - k_{i,t-1})$$
(10)

Equation (10) can after substitutions be rewritten as

$$k_{i,t} - k_{i,t-1} = \lambda(k_{i,t}^* - k_{i,t-1}^*) + (1-\lambda)\lambda(k_{i,t-1}^* - k_{i,t-2}^*) + (1-\lambda)^2 \lambda(k_{i,t-2}^* - k_{i,t-3}^*) + ... \tag{11}$$

Changes in the R&D stock are therefore expressed as a weighted sum of the changes in the desired R&D stocks in the past. Equation (9) can then be rewritten as

$$\frac{R_{i,t}}{K_{i,t-1}} = \delta + \phi \sum_{h=0}^{\infty} \mu_h \Delta v_{i,t-h} - \sigma \sum_{h=0}^{\infty} \mu_h (\Delta u_{i,t-h}^R - \Delta p_{I,t-h}) + \gamma \sum_{h=0}^{\infty} \mu_h \Delta q_{I,t-h} + \varepsilon_{i,t} \tag{12}$$

where μ_h follow a Koyck scheme of exponentially declining coefficients $\mu_h = \lambda(1-\lambda)^h$ with h=0,1, ..., and λ<1. We have appended a random error term in (12) to account for random unobserved disturbances. Any individual effect present in (8) is removed by the first-differencing in (11).

Equation (12) can be simplified as

$$
\begin{aligned}
\frac{R_{i,t}}{K_{i,t-1}} &= \delta + \phi\sum_{h=0}^{\infty}\mu_h L^h \Delta v_{i,t} - \sigma\sum_{h=0}^{\infty}\mu_h L^h(\Delta u_{i,t}^R - \Delta p_{I,t}) + \gamma\sum_{h=0}^{\infty}\mu_h L^h \Delta q_{I,t} + \varepsilon_{i,t} \\
&= \delta + \phi\frac{\lambda\Delta v_{i,t}}{I-(1-\lambda)L} - \sigma\frac{\lambda(\Delta u_{i,t}^R - \Delta p_{I,t})}{I-(1-\lambda)L} + \gamma\frac{\lambda\Delta q_{I,t}}{I-(1-\lambda)L} + \varepsilon_{i,t} \\
&= \lambda\delta + (1-\lambda)\frac{R_{i,t-1}}{K_{i,t-2}} + \phi\lambda\Delta v_{i,t} - \sigma\lambda(\Delta u_{i,t}^R - \Delta p_{I,t}) + \gamma\lambda\Delta q_{I,t} + \varepsilon_{i,t} - (1-\lambda)\varepsilon_{i,t-1}.
\end{aligned}
\tag{13}
$$

The short-run elasticity of R&D stock with respect to the user cost of R&D is given by $-\sigma\lambda$. The long-run elasticity is given by $-\sigma$.

A third approach would be to assume an autoregressive distributed lag (ADL) specification for the R&D stock and to express the resulting equation in an error-correction (EC) form. This model has been adopted by Jaumotte and Pain (2005) and Mairesse and Mulkay (2004). Instead of equation (8) we have

$$
k_{i,t} = \xi_1 k_{i,t-1} + \phi_0 v_{i,t} + \phi_1 v_{i,t-1} - \sigma_0(u_{i,t}^R - p_{I,t}) - \sigma_1(u_{i,t-1}^R - p_{I,t-1}) + \gamma_0 q_{I,t} + \gamma_1 q_{I,t-1} + \alpha_i + \eta_{i,t} \quad (14)
$$

where ξ_1<1, α_i is the individual effect and and η_{it} the idiosyncratic random effect. After rewriting (14) and combining it with (9) an ECM(1, 1) specification is obtained:

$$
\begin{aligned}
\frac{R_{i,t}}{K_{i,t-1}} &= \delta + (\xi_1 - 1)[k_{i,t-1} - \frac{(\varphi_0 + \varphi_1)}{(1-\xi_1)}v_{i,t-1} + (\frac{\sigma_0 + \sigma_1}{(1-\xi_1)})(u_{i,t-1}^R - p_{I,t-1}) - \frac{\gamma_0 + \gamma_1}{(1-\xi_1)}q_{I,t-1}] \\
&+ \varphi_0\Delta v_{i,t} - \sigma_0\Delta(u_{i,t}^R - p_{I,t}) + \gamma_0\Delta q_{I,t} + \alpha_i + \varepsilon_{i,t}.
\end{aligned}
\tag{15}
$$

The ECM(1,1) model gives us directly the short-run and long-run elasticities[4]. The short-run elasticity of R&D stock with respect to the user cost of R&D is given by $-\sigma_0$. The long-run elasticity is given by $-(\frac{\sigma_0 + \sigma_1)}{(1 - \xi_1)}$. This specification presents a somewhat more flexible adjustment mechanism at the price of three additional parameters to be estimated. It has also the advantage compared to (14) to include regressors in levels instead of only first differences. To the extent that these variables are persistent, taking first differences magnifies their noise component and thereby the errors in variable problem and the weak instrument problem. We shall nevertheless estimate all three specifications to check the robustness of our estimates.

3. Data and descriptive statistics

Data sample

The empirical analysis makes use of the Dutch Central Bureau of Statistic's annual CIS and R&D surveys in combination with production statistics. The R&D surveys contain information on firms' R&D expenditures and their breakdown by type, and the production statistics database contains information on output, employment and output deflators. These data sources and the process of merging them are explained in detail in Lokshin and Mohnen (2007b). We estimate the model on an unbalanced panel of annual firm observations between 1996 and 2004.

All enterprises doing R&D can apply for R&D tax deductions. In 2004 there was the following distribution of WBSO users by sector: agriculture (7%), food (5%), chemicals (11%), machines (29%), other manufacturing (22%), ICT (11%), and other services (14%). This distribution has stayed more or less constant from 1996 till 2004 (de Jong and Verhoeven, 2007). A large proportion of firms that perform R&D on a continuous basis apply for R&D tax credits. More than 80% of the large firms (with more than 200 employees) and about 70% of the small firms (with less than 50 employees) apply on average for the WBSO facility. However, among the firms with at least 5 full-time R&D employees, more than 88% use the facility. For all size classes the coverage gradually increased between the inception of the program in 1994 to 2004, both in terms of the number of firms applying and the number

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[4] It is possible to increase the number of lags and to test for an ECM(2,2) or ECM(3,3) specification, as estimated for example by Mairesse and Mulkay (2004). Compared to their study we have a relatively short time dimension and therefore we opt for an ECM(1,1) specification.

of total applications by these firms. The WBSO budget increased by almost 80% from 1996 to 2004.

Table 1 lists the main parameters of the WBSO program for our sample period. For example, in the year 2004, there were two brackets: firms could deduct 42% of their R&D labor cost on the first 110 thousand Euros in firm R&D wage expenditure, followed by a 14% deduction rate on the remaining amount below the ceiling, which was set at 7.9 million Euros. There have been a couple of changes over time in the length of the two brackets and the corresponding rates of R&D wage cost deductions. For example, in 2001 the length of the first bracket was extended from € 68,067 to € 90,756 and in the same year a higher additional first-bracket tax credit for starters (60% as opposed to 40% for the rest) was introduced.

[INSERT TABLE 1 HERE]

After cleaning the data, we are left with the following distribution of our sample across size classes.[5] The middle size group (50 to 200 employees) represents around 59% of the total number of firms. The largest firms (over 200 employees) are somewhat over-represented in our sample. The smallest size group (fewer than 10 employees) is under-represented due to the absence of innovation and R&D survey data from CBS over the whole period for firms with less than 10 employees. In the end, firms in our dataset account on average, across all years, for 15% of total WBSO expenditures and almost 25% of all R&D performed in the Netherlands.

Variables

The dependent variable in specifications (13) and (15) is the firm real R&D expenditures $R_{i,t}$ divided by its R&D stock in the previous period $K_{i,t-1}$. The main explanatory variables are the user cost of R&D, value added and the industry output, in first differences in (13) and in

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[5] We selected only those firms that perform R&D on a continuous basis, the so-called continuous R&D performers, because in odd years CBS only collects data for continuous R&D performers. We also selected only those firms that have a positive R&D in the mentioned data sources. The use of lags in the dynamic econometric specification as well as the construction of R&D stock further eliminates firms with non-contiguous observations over time.

first differences and in levels in (15). We used the Fisher test as developed by Maddala and Wu (1999) to check the stationarity of variables. The null hypothesis of unit root is rejected for each of the variables. Table 2 provides descriptive statistics on the variables used in the estimation.

[INSERT TABLE 2 HERE]

As explained in the modeling section, a negative relation is expected between the user cost and the firm's R&D investment and a positive relationship between output and the R&D investment rate. To construct the user cost of R&D, we use the information about the R&D cost composition, provided by CBS. The construction of the user cost is explained in detail in appendix A. Table 3 shows the average user cost of R&D constructed using expression A2 in appendix A and its components for all the firms in our sample.

[INSERT TABLE 3 HERE]

For identification purposes it is important that there be sufficient variation in u_i^R. Formula A2 indicates that variation in the time dimension comes from two sources. First, there were a number of changes (taken to be exogenous) in the fiscal incentives scheme's parameters. Such changes, reported in Table 1, occurred in every year except one within our estimation sample period. The first bracket threshold increased three times, the rate applied to the first bracket increased three times, the rate applied to the second bracket changed five times and the ceiling changed twice. The second source of variation in u_i^R in the time dimension comes from the changes in the macro variables such as the interest rate and the corporate income tax rate. The latter was gradually reduced from a high 37% in 1996 to 29% in 2004. Variation of u_i^R in the cross-section comes from two sources. First, the variation is determined by whether a firm applies the standard or the preferential starter's rate. Second, the level of tax credit depends on the remittance rate that in turn depends on how high a firm's R&D wage bill is. The ensuing endogeneity of the user cost calls for good instruments. We discuss how we address the endogeneity issue in the estimation section below.

The user cost in the absence of R&D tax incentives increased by 26% between 1997 and 2004. The average WBSO tax credit increased from 17.3 to 19.4 percent. This slight increase

is attributable mostly to increases in the two scheme's ceilings and a resulting compositional change of the firms with respect to the WBSO scheme: (i) an increase of the percentage of firms applying for tax credits from 66.4% to 73.4% , (ii) an increase from 12.8% to 36.3% in the percentage of non-starter R&D performers that fall under the first bracket ceiling, and (iii) an increase from 16.5% to 36.6% in the percentage of non-starter R&D performers that fall between the first bracket and the second bracket ceiling. Column (3) in Table 3 contains the average B-index, including the tax credits and other R&D tax incentives. Between 1997 and 2004 the overall R&D tax incentives decreased the R&D user cost by 12%. This percentage is lower than the increase in the WBSO because the change in the corporate income tax rate partly reduced the usual deductions due to expensing and depreciation allowances. Column (4) presents the user costs of R&D obtained as the product of the corresponding averages in columns (1) and (3). The nominal user cost has increased from 0.258 to 0.314, i.e. by 22% between 1997 and 2004. The increases in inflation and in the real interest rate have been tempered by the increase in R&D tax incentives. In column (5) we present the average user cost of R&D without the WBSO tax credit. We see that without WBSO the user cost of R&D would have increased by 25% between 1997 and 2004. The user cost of R&D would on average be higher by 18 to 24 % without WBSO.

4. Econometric Results

The main results are reported in Table 4. The results from estimating a dynamic version of equation (8), the ECM(1,1) specification (15) and the geometrically lagged distribution partial adjustment model (13) are presented in columns (1) – (3) of Table 4, respectively.

Because of the simultaneity between the user cost and the amount of R&D we have to instrument for the level or the change in the user cost of R&D in each specification. It is also reasonable to consider that the output of the firm is endogenous and needs to be instrumented. To follow Bloom at al. (2002) as closely as possible we estimate (8) using the within estimator instrumenting for the level of the real user cost of R&D, the level of output and the lagged dependent variable because of the presence of the individual effect. We use the following instruments: two- and three-period lagged levels of the R&D stock, the lagged level of real output, and the length of the first and second brackets of the WBSO tax incentive scheme (see appendix A), as well as the contemporaneous real R&D deflator, which varies at the sectoral level. The fiscal incentives scheme's parameters are valid instruments because

they are exogenous policy decisions and yet reasonably correlated with the firm's user cost. The Shea partial R^2 in the first-stage user-cost equation is 0.23 (F-test based on this measure is 39.62, p-value<0.01) and 0.09 for output. The Sargan test statistic is small (5.19 with a p-value of 0.16) and does not reject the validity of the instruments. The estimated short-run user cost elasticity is -0.21 and the long-run elasticity -0.56, both statistically significant.

[INSERT TABLE 4 HERE]

Column (2) of Table (4) lists the results from the ECM(1,1) specification. We estimate equation (15) using the within estimator. The individual effects are treated as fixed as the Hausman test rejects the null hypothesis of orthogonality of the individual effects and the regressors (Chi2 = 112.28, p-value 0.00). The change in the real user cost of R&D and the change in output are likely to be correlated with the error term. Variables in levels are lagged by one period and do not cause problems of endogeneity. The Hausman test rejects the null hypothesis that the growth rate in the real user cost of R&D is exogenous ($\chi^2(1) = 8.11$) but we cannot reject the exogeneity of contemporaneous change in output based on the difference-in-Sargan statistic (0.01, p-value = 0.95). We instrument the change in the user cost of R&D with the exogenous parameters of the fiscal incentive scheme, i.e. the length of the first bracket and the second bracket rate, as well as the contemporaneous real R&D deflator in first differences. We use a number of tests to check the validity of our instruments. The rank test of under-identification rejects the null hypothesis that the matrix of reduced from coefficients has less than full rank and hence points to the relevance of the instruments and the identification of the model with those instruments ($\chi^2(2) = 188.27$). The Shea partial R^2 is reasonable 0.21 (F-test based on this measure is 52.5, p<0.01). We also checked the Cragg-Donald statistic (the minimum eigenvalue of the first stage F-statistic matrix) to test whether the instruments are weak in terms of relative bias (the maximum relative squared bias of the IV estimator relative to the OLS estimator) and in terms of bias in the Wald test size (whether the actual size of the test is at least some value b above the nominal level of the test). The Cragg-Donald statistic is 52.53 and at 5% level (critical value 16.85) we reject the null hypothesis that the instruments bias the IV estimate relative to the OLS estimate by more than 5% and we do not reject the null hypothesis that the bias in the size of the Wald test exceeds 10% (critical value 24.58). The Sargan test statistic is small (0.21, p-value = 0.85) and does

not reject the validity of the instruments. The estimated short-run user cost elasticity is -0.50 and the long-run elasticity -0.54, both statistically significant.

Column (3) in Table 4 presents the results from equation (13). There is no particular reason to include an individual effect as the equation is already in first-differences and the depreciation of R&D as well as the adjustment speed towards the desired R&D stocks are supposed to be constant across firms. Indeed, when we introduce the individual effects, the individual effects turn out to be insignificant (F-test of the null hypothesis that all individual effects are zero is 0.13, p-value = 0.98).[6]

The lagged dependent variable, the change in the real user cost of R&D, and the change in output are likely to be correlated with the error term. The Hausman test rejects the null hypothesis that the growth rate in the real user cost of R&D, is exogenous ($\chi^2(1)$ is 7.95). The lagged dependent variable in (13) is also correlated with the error term because of its MA(1) nature. Therefore, we instrument the change in the user cost and $R_{i,t-1}/K_{i,t-2}$ by the length of the first bracket and the second bracket rate, the contemporaneous real R&D deflator (in first differences), and $R_{i,t-2}/K_{i,t-3}$. The instruments are significant and valid in this equation, using Sargan test (0.61, p-value = 0.89), the rank test of under-identification (52.8, p-value = 0.00), and Cragg-Donald statistic (10.7), although the Shea partial R^2 for this equation is somewhat smaller, 0.11. The estimated short-run user cost elasticity is -0.42 and the long-run elasticity -0.79, both statistically significant.

Our estimated partial adjustment coefficient of 0.5 is also quite reasonable, indicating that firms accomplish half of their desired capital stock growth in every period. The output elasticity is relatively low and only significant at a 10% level of confidence. The elasticity with respect to the industry price is significant only at 10%. Parameter δ is estimated at 0.1

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[6] In the model selection process we experimented with several control variables. We included controls for business cycle influences on R&D investment by using industry-specific business cycle indicators: for investment potential (i.e. solvability and return on total assets) and indicators for perceived competition, turbulence and economic development. These variables were constructed and provided to us by EIM. None of these control variables had a significant coefficient. We also tried to control for a possible size effect in the R&D investment rate by including the log of the number of employees as an additional regressor. This size effect would capture, not scale effects but, differences in the speed of adjustment of the R&D stock. This coefficient was also insignificant. To include more firm specific control variables we would have to resort to the CIS surveys, which are only available in even years. We have refrained from doing so in order not to lose too many observations.

and is statistically significant. The output price markup and returns to scale coefficients (ζ and v, resp.) are not reported because they are derived from industry and firm output elasticities which are not statistically significant[7].

Both short-term and long-term price elasticities are statistically different from zero at the 1% level of significance in all three specifications. We also note that the three models, which differ essentially in the assumed dynamics of R&D stock accumulation, produce consistent results. A 10 percent decrease in the user cost of R&D is predicted by the three models to increase the R&D stock by respectively 2, 5 and 4 percent in the short run and 5.6, 5.4 and 7.9 percent in the long run. The estimated R&D price elasticities reported in the literature vary widely depending on the data, the estimation method and perhaps the underlying tax incentive system (see Hall and van Reenen, 2000, Wilson, 2007). Our estimated R&D price elasticities are in the ballpark of those reported elsewhere. If ever there was a systematic deviation, which would require a proper meta-analysis to control for other differences in the conducted studies, it would be a lower long-run elasticity and a lower spread between short-run and long-run elasticities.

We ran a number of alternative specifications to test the sensitivity of our results. We estimated a finite-distributed lag model similar to one employed for example by Chirinko, Fazzari, and Meyer (1999). We experimented with several specifications with up to four lags of u_i^R. In our preferred specification based on the Akaike information criterion with three lags all short-run elasticities ($-\sigma_0$, $-\sigma_1$, $-\sigma_2$) are statistically significant. The long-run price elasticity was estimated to be -0.89 and was significant. We estimated specification (15) for large (200 or more employees) and small firms (less than 200 employees). As expected, the estimated R&D user cost elasticity is larger for small firms (-0.57 versus -0.15 in the short run and -1.1 versus -0.25 in the long run), suggesting that small firms are much more sensitive to fiscal incentives. Large firms consider tax incentives more as a bonus and do not let their R&D investments be greatly affected by variations in the level of tax incentives. Small firms are more likely to be credit constrained and therefore more sensitive to tax incentives. As

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[7] Some of the reported tests can be sensitive to the presence of heteroskedasticity, in which case a more efficient GMM estimator can be used. To check this, we perform several heteroskedasticity tests on residuals in all our models. We use Pagan and Hall's (1983) general test of heteroskedasticity for instrumental variables (IV) estimation as well as the standard heteroskedasticity test of White/Koenker. These tests do not reject the assumption of homoskedasticity of the residuals in our models.

expected, the adjustment speed towards the optimal R&D stock is somewhat higher for large firms (0.58 versus 0.52), although the difference is statistically not significantly different from zero.

5. Effectiveness of tax credits to R&D

On the basis of the estimated elasticity of R&D with respect to its user cost we can analyze the effectiveness of the tax credits, i.e. find out whether the additional R&D stimulated by the tax incentive policy is greater than the tax expenditures related to this program. We shall be interested in evaluating the effectiveness of the whole fiscal incentives program and not of particular aspects of it[8].

In the absence of a proper cost-benefit calculation, that would include all direct and indirect costs and benefits related to such a program, the usual way to assess the efficiency of R&D tax incentives consists in computing the so-called "bang for the buck" (BFTB). The BFTB calculates how much private R&D gets generated per Euro of R&D tax receipts foregone. It is greater than 1, R&D tax incentives are considered to be efficient in stimulating additional R&D; a value smaller than 1 means that part of the money received from tax incentives substitutes for private financing[9]. What is important, but generally not done in this kind of evaluation, is to compare not just the present but also all future R&D and tax receipts foregone, because if firms adjust their desired R&D stock only gradually, it takes time for the additional R&D expenditures, and the associated costs to the government that go with it, to realize.

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[8] For instance, from the policy perspective, it would also be interesting to examine the effect of R&D tax credits, or changes in it, on the probability to become an R&D performer (e.g., Dagenais et al., 2004). Unfortunately, we are unable to examine this issue because our sample is limited to 'hard-core' continuous R&D performers, first because the Dutch R&D surveys concern only hard-core R&D performers, and secondly because we eliminate firms with less than three contiguous years of observations in order to construct R&D stocks. We have no pre-sample information and only a handful of startup firms. Finally, it would be preferable to control also for the use of direct R&D subsidies (as done in Hægeland and Møen, 2007 and Corchuelo and Martínez-Ros, 2009). We did not have this information. This might overestimate our price elasticity since part of what we attribute to tax incentives may actually be due to direct R&D support.

[9] It goes without saying that the threshold value of 1 is no longer relevant if we include external and side effects in the benefits of the tax program and administrative and implementation costs for the firms as well as for the government in the additional costs due to the tax program.

To evaluate the entire fiscal incentives program, and not just particular aspects of it, we shall compare the present situation with the scheme in place to a fictive scenario where the government would remove the entire program. In our model based on the user cost of R&D the price elasticity has no longer a direct connection to the BFTB[10]. To calculate the BFTB related to the whole fiscal incentives program we evaluate the R&D (in Euros) that would be lost following the suppression of the WBSO program and the ensuing increase in the user cost of R&D to the money saved by the government for no longer having to support the program, from the time 0 that corresponds to the removal of the WBSO to the time where firms reach their new steady state in R&D stocks.

To find out how much R&D decreases from period 1 onwards because of the removal of the fiscal incentives scheme occurring in period 0 ($\Delta u_{i,0}^R$), we have to compute the differences in R&D flows (or expenditures) from period 1 onwards between the two scenarios, where the flows of each additional year are discounted by $(1+r)$ vis-à-vis the previous year. This in our particular case is equal to[11]

$$\sum_i \sum_{t=1}^{\infty} (\widetilde{R}_{i,t} - R_{i,t})/(1+r)^{t-1} = \sum_i \sum_{t=1}^{\infty} \left[\delta \left(\frac{\partial K_{i,1}}{\partial u_{i,0}^R} + ... + \frac{\partial K_{i,t-1}}{\partial u_{i,0}^R} \right) + \frac{\partial K_{i,t}}{\partial u_{i,0}^R} \right] \Delta u_{i,0}^R \Bigg/ (1+r)^{t-1} \qquad (16)$$

In expression (16) we have[12]

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[10] Brouwer et al. (2002) regress private labor R&D expenditures on WBSO disbursements and obtain a figure, which they interpret as being the BFTB, of 1.01. The advantage of their specification is that it obviates the need to eliminate observations in order to construct an R&D stock. For comparison, in Lokshin and Mohnen (2007a) we have re-estimated their model on a dataset somewhat larger than the one used in this paper, adding a fixed effect, and obtained a coefficient of 1.25. This estimate was also not very different if we increased the sample to the maximum number of available observations instead of the restricted number of observations allowing the construction of an R&D stock. This approach suffers, however, from a simultaneity bias, because not only do the WBSO tax credit rates depend on the amount of R&D performed, but, even more so, the disbursements are directly determined by the amount of R&D performed. It is, therefore, impossible to establish the direction of causality, unless an arbitrary lag between disbursements and R&D expenditures is assumed.

[11] Because $\widetilde{K}_{i,t-1} = K_{i,0} + (\partial K_{i,1}/\partial u_{i,0}^R + \partial K_{i,2}/\partial u_{i,0}^R + ... + \partial K_{i,t-1}/\partial u_{i,0}^R) \Delta u_{i,0}^R$ we can write

$\widetilde{R}_{i,t} - R_{i,t} = \delta(\widetilde{K}_{i,t-1} - K_{i,0}) + (\partial K_{i,t}/\partial u_{i,0}^R)\Delta u_{i,0}^R = \delta(\partial K_{i,1}/\partial u_{i,0}^R + \partial K_{i,2}/\partial u_{i,0}^R + ... + \partial K_{i,t-1}/\partial u_{i,0}^R)\Delta u_{i,0}^R + (\partial K_{i,t}/\partial u_{i,0}^R)\Delta u_{i,0}^R$

$= [\delta(\partial K_{i,1}/\partial u_{i,0}^R + \partial K_{i,2}/\partial u_{i,0}^R + ... + \partial K_{i,t-1}/\partial u_{i,0}^R) + \partial K_{i,t}/\partial u_{i,0}^R]\Delta u_{i,0}^R$.

[12] Given the robustness of the results across specifications, for analytical simplicity we compute the BFTB using the partial adjustment model (10).

$$\frac{\partial K_{i,t}}{\partial u_{i,0}^R} = -\sigma\lambda(1-\lambda)^{t-1}\frac{\widetilde{K}_{i,t}}{u_{i,t}^R}, \tag{17}$$

where $-\sigma\lambda$ is the estimated user cost elasticity of R&D stock in the first period, λ is the estimated partial adjustment coefficient, δ is depreciation parameter for the R&D stock, taken to be 15%, r is the risk-free interest rate, on average 3%, and where the user cost elasticity, common to all firms of a given size class and constant over time, is converted to a marginal effect for period t using the optimal R&D stock and the user cost of R&D of period t.

The discrete change in the user cost when the tax credit is suppressed in period $0, \Delta u_{i,0}^R$, is given by the following expression:

$$\Delta u_{i,0}^R = -P_R(r+\delta)w_i^L G_i(R_i) \tag{18}$$

The construction of $G_i(R_i)$ – the fraction of the private R&D supported by the WBSO tax incentive program – is explained in Appendix A. Substituting (17) and (18) into (16) gives

$$\sum_i\sum_{t=1}^{\infty}(\widetilde{R}_{i,t}-R_{i,,t})/(1+r)^{t-1} = \sum_i\sum_{t=1}^{\infty}\frac{-\sigma\lambda(r+\delta)\Delta u_{i,0}^R}{r}\left(\frac{(1-\lambda)}{(1+r)}\right)^{t-1}\left(\frac{\widetilde{K}_{i,t}}{u_{i,t}^R}\right) \tag{19}$$

where, given that $0 < \lambda < 1$, $\widetilde{K}_{i,t}$ can be computed recursively as[13]

$$\widetilde{K}_{i,t} = \frac{\widetilde{K}_{i,t-1}}{1+\sigma\lambda\Delta u_{i,0}^R(1-\lambda)^{t-1}/u_{i,t}^R} \ .$$

The cost saving for the government for no longer supporting the R&D tax credit program is denoted by W_t. The difference in government costs between the old and the new scenario is given by

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[13] Notice that if we drop the whole WBSO scheme, the user cost of R&D actually remains constant over time.

$$\sum_{t=1}^{\infty}(\widetilde{W}_t - W_t)/(1+r)^{t-1} = \frac{1}{(1+r)^{t-1}}\sum_i\sum_{t=1}^{\infty}(1-\tau)w_i^L[G_{i,t}(\widetilde{R}_{i,t})\widetilde{R}_{i,t} - G_{i,t}(R_{i,t})R_{i,t}]$$

$$+\frac{1}{(1+r)^{t-1}}\sum_i\sum_{t=1}^{\infty}\tau(w_i^B z_i^B + w_i^E z_i^E + w_i^O + w_i^L)(\widetilde{R}_{i,t} - R_{i,t}).$$

(20)

We can compute (20) for each period iteratively using the expression $\widetilde{R}_{i,t} = \delta\widetilde{K}_{i,t-1} + (\widetilde{K}_{i,t} - \widetilde{K}_{i,t-1})$, assuming that the factor composition of the R&D costs does not vary with the tax credit rate.[14]

The BFTB related to the removal of the entire program is given by the ratio of equations (19) and (20):

$$BFTB = \frac{\sum_i\sum_{t=1}^{\infty}(\widetilde{R}_{i,t} - R_{i,t})/(1+r)^{t-1}}{\sum_{t=1}^{\infty}(\widetilde{W}_t - W_t)/(1+r)^{t-1}}.$$

(21)

In other words, we compare the ratio of the decreases in R&D along the entire trajectory to the savings in government costs to support the WBSO program along the whole trajectory, both appropriately discounted[15]. The convergence to a new steady state is basically achieved after 15 years, i.e. $(\widetilde{K}_{i,0+15} - \widetilde{K}_{i,0+14})$ is negligible. The BFTB computed for all firms in the sample is equal to 1.05 (standard error 0.23) one year after the removal of WBSO after which it monotonically declines to about 0.54 (s.e. 0.73) 15 years after.[16] The BFTB estimate is statistically significant in the short run (the first four periods) at the conventional levels, but its confidence interval becomes wider with t. The long-run BFTB is not statistically significant at the conventional levels. The computation of the standard error of the BFTB is

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[14] In (20) $R_{i,t} = R_{i,0}$, i.e. the steady state level of R&D expenditures in the scenario with WBSO in place.

[15] Because of the unbalanced nature of our sample, the reference year 0 is different for every firm. We take it to be the last year a firm is observed in the sample. All parameters that enter the computation of (19) and (20) are taken for that particular year for each firm.

[16] The cumulative decrease in R&D up to t years after a removal of the WBSO is given by

$$-\sigma\lambda\sum_i\sum_{\tau=1}^{t}\Delta u_{i,0}^R\left(\frac{\widetilde{K}_{i,\tau}}{u_{i,\tau}^R}\right)\left(\frac{(1-\lambda)}{(1+r)}\right)^{\tau-1}\left[\left(\frac{r+\delta}{r}\right) - \left(\frac{\delta}{r(1+r)^{t-\tau}}\right)\right].$$

explained in appendix B. According to our estimates, the decrease in R&D due to removal of the tax incentives is more than compensated by the decrease in the government tax expenditures. In other words, the introduction of the WBSO would lead eventually to less additional R&D than the WBSO budget devoted to it.[17]

The effectiveness of the fiscal scheme differs, however, by size class. We distinguish two size classes: the small firms with less than 200 employees and the large firms with at least 200 employees. We re-compute BFTB for the two size classes by using the estimated elasticities for each size class. One year after the removal of the program the BFTB is equal to 3.24 (t-statistic 3.07) for small firms and 0.78 (t-statistic 4.04) for large firms. If we limit the analysis to the immediate business R&D outlays and associated costs to the government, the program seems to be effective in stimulating new R&D for small firms but not for large firms. If we consider the whole sequence of R&D outlays and associated costs to the government, i.e. 15 years after the removal of the program, we conclude that the BFTB drops to 1.21 (t-statistic 0.77) for small firms and to 0.42 (t-statistic 0.17) for large firms. The costs to the government exceed the additional private R&D for the latter group.

The long-term ineffectiveness of a fiscal incentive scheme like the Dutch WBSO reflects the dead-weight loss related to a level-based system of R&D tax incentives[18]. With a level-based R&D fiscal incentive scheme firms can apply for tax deductions regardless of their past R&D effort. The tax credit applies to the total R&D labor bill, i.e. the current incremental R&D and the level of R&D existing before the introduction of the scheme. Supporting pre-existing R&D, which was done anyway, is a dead-weight loss from the social planner's perspective. In contrast, with increment-based R&D tax incentives scheme only the additional R&D would be supported. Conversely, removing the existing scheme, as we have experimented with, would decrease R&D to an extent determined by the user-cost elasticities, but not remove it completely. For government, this measure would decrease not just the expensing related to the

[17] This conclusion does not change much when we assume a zero discount rate. If we assume that there are no adjustment costs and hence that firms reach immediately their new long-run equilibrium R&D stock, then we need only compare the additional R&D and associated revenue loss between the old and the new steady state, using the long-run price elasticity.

[18] Although we acknowledge that small firms are underrepresented in our sample it does not seem to affect our conclusions about the dead-weight loss of the level based program. To check how sensitive our outcomes are for the sample composition, we conducted Monte Carlo simulations in which we mimicked population of R&D performers in The Netherlands. The results of these experiments do not change the substantive conclusions and are described in more detail in Mohnen and Lokshin (2010).

decrease in R&D but also the WBSO support of all present R&D. Removing the WBSO would result in regaining the dead-weight loss[19].

The results of the simulations suggest that for the small firms the hypothesis of crowding out can be rejected and that the fiscal incentives program is successful in stimulating small firms' investment in R&D especially in the short run. For large firms the Dutch R&D support program does not look to be effective. From the beginning the deadweight loss overshadows the increase in R&D generated from the program.

To compute the magnitude of the deadweight loss, we evaluate the WBSO support for the amount of R&D that would be done even in the absence of the program, i.e. in our experiment at the new steady state after complete removal of the WBSO (let's denote the new optimal R&D as $\widetilde{R}_i^*$)

$$-\sum_i G_i(\widetilde{R}_i^*) w_i^L \widetilde{R}_i^*(1-\tau) \tag{22}$$

and divide this expression by the difference in revenue loss for the government with and without the fiscal incentives scheme

$$-\sum_i (1-\tau) w_i^L [G_i(\widetilde{R}_i^*)\widetilde{R}_i^* - G_i(R_{i0})R_{i,0}] + \sum_i \tau(w_i^B z_i^B + w_i^E z_i^E + w_i^O + w_i^L)(\widetilde{R}_i^* - R_{i,0}). \tag{23}$$

Expression (22) indicates how much unnecessary WBSO disbursement the government would save by removing the whole WBSO. It corresponds to the subsidizing of the amount of R&D that would be done in the absence of the WBSO. Giving WBSO disbursement on that amount

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[19] We have also simulated the effects of marginal changes in the parameters entering the WBSO tax scheme by calculating the changes in R&D due to those changes in the tax parameters and comparing it to the related cost savings/increases in revenue losses for the government. In the case of a marginal change the expression for Δu_{Ri} that enters (16) can be expressed as:

$$\Delta \widetilde{u}_i^R = u_i^R \mid (\widetilde{\omega}_1^1, \widetilde{\omega}_1^2, \widetilde{R}_L^1, \widetilde{R}_L^2) - u_i^R \mid (\omega_1^1, \omega_1^2, R_L^1, R_L^2)$$

representing the difference in the user cost evaluated at the new and the old tax scheme parameters. The expression (20) for the denominator of BFTB ratio becomes the difference in the costs to the government evaluated at the old and new parameters. While the BFTB curves shift up or down as a result of the marginal changes in parameters, the dead-weight loss remains, as does the shape of the BFTB curve.

is precisely the source of the dead-weight loss. Expression (23) is nothing but expression (20), evaluated between the two steady states, $\widetilde{R}_i^*$ (without WBSO) and $R_{i,0}$ (with the WBSO), instead of comparing the accumulated amounts between the two steady states. The dead-weight loss amounts to 85% of the total revenue loss saving due to the removal of the WBSO.

Finally, we have considered whether our conclusions would change if we allowed in our experiment for the social rates of returns to R&D, including R&D spillovers. Substantive R&D spillovers have been reported in the literature and in principle, would act as a positive counterbalance to the inefficiency of the R&D support scheme. The results of our Monte Carlo experiments (see Mohnen and Lokshin, 2010 for details) suggest that spillovers have to be sizeable to compensate for the deadweight loss. Even with a social rate of return as large as 50% there can be a net welfare loss when introducing level-based tax incentives if administration and compliance costs and the costs associated with tax distortion are considered.

5. Conclusions

In this paper we have assessed the effectiveness of the R&D fiscal incentive program in the Netherlands, which consists in reducing the employer's social security contributions in proportion to the R&D wage bill (known as the WBSO program). Although we used in our simulations specific numeric values characteristic of the support scheme in one country, we believe our conclusions can be generalized to any level-based R&D support scheme, which now gain popularity in Europe.

We estimated dynamic factor-demand models based on a CES production function to measure the responsiveness of a firm's R&D capital accumulation to changes in its user cost due to changes in R&D tax incentives. We have estimated our econometric models on a firm-level sample covering 1996-2004. The richness of the dataset allowed us to construct firm-specific R&D user costs as a function of R&D tax incentives. The results suggest that R&D is responsive to its user cost. We obtain a statistically significant short-run elasticity of the order of 0.2 to 0.5 and a significant long-run elasticity of the order of 0.54 to 0.79. According to our

preferred specification the adjustment speed to the new optimal R&D knowledge level is quite high, 90% of the adjustment being completed within 2-3 periods.

To evaluate whether a level-based R&D incentives program is successful we have performed policy experiments in which we simulated the reduction in R&D following the suppression of the fiscal program and changes in specific tax parameters. By calculating the amount of the decrease in R&D in the absence of the tax incentives and comparing it to the decrease in present and future tax expenditures related to the WBSO we have computed the so-called "bang for the buck" (BFTB), given by the ratio of these two amounts. According to our results a level-based tax incentives scheme has the largest impact in the first period after which the effect of the tax incentives declines. Our results suggest that the positive effect of the program is larger for small firms. Our simulations show that after an initial shock the impact of a level-based tax incentives program gradually declines until a new steady state is reached. The BFTB decline is due to the level-based nature of the scheme, meaning that firms can apply for the wage tax deductions for the current year regardless of their past R&D efforts. As a result, the cost to the government of a level-based scheme in our experiment grows faster than the incremental (additional) firm R&D that such a program stimulates. This dead-weight loss is typical for level-based R&D tax incentives and would not occur in incremental R&D tax incentives. If recently various governments seem to steer away from incremental R&D tax incentives, there must be other reasons for it that we have not investigated (e.g. higher administration costs). The deadweight loss is immediately visible for large firms (the bang-for-the-buck being smaller than one from the first period on) and is also significant for small firms. Bringing forward the extent of this invisible deadweight loss associated with a level-based R&D support program, such as WBSO scheme, and similar level-based fiscal R&D support programs elsewhere, is the main message of this paper.

Several other elements would have to be included in a more refined cost-benefit analysis of a tax incentive program. In addition to possible external effects and side effects in the benefits of the tax program, one would also need to consider the administrative and implementation costs for the firms and the government and the opportunity cost of the tax expenditures devoted to the WBSO. These costs are however difficult to measure accurately. A first attempt at such analysis is reported in Mohnen and Lokshin (2010). Another interesting avenue for future research would be to estimate whether there is a difference in returns for the R&D stimulated by tax incentives and the R&D done in the absence of tax incentives. After

all, there are good reasons to believe that the additional R&D would have been done anyway if it yielded a higher return than the R&D done in the absence of tax incentives. In the experiments we also did not take into account a possible price effect of R&D tax incentives. Some of the government support may get dissipated in higher R&D wages instead of real R&D spending (see Goolsbee, 1998). If that is the case, the benefit from tax incentives might be overestimated.

And, finally, as already mentioned, it would be certainly be interesting to estimate the effect of tax incentives on the probability to engage in R&D. Bringing firms to become R&D performers is perhaps the major goal of R&D tax incentives, and since these firms did no R&D beforehand, for these firms there is no deadweight loss.

Table 1 Overview of WBSO program parameters

Year	WBSO budget (in mln. Euro)	Length of the first bracket (in Euro)	% First bracket	% Second bracket	Ceiling (in mln. Euro)
1996	253	68067	40	12.05	4.5
1997	274	68067	40	12.5	6.8
1998	372	68067	40	17.5	6.8
1999	353	68067	40	13	6.8
2000	365	68067	40	13	6.8
2001	435	90756	40 or 60 (s)	13	7.9
2002	464	90756	40 or 70 (s)	13	7.9
2003	425	90756	40 or 60 (s)	13	7.9
2004	466	110000	40 or 60 (s)	14	7.9

Source: de Jong and Verhoeven (2007); (s) stands for 'starters'

Table 2 Variable constructions and descriptive statistics

Variable	Construction	Mean	Standard Dev.
R/K	R&D expenditure to R&D stock constructed at the beginning of the period	0.19	0.29
U^R	User cost of R&D (see construction in Appendix A)	0.26	0.06
v	Firm output in logarithm*	16.27	1.36
q_I	Mean 2-digit industry output in logarithm *	18.05	1.02
Δu^R	Growth rate in user cost	0.04	0.23
Δv	Growth rate in firm output	0.03	0.35
Δq_I	Growth rate in industry output	0.11	0.35
K	R&D capital stock*	20.2	74.5

Note: The sample means and standard deviations are taken for the years 1996-2004. * in million 1994 Euro

Table 3 Annual average user cost of R&D and its components

Year	$P_R(r+\delta)$	WBSO Tax credit	B-index	User cost of R&D	User cost of R&D w/o WBSO tax credit
	(1)	(2)	(3)	(4)	(5)
1997	0.308	0.173	0.833	0.258	0.310
1998	0.298	0.191	0.815	0.243	0.300
1999	0.306	0.200	0.806	0.246	0.308
2000	0.311	0.207	0.797	0.248	0.312
2001	0.309	0.216	0.791	0.245	0.312
2002	0.334	0.200	0.803	0.268	0.334
2003	0.364	0.187	0.815	0.298	0.366
2004	0.388	0.194	0.808	0.314	0.389

Notes: The corporate income tax rate used in the construction of the user cost has decreased on average for the sampled firms from 36% to 29% between 1997 and 2004. B-index (column 3) is calculated using expression (A4) in Appendix A; WBSO tax credit (column 2) is calculated using the expression in square brackets (times wage share) of A4. Column (4) is a product of column (1) and column (3). Column (5) is the product of column (1) and the sum of column (3) and column (2).

Table 4. Estimation of R&D equation (14) by instrumental variables

Dependent variable	$k_{i,t}$	$\dfrac{R_{it}}{K_{i,t-1}}$	$\dfrac{R_{it}}{K_{i,t-1}}$
	Simple dynamic model (eq. 8)	ECM (1,1) model (eq. 15)	Partial adjustment model (eq. 13)
$\dfrac{R_{it-1}}{K_{i,t-2}}$ R&D flow/stock	--	--	0.47*** (0.13)
$k_{i,t-1}$ ln(R&D stock)	0.62*** (0.04)	-0.89*** (0.06)	--
$d(u^R_{i,t} - p^I_{i,t})$ d(ln user cost)	--	-0.50*** (0.18)	-0.42*** (0.14)
$u^R_{i,t} - p^I_{i,t}$ ln(user cost)	-0.21*** (0.05)	--	--
$u^R_{i,t-1} - p^I_{i,t-1}$ ln(lagged user cost)	--	-0.48*** (0.18)	--
dv_{it} dln(output)	--	0.05 (0.04)	0.06* (0.03)
$v_{i,t}$ ln(output)	0.14** (0.06)	--	--
$v_{i,t-1}$ ln(lagged output)		0.08* (0.04)	--
dq_{Iit} dln(industry output)		0.09* (0.04)	0.05 (0.03)
$q^I_{i,t-1}$ ln(lagged industry output)	0.01 (0.01)	0.13* (0.05)	
δ		--	0.10*** (0.03)
Long-run user cost elasticity	-0.56*** (0.15)	-0.54*** (0.20)	-0.79*** (0.35)
Time dummies	Included	Included	Included
Individual effects	Fixed	Fixed	--
Sargan test (p-value)	5.18 (0.16)	0.21 (0.97)	0.61 (0.89)
Number of observations	1185	1185	1185

Notes: Estimation period is 1996-2004. *** indicates significance at 1%, ** at 5%, * at 10%.
Standard errors of the long-run elasticities are computed using the delta method.

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Appendix A: Measurement of the user cost of R&D in the Netherlands

The user cost of R&D measures how much it costs a firm to hold a unit of R&D stock of knowledge. It corresponds to the price for this unit of knowledge if there was a rental market for knowledge. It can be derived from the equality between the discounted value of the net (after income tax) "rental" cost of a unit of R&D and the net (of tax incentives) purchase price of that same unit. Deleting the time subscript to ease notation, we can write the user cost of R&D for firm i as

$$u_i^R = P_R(r + \delta)B_i \tag{A1}$$

where P_R is the R&D deflator (an index of the purchase price of the various R&D components (labor, buildings, equipment, and material)[20], r is the real interest rate[21], δ is the depreciation rate of the stock of knowledge[22], and B_i is what is known in the literature as the B-index. The latter, introduced by McFetridge and Warda (1983), is defined as the ratio of the net cost of a euro spent on R&D, after all quantifiable tax incentives have been accounted for, to the net income from one euro of revenue. If, for instance, a firm spends one euro on R&D and can expense it, and the corporate tax rate is 50%, then one euro of R&D costs effectively 50 eurocent, hence one euro of return before tax is equivalent to 50 eurocent after tax. The B-index in this case is equal to 1.

Given the R&D tax incentive structure in the Netherlands, the B-index looks as follows:

$$B_i = \frac{1}{1-\tau}\left\{1 - (1-\tau)w_i^L G_i(R_i) - \tau w_i^B z_i^B - \tau w_i^E z_i^E - \tau w_i^O - \tau w_i^L\right\} \tag{A2}$$

We denote the fraction of the private R&D supported by the WBSO tax incentive program for firm i by

---

[20] The R&D deflator is constructed as the average of the GDP deflator and the R&D wage index as suggested by Jaffe and Griliches (see Bureau of Labor Statistics (1989)).

[21] The interest rate in the user cost of R&D expression could be corrected for risk. The returns from riskier projects would be discounted more. However, in practice it is difficult to measure this risk factor. Since the risk element is probably case specific, it will be partially eliminated in panel data by correcting for an individual effect.

[22] The R&D depreciation rate is assumed to be equal to 15%. We also experimented with rates ranging from 10% to 25%. 25% corresponds to a depreciation rate consistent with patent decays (see Pakes and Schankerman (1984)). These changes do not lead to statistically different outcomes in our models. Insensitivity of R&D rates of return to assumed R&D depreciation rates are also reported by Hall and Mairesse (1995).

$$G_i(R_i) = D_{1i}\left[a_i\min\left(\frac{R_L^1}{w_i^L R_i},1\right) + d_i b_i \min\left(1 - \frac{R_L^1}{w_i^L R_i}, \frac{(R_L^2 - a_i R_L^1)/b_i}{w_i^L R_i}\right)\right].$$

where[23]

τ = the corporate income tax rate

$a_i = \omega_1^1(1 - D_{2i}) + \omega_2^1 D_{2i}$,

$b_i = \omega_1^2(1 - D_{2i}) + \omega_2^2 D_{2i}$

$d_i = 1$ if $w_i^L R_i > R_L^1$, else $d_i = 0$

w_i^L = % of labor costs in total R&D

w_i^B = % of land and building expenses in total R&D

w_i^E = % of machinery and equipment expenses in total R&D

w_i^O = % of current R&D expenses other than labor

$D_{1i} = 1$ if R&D performer is eligible and willing to use WBSO, else $D_{1i} = 0$

$D_{2i} = 1$ if the "starters facility regulation" can be applied, else $D_{2i} = 0$

ω_1^1 : first bracket WBSO rate for firms eligible to WBSO but not to the "starters facility regulation"
ω_2^1 : first bracket WBSO rate for firms eligible to the starter's facility regulation
ω_1^2 : second bracket WBSO rate for firms eligible to WBSO but not to the starter's facility regulation
ω_2^2 : second bracket WBSO rate for firms eligible to the starters facility regulation, (N.B. $\omega_1^2 = \omega_2^2$)
R_L^1 : first bracket ceiling (expressed in terms of deductible R&D labor costs) deflated by the R&D deflator (e.g. in 2001, $p_R R_L^1 = 90.756$ €)
R_L^2 : second bracket ceiling (expressed in terms of reduced labor taxes) deflated by the R&D deflator (e.g. in 2001, $p_R R_L^2 = 7.9$ million €)[24]
z_i^B = present value of all future depreciation allowances due to land and buildings, where ϕ^B

is the rate of capital consumption allowance for land and buildings (5%)[25],

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[23] The B-index and function $G_i(R_i)$ also vary over time. We omit the index t for ease of exposition.

[24] We express the ceilings in real terms, because R&D is expressed in base-year prices. There is a slight problem of deflation here, in so far as the WBSO concerns only labor R&D costs which ought to be deflated by the wage index of R&D costs instead of the general R&D deflator.

z_i^E = present value of all depreciation allowances due to machines and computers, where ϕ^E is the rate of capital consumption allowance for machines and computers ranging from 10% to 33%. We use the straight-line depreciation schedule and we take an average rate of 20% for all firms

R_i : R&D expenditures.

The term in curly brackets in (A2) reads as follows. In the presence of R&D tax incentives it costs less than 1 € to purchase the equivalent of one € of R&D knowledge. The 1 corresponds to the one € of expenditures in R&D. Get deducted from this one € various fractions that correspond respectively to WBSO deductions from labor taxes, building and equipment amortizations, labor and other current costs expensing. Let us examine these expressions one by one.

The second term in square brackets corresponds to the WBSO. To the extent that R&D is labor cost, and depending on the amount of R&D that is performed, and on whether the "starters facility regulation" can be invoked, a percentage of the R&D labor costs can be deducted from social security contributions. If the amount of R&D labor falls below level R_L^1, the first bracket rate can be used, above that level the second rate is applicable up to a total permissible deduction of R_L^2. In case of start-up firms, the first bracket rate is a bit more generous. Finally, the WBSO deductions are themselves taxed, hence only the non-taxed part represents a true deduction from the initial purchase price. For illustration, suppose w_i^L=0.80, R&D is eligible for WBSO ($D_{1i}=1$), it occurs at an R&D level below the first bracket ceiling, R_L^1 for a non-starter ($D_{2i}=0$), where the WBSO rate ω_1^1=0.40, and the corporate income tax rate is 0.40. Then thanks to the WBSO the average R&D investment of one € benefits from a WBSO-driven tax incentive of 0.192.

The next two terms in curly brackets in (A2) correspond to what can be recovered from the purchase of one Euro of R&D because of amortization, either in terms of land and buildings (B) or in terms of machinery and equipment (E). The present value of all future depreciation deductions can be deducted from the effective purchase price. The amount then depends on the allowable depreciation deductions and the schedule of those reductions (e.g. straight-line or geometric) and the corresponding rates. For

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[25] Under straight-line depreciation, which is the norm in the Netherlands,

$$z_i^B = \phi_B + \frac{\varphi_B}{1+r+\pi} + ... + \frac{\varphi_B}{(1+r+\pi)^{T-1}} = \frac{\phi_B}{1-(1/1+r+\pi)} - \frac{\phi_B/(1+r+\pi)^T}{1-(1/1+r+\pi)} = \frac{\varphi_B}{r+\pi}(1+r+\pi)(1-\frac{1}{(1+r+\pi)^T}),$$

where π is the inflation rate in the R&D deflator and T is the finite lifetime of the capital item under straight-line depreciation. The interest rate in the user cost of R&D expression can be tax deductible if the R&D is financed by borrowed funds. But most R&D is financed by retained earnings and the opportunity cost from retained earnings is not tax deductible. In any case information on the source of finance (retained earnings versus borrowings from banks or issuing shares) is only available at the company level and not at the business unit level at which we are working.

the sake of illustration, suppose $w_i^B = 0.05$ and $w_i^E = 0.05$ and straight-line depreciation for both (B) and (E), a capital consumption allowance of $\phi^B = 0.05$ for buildings and of $\phi^E = 0.20$ for machinery and equipment, and a nominal interest rate plus risk premium of 0.20. The respective lifetimes are thus 20 years for buildings and 5 years for machinery and equipment. The magnitude of $\tau w_i^E z_i^E$ and $\tau w_i^B z_i^B$ are then respectively 0.014 and 0.006.

To the extent that this euro invested in R&D corresponds to current costs (labor or other) it can be immediately expensed (i.e. deducted from taxable profits). The income tax so recoverable can be deducted from the purchase price. This explains the last two terms of the expression in curly brackets in equation (A2). For illustration, suppose that $w_i^O = 0.10$. The last two terms in the curly brackets of (4) are then 0.32 and 0.02 respectively. Hence, in our example the net cost of 1 Euro of R&D is equal to 1-0.192-0.014-0.006-0.32-0.02=0.448. The B-index would then be equal to 0.448/0.60 =0.745.

It could be argued that what matters for a marginal investment for firms above the first WBSO ceiling is the second bracket WBSO rate. Any increase in the first bracket rate would be considered as windfall profit and not affect the marginal R&D decision: we believe that it makes sense to consider that this windfall profit gets reinvested in R&D. If, however, we assumed that only the marginal WBSO rates matter, then the B-index would be:

$$
\begin{aligned}
B_i = \frac{1}{1-\tau} \cdot \{1 - (1-\tau)\ w_i^L D_{1i}[(\omega_1^1(1 - D_{2i}) + \omega_2^1 D_{2i})D_{1i}^1 + (\omega_1^2 D_{1i}^2(1 - D_{2i}) + \omega_2^2 D_{2i}^2 D_{2i})] \\
- \tau w_i^B z^B - \tau w_i^E z_i^E - \tau w_i^O - \tau w_i^L\}
\end{aligned}
\tag{A3}
$$

where

$D_{1i}^1 = 1$ if $w_i^L R_i \le R_L^1$, i.e. R&D labor costs are below the first bracket ceiling.

$D_{1i}^2 = 1$ if $R_L^1 < w_i^L R_i \le (R_L^2 - \omega_1^1.R_L^1)/\omega_1^2$, i.e. if R&D is between the first bracket and the second bracket ceiling for cases, where D_{2i} is not applicable.

$D_{2i}^2 = 1$ if $R_L^1 < w_i^L R_i \le (R_L^2 - \omega_2^1.R_L^1)/\omega_2^2$ (N.B. $\omega_1^2 = \omega_2^2$), i.e. if R&D is between the first bracket and the second bracket ceiling for cases, where D_{2i} is applicable for new starters.

Given the R&D tax incentives structure in the Netherlands, we used expression (A2) to construct the B-index contained in the user cost measure. This expression is a weighted average of the first and second bracket rates. According to this expression, a firm that is situated in the second bracket but below the ceiling would receive a wind-fall profit if the rate of the first bracket or the length of the

first bracket was extended, even if all other parameters remained unchanged. Such changes occurred several times during 1996-2004, the period covered in our panel (see table 2). One of the premises of economic theory is that economic agents take decisions at the margin. Therefore, one could argue that firms decide on their marginal R&D investments on the basis of the marginal WBSO rates, hence for firms that are in the second bracket it would be that rate and only that rate which matters. This would mean that the wind-fall profits would not affect firms' R&D decisions. If we assume that only the marginal WBSO rates matter, then we would use the expression for the B-index given by formula (A3). In this case the constructed user cost is higher and the effective tax credit part is lower. The estimated short-run elasticity decreases to 0.13 and the long-run elasticity to 0.25. It has, however, been argued in the capital investment literature that liquidity can affect firms' capital investment decisions (Fazzari et al., 1988). Liquidity effects may be even more important for investment decisions in non-tangible assets like R&D, which are relatively more risky than investment in physical capital. Hall (1992), Hao and Jaffe (1993), Harhoff (1998), Himmelberg and Petersen (1994) provide empirical evidence that liquidity has an effect on firms' R&D investment. Therefore we argue that firms decide on their R&D investment based on the average user cost of R&D (expression A4), so that firms in the second bracket would increase their R&D even if the rate of the first WBSO bracket increases, providing them with more liquidity. De Jong and Verhoeven (2007) report the results of the interviews conducted with companies' R&D managers in order to solicit feedback on WBSO effectiveness. The outcomes of these interviews suggest that WBSO tax rebates are reinvested back into R&D. Based on these arguments we favor the specification based on the average user cost of R&D.

Appendix B (for referees only): Computation of the standard error of the BFTB estimate

The variance of BFTB measure is the gradient of BFTB with respect to the two parameters, $\sigma\lambda$ and $1-\lambda$ multiplied by the variance-covariance matrix of the parameters multiplied by the inverse of the gradient. The gradient of the BFTB measure is computed as follows:

To save on notation, let $Nom = \sum_{t=1}^{\infty}\left[\sum_i\left(\widetilde{R}_{i,t} - R_{i,t}\right)\right]\bigg/(1+r)^{t-1}$ and $Den = \sum_{t=1}^{\infty}(\widetilde{W}_t - W_t)/(1+r)^{t-1}$

Applying the chain rule to equation (20), we have

$$\frac{\partial(BFTB)}{\partial(\sigma\lambda)} = \left(Den\frac{\partial Nom}{\partial(\sigma\lambda)} - Nom\frac{\partial Den}{\partial(\sigma\lambda)}\right)\bigg/Den^2 \tag{B1}$$

$$\frac{\partial(BFTB)}{\partial(1-\lambda)} = \left(Den\frac{\partial Nom}{\partial(1-\lambda)} - Nom\frac{\partial Den}{\partial(1-\lambda)}\right)\bigg/Den^2 \tag{B2}$$

where

$$\frac{\partial Nom}{\partial(\sigma\lambda)} = \sum_{t=1}^{\infty}\left[\sum_i\frac{\partial\widetilde{R}_{i,t}}{\partial(\sigma\lambda)}\right]\bigg/(1+r)^{t-1} \text{ and } \frac{\partial Nom}{\partial(1-\lambda)} = \sum_{t=1}^{\infty}\left[\sum_i\frac{\partial\widetilde{R}_{i,t}}{\partial(1-\lambda)}\right]\bigg/(1+r)^{t-1}$$

$$\frac{\partial Den}{\partial(\sigma\lambda)} = \sum_{t=1}^{\infty}\left[\frac{\partial(\widetilde{W}_t - W_t)}{\partial(\sigma\lambda)}\right]\bigg/(1+r)^{t-1} \text{ and } \frac{\partial Den}{\partial(1-\lambda)} = \sum_{t=1}^{\infty}\left[\frac{\partial(\widetilde{W}_t - W_t)}{\partial(1-\lambda)}\right]\bigg/(1+r)^{t-1}$$

The derivative of $\dfrac{\partial(\widetilde{W}_t - W_t)}{\partial(\sigma\lambda)} = \sum_i \tau(w_{it}^B z_i^B + w_{it}^E z_i^E + w_{it}^O + w_{it}^L)\dfrac{\partial\widetilde{R}_{i,t}}{\partial(\sigma\lambda)}$

$$\frac{\partial(\widetilde{W}_t - W_t)}{\partial(1-\lambda)} = \sum_i \tau(w_{it}^B z_i^B + w_{it}^E z_i^E + w_{it}^O + w_{it}^L)\frac{\partial\widetilde{R}_{i,t}}{\partial(1-\lambda)}$$

To compute the partial derivative of $\widetilde{R}_{i,t}$ with respect to $\sigma\lambda$ and $1-\lambda$ we use the expression $\widetilde{R}_{i,t} = \delta\widetilde{K}_{i,t-1} + (\widetilde{K}_{i,t} - \widetilde{K}_{i,t-1})$. The partial derivatives of $\widetilde{R}_{it}$ with respect to $\sigma\lambda$ and $1-\lambda$ are:

$$\frac{\partial\widetilde{R}_t}{\partial(\sigma\lambda)} = (\delta-1)\frac{\partial\widetilde{K}_{i,t-1}}{\partial(\sigma\lambda)} + \frac{\partial\widetilde{K}_{i,t}}{\partial(\sigma\lambda)} \tag{B3}$$

and

$$\frac{\partial \widetilde{R}_{i,t}}{\partial (1-\lambda)} = (\delta - 1)\frac{\partial \widetilde{K}_{i,t-1}}{\partial (1-\lambda)} + \frac{\partial \widetilde{K}_{i,t}}{\partial (1-\lambda)} \tag{B4}$$

From the recursive equation $\widetilde{K}_{i,t} = \dfrac{\widetilde{K}_{i,t-1}}{1+\sigma\lambda\Delta u_{i,0}^{R}(1-\lambda)^{t-1}/u_{i,t}^{R}}$ we can express $\widetilde{K}_{i,t}$ as

$$\widetilde{K}_{i,t} = K_{i,0}^{*}\Big/\Big[(1+\sigma\lambda\Delta u_{i,0}^{R}/u_{i,0}^{R})(1+\sigma\lambda(1-\lambda)\Delta u_{i,0}^{R}/u_{i,1}^{R})\ldots(1+\sigma\lambda(1-\lambda)^{t-1}\Delta u_{i,0}^{R}/u_{i,t-1}^{R})\Big] \tag{B5}$$

Which after taking the logarithms of both sides becomes

$$\ln \widetilde{K}_{i,t} = \ln K_{i,0}^{*} - \sum_{j=0}^{t-1}\ln\Big[1 + \sigma\lambda(1-\lambda)^{j}\Delta u_{i,0}^{R}/u_{i,j}^{R}\Big] \tag{B6}$$

Expression (B6) can be now differentiated to obtain the derivative of $\widetilde{K}_{it}$ with respect to $\sigma\lambda$ and $1-\lambda$:

$$\frac{\partial \widetilde{K}_{i,t}}{\partial (\sigma\lambda)} = -\left[\sum_{j=0}^{t-1}\frac{(1-\lambda)^{j}\Delta u_{i,0}^{R}/u_{i,j}^{R}}{1+\sigma\lambda(1-\lambda)^{j}\Delta u_{i,0}^{R}/u_{i,j}^{R}}\right]\widetilde{K}_{i,t} \text{ for } t = 1,2,\ldots \tag{B7}$$

$$\frac{\partial \widetilde{K}_{i,t}}{\partial (1-\lambda)} = -\left[\sum_{j=1}^{t-1}\frac{\sigma\lambda j(1-\lambda)^{j-1}\Delta u_{i,0}^{R}/u_{i,j}^{R}}{1+\sigma\lambda(1-\lambda)^{j}\Delta u_{i,0}^{R}/u_{i,j}^{R}}\right]\widetilde{K}_{i,t} \text{ for } t = 2,3,\ldots \tag{B8}$$

The derivatives $\dfrac{\partial \widetilde{K}_{i,t}}{\partial (\sigma\lambda)}$ and $\dfrac{\partial \widetilde{K}_{i,t}}{\partial (1-\lambda)}$ can be computed recursively, i.e.

$$\frac{\partial \widetilde{K}_{i,t}}{\partial (\sigma\lambda)} = \frac{\partial \widetilde{K}_{i,t-1}}{\partial (\sigma\lambda)}\Big/\Big(1 + \sigma\lambda(1-\lambda)^{t-1}\Delta u_{i,0}^{R}/u_{i,t}^{R}\Big)$$
$$- (1-\lambda)^{t-1}(\Delta u_{i,0}^{R}/u_{i,t}^{R})\widetilde{K}_{i,t-1}\Big/\Big(1 + \sigma\lambda(1-\lambda)^{t-1}\Delta u_{i,0}^{R}/u_{i,t}^{R}\Big)^{2} \text{ for } t = 1,2,\ldots \tag{B9}$$

$$\frac{\partial \widetilde{K}_{i,t}}{\partial (1-\lambda)} = \frac{\partial \widetilde{K}_{i,t-1}}{\partial (1-\lambda)}\Big/\Big(1 + \sigma\lambda(1-\lambda)^{t-1}\Delta u_{i,0}^{R}/u_{i,t}^{R}\Big)$$
$$- \sigma\lambda(t-1)(1-\lambda)^{t-2}(\Delta u_{i,0}^{R}/u_{i,t}^{R})\widetilde{K}_{i,t-1}\Big/\Big(1 + \sigma\lambda(1-\lambda)^{t-1}\Delta u_{i,0}^{R}/u_{i,t}^{R}\Big)^{2} \text{ for } t = 2,3,\ldots \tag{B10}$$

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