R&D subsidies and production effects of R&D personnel: evidence from the Flemish region

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Abstract

We examine whether in Flanders R&D subsidies enhance the hiring of R&D personnel or rather substitutes for private R&D on the one hand and whether and to which degree the knowledge stock is an important production factor on the other hand. As such we estimate two equations, i.e. an R&D equation and an output equation. In the R&D equation we control for possible simultaneity between private and public R&D decisions and between private R&D and private output. The output equation is a simple Cobb-Douglas production function where the private knowledge stock — proxied by the amount of R&D employees — enters as a production factor. We also control for possible simultaneity between private R&D and private output.

We perform an econometric analysis of cross-sectional and time series data of Flemish firms for the period 1992-1999. The data on R&D and subsidies are gathered from IWT, which is the institute that

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stimulates industrial research and technology transfer in the Flemish industry and the other data from the annual accounts database made available by the Belgian Central Balance Sheet Office.

1 Introduction

The importance of technological innovation as a determinant of economic growth and competitiveness of a country has been recognized since several years. Investment in R&D, knowledge and new technologies indeed seems an important condition for firms to remain competitive at an international level. To investigate this issue, several authors use a production function framework with a Cobb-Douglas production function that serves as a basis to model growth or productivity of either firms or an economy as a whole econometrically. Next to the traditional production factors, labor and capital, the production function contains a third factor representing the knowledge stock, which is often approached by the R&D stock. To construct the stock of R&D of a firm, it is necessary to make some assumptions on the depreciation rate and the growth rate of R&D investment. For this purpose, in Hall and Mairesse (1995) a perpetual inventory method is used. When transforming the output equation in an equation with growth rates, it is possible to circumvent some of the difficulties related to establishing the knowledge stock variable. Indeed, investment in, instead of stock of, traditional and R&D capital divided by output are then included as explanatory variables such that it becomes possible to estimate marginal products of traditional and R&D capital in a direct way (see e.g. Capron and Cincera (1998)). An implicit assumption made in this approach is that marginal products, and not elasticities, of traditional and R&D capital are constant across observations. In Hall and Mairesse (1995) it is shown though that the direct production function approach is to be preferred over the direct estimation of marginal products.

A first important drawback of defining the knowledge stock as the amount of R&D capital is related to the arbitrary choice of the depreciation rate of R&D capital. Indeed, R&D capital often is of intangible kind and thus subject to a depreciation rate that is relatively hard to estimate (see Hall (1993) and Nadiri and Prucha (1996)). Another drawback is that double-counting between R&D investment and the total labor stock, which also includes R&D personnel, is difficult to avoid. In Hall and Mairesse (1995) a correction for double-counting has been done and has been found to be important for the estimations of the rates of return. They have found that if double-counting is not corrected for, estimates of rates of return are to be interpreted as 'excess' rates. Finally, historic data on R&D behavior of Flemish firms are not reliable such that a long history of R&D investment — which improves the estimates of the R&D knowledge stock — is not available. To get around these issues, we use total R&D personnel as a proxy for the knowledge stock.

Another problem related to the econometric estimation of the production function is the simultaneity of dependent and independent variables. E.g. Griliches (1986) remarks that it could be that productivity, which is a measure of 'success', causes firms to invest in 'risky' R&D projects, such that causality also works in the opposite direction. In this paper we take this endogeneity of the R&D decisions into account by correcting for it using instrumental variables techniques and by estimating a separate R&D function.

It is generally accepted that R&D and knowledge are not common private goods that are traded according to the market mechanism because of their public good characteristics. It is not always possible for firms to appropriate all returns that result from their R&D activities such that other economic agents are also able to reap benefits without bearing large costs. Obviously as a consequence of this —in neoclassical reasoning— firms invest less in R&D than socially desired. Government intervention in the technological domain is aimed at bridging the resulting gap between private and socially optimal R&D efforts. Whether government intervention, e.g. R&D subsidy policy, is efficient in the sense that additional private R&D expenditures are elicited[1], is a question that has been examined extensively in empirical literature[2]. The by far most common practice is to define the private R&D decision as private R&D investment. In this paper, we use firms' R&D employment as a dependent variable (see also Lichtenberg (1984)).

Empirical analyses have not led to unambiguous results regarding the relationship between subsidies and private R&D investment, which is not surprising when differences in specification and/or data are taken into account. Focusing on firm-level time-series analyses, one conclusion that should be made, is that controlling for simultaneity between public and private R&D decisions is necessary in order to improve the econometric estimations (David

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[1] David and Hall (2000) argue that it is not necessarily true that social rates of return on R&D investment exceed private rates of return. The authors consider the existence of patent races, imitation, 'excess correlation' among R&D projects of different firms, etc. that possibly result in a waste of R&D funds in some industries or domains such that the social rate of return is eventually lower than the private one. It is obvious that in such situation government subsidies aimed at raising private R&D in general elicit even more waste of funds.

[2] Recent papers are e.g. Meeusen and Janssens (2001),Czarnitzki and Fier (2001) and Almus and Czarnitzki (2001), for a complete and clear overview of previous econometric literature see David et al. (2000).

et al., 2000). Indeed, estimates of the private R&D response to policy measures are often biased because of the existence of unknown technological opportunities that vary between firms and in time and that influence private as well as public R&D decisions. Beside this, it is not clear whether subsidies cause firms to do more R&D or whether subsidies are granted to firms that do more R&D than others[3]. Wallsten (2000) compares results of an analysis that ignores possible endogeneity of public R&D support to results of a two-equations model and finds important differences in the estimates[4].

The point of view from which R&D subsidies are assessed usually is one of the kind of 'the more R&D, the better' and thus ignores the productivity of R&D in the broad sense. Most empirical analyses in this field have ignored whether R&D indeed leads to more new products, lower cost prices, higher GDP and higher welfare. Combining this argument with the need for a system approach to the evaluation of R&D subsidies (Georghiou, 2002; Suetens and Larosse, 2002) and the study of innovation in general, pleads for the use of econometric methods that simultaneously estimate several equations consisting a system. An example of a systemic approach to estimate effects of R&D subsidies in Norway is Braein et al. (2002). In their paper a structural model of R&D investment and the impact of R&D subsidies is developed and serves as a base to do econometric estimations.

In this paper we tend to take a first step in the direction of a systemic approach by estimating a system of two equations, i.e. an output equation and an R&D equation. We use panel data of Flemish firms on the period 1992-1999 to estimate this model and compare the results of single and system equation techniques. In the following section we present the model, the data and the econometric results. Section 3 concludes.

2 Model, data and results

To investigate the degree to which R&D personnel contributes to output, we use a production function framework with the following Cobb-Douglas production function that often serves as a basis to model growth or productivity of either firms or an economy as a whole econometrically (see e.g. Hall and Mairesse (1995), Capron and Cincera (1998)):

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[3] Recent papers that deal with the simultaneity problem, are e.g. Toivanen and Niininen (2000), Busom (2000) and Lach (2000).

[4] In another recent paper (Almus and Czarnitzki, 2001) a non parametric matching approach is used to investigate the relation between R&D policy measures and private R&D investment.

$$y = e^{a(t)} K^{\alpha} L^{\beta} R^{\gamma}, \tag{1}$$

where K is the physical capital stock, L the labor stock and R the knowledge stock. Note that since R&D explicitly enters the production function, this approach is of another kind than modelling the impact of R&D on total factor productivity or TFP growth such as in e.g.Lichtenberg and Siegel (1991), which is based on growth accounting. The knowledge stock is represented by total R&D personnel, implying that knowledge is assumed to be mainly embodied in the R&D workers. The part of knowledge that is not embodied in the R&D workers, is part of the physical capital and not separable from 'ordinary' capital. Disembodied technological change is, as usually, represented by $e^{a(t)}$, with a growth rate which is a function of time. Linearising the model, adding indices and a residual term and introducing a lagged dependent variable to capture autocorrelation problems yields the following econometric equation[5]:

$$\ln y_{it} = a(t) + \delta \ln y_{it-1} + \alpha \ln K_{it} + \beta \ln L_{it} + \gamma \ln R_{it} + u_{it}. \tag{2}$$

Data on y, K and L are gathered from the Belgian national accounts database, made available by the Belgian Central Balance Sheet Office. To measure y we use added value, K is the net book value of tangible and financial fixed assets and L is the average number of employees minus the number of R&D workers in full time equivalents. Data on R&D variables such as R&D personnel are gathered from the biannual surveys on research and development that serve as a basis for the estimations of the ANBERD and BERD[6] time series of OECD. For the Flemish region it is IWT[7], that designs the survey and collects the data in cooperation with OSTC[8].

The second equation of the model is an R&D equation, in which the natural logarithm of R&D personnel, enters as the dependent variable. Government support for R&D is the main right-hand-side variable. Data on subsidies that are granted to Flemish firms come from IWT, the main responsible institute for implementing subsidy policy. IWT handles the granting of direct subsidies in the Flemish region, i.e. subsidies for industrial basic research (including EUREKA projects) and for development of prototypes, and offers separate programs specifically aimed at stimulating innovation in SMEs. The

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[5] In a first tentative econometric analysis we included lags of the right-hand-side variables, but they were found to be insignificant. Therefore, we deleted them from the analysis.

[6] (Analytical) Business Enterprise Research and Development.

[7] Institute for the Promotion of Innovation by Science and Technology in Flanders.

[8] Federal Office for Scientific, Technical and Cultural affairs.

subsidies for basic or precompetitive research amount to a maximum of 50% of the project costs for large and to 60% for small and medium-sized enterprises having a turnover of less than 1 500 000 Euro, employment of less than 200 employees and a rate of control by a large enterprise of less than 30%. Support for prototype research, which is aimed at developing new products and processes, amounts to 25% for large enterprises and to 35% for SMEs. Also EUREKA projects are financed according to the above scheme, with an additional subsidy of 10% (OSTC, 2001). Other support measures towards SMEs, of which some are recently launched, are subsidies for hiring R&D personnel, for loss-coverage guarantees on risk capital, for feasibility studies of innovative projects and for partnerships between higher education institutes and other firms. These subsidies usually cover 60% of the project costs, with maxima between 5000 and 25000 Euro. Since IWT mainly finances personnel costs and since data on the amount of R&D workers in full time equivalents, sponsored by IWT are available, we use this variable to measure government support for R&D. We again use a log-log specification. Control variables that enter the R&D equation are year dummies, a lagged dependent variable to capture autocorrelation problems, the natural logarithm of added value to proxy firm size and the natural logarithm of the average number of non R&D employees as possibly a fixed relation exists between R&D and other personnel. This personnel variable can alternatively be interpreted as a measure of the business cycle in the sense that when economic activity is high, so is non-R&D employment. As such, the R&D equation is the following:

$$\ln R_{it} = a(t) + \theta_0 \ln R_{it-1} + \theta_1 \ln IWT_{it} + \theta_2 \ln y_{it} + \theta_3 \ln L_{it} + v_{it}. \qquad (3)$$

Note that the estimated parameters should again be interpreted as elasticities.

Both equations are estimated with inclusion of industry dummies. To classify firms in industries we mainly based ourselves on the existing classifications ISIC revision 2 and 3. A few adjustments were made to be able to separate some relatively new industries that are important in Flanders, but that are not (yet) separately classified in the ISIC classification. These industries are biotechnology, health and environmental technology. Industries are aggregated such that each industry contains at least 10 firms. As a result of this, 13 industries[9] remained. All variables in the analysis are measured

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[9] Sector 1: biotechnology, agriculture, health, environment, energy and pharmaceuticals; sector 2: food, beverages and tobacco; sector 3: textiles, wearing apparel and leather; sector 4: chemicals; sector 5: rubber, plastic and non-metallic mineral products, sector 6: basic metal, sector 7: fabricated metal products, electrical and non-electrical machinery and equipment, sector 8: electronics, components, instruments and telecommunication,

in real terms. To deflate added value we used the OECD GDP deflator for Belgium and to deflate the capital stock, we used the OECD business investment deflator[10]. Observations on negative added values were deleted. To enter the analysis a firm was required to have at least 4 observations in time on all variables that are included in the econometric analysis. We maintained 1032 observations covering 262 firms.

We estimated the equations using (pooled) single equation and system equation techniques to check for robustness of the parameters with respect to the estimation method and to compare the results of taking into account endogeneity of the IWT subsidy variable. We instrumented the IWT variable by its lagged value[11], as also $\ln y$ in the R&D equation, $\ln R$ in the output equation and $\ln L$ in the R&D and output equations. Table 1 presents the econometric results of regressions with sector dummies on the one hand and with firm dummies, i.e. fixed effects estimation, on the other hand. In the regressions with fixed effects we did not include sector dummies because of their insignificance.

What matters more than the immediate effects or elasticities are the stable long-run effects or elasticities. After all, policy makers are concerned about the (stabilized) long-run effects of their policies. Since in both equations the lagged dependent variables are significant, the long-run elasticity estimates differ from their short-run equivalents. These long-run estimates and their respective p-values[12] are in table 2.

From table 1 and 2 we learn that correcting for endogeneity of right-hand-side variables, using system estimation methods and including fixed firm effects, have some limited but straightforward consequences for the estimates. First, note that Hausman tests revealed that for all specifications fixed effect estimates are to be preferred over total estimates and that Wu tests revealed for the single equation estimations that 2SLS is to be preferred over OLS[13]. In the estimations without fixed effects, correcting for endogeneity (compare

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sector 9: transport equipment, sector 10: other industries, sector 11: IT and software, sector 12: other business consulting and services, sector 13: trade and renting.

[10] Regional deflators are not available.

[11] We also experimented with taking the (logarithm of the) total number of subsidized personnel in full time equivalents per year as suggested in David et al. (2000) as an instrument, but correlation of this variable with firm level subsidized personnel was very low.

[12] The calculation of the standard errors of a long-run estimate $f(\beta)$ is based on GVG', where V is the asymptotic covariance matrix of the estimated parameters and G the vector of derivatives of $f(\beta)$ with respect to β_i evaluated at the respective parameter estimates $\hat{\beta}_i$ (Fomby et al., 1984).

[13] The Wu test is a simple alternative approach to the Hausman test. For more details see **?**.

	OLS	2SLS	SUR	3SLS
output equation with sector dummies				
$\ln y_{t-1}$	0.723 (0.000)	0.755 (0.000)	0.711 (0.000)	0.753 (0.000)
$\ln K_t$	0.080 (0.000)	0.080 (0.000)	0.080 (0.000)	0.080 (0.000)
$\ln L_t$	0.146 (0.000)	0.114 (0.000)	0.151 (0.000)	0.114 (0.000)
$\ln R_t$	0.042 (0.000)	0.038 (0.000)	0.052 (0.000)	0.038 (0.000)
R^2	0.981	0.981	0.981	0.981
output equation with firm dummies				
$\ln y_{t-1}$	0.197 (0.007)	0.171 (0.017)	0.185 (0.002)	0.160 (0.026)
$\ln K_t$	0.063 (0.025)	0.057 (0.224)	0.059 (0.009)	0.075 (0.126)
$\ln L_t$	0.369 (0.000)	0.405 (0.001)	0.386 (0.000)	0.391 (0.001)
$\ln R_t$	0.071 (0.006)	0.202 (0.001)	0.140 (0.000)	0.202 (0.001)
R^2	0.990	0.990	0.990	0.990
R&D equation with sector dummies				
$\ln R_{t-1}$	0.881 (0.000)	0.892 (0.000)	0.870 (0.000)	0.890 (0.000)
$\ln IWT_t$	0.005 (0.000)	0.003 (0.068)	0.005 (0.000)	0.003 (0.060)
$\ln y_t$	0.148 (0.000)	0.075 (0.058)	0.194 (0.000)	0.083 (0.038)
$\ln L_t$	-0.091 (0.002)	-0.020 (0.586)	-0.130 (0.000)	-0.026 (0.479)
R^2	0.931	0.930	0.931	0.931
R&D equation with firm dummies				
$\ln R_{t-1}$	0.407 (0.000)	0.442 (0.000)	0.386 (0.000)	0.408 (0.000)
$\ln IWT_t$	0.005 (0.011)	-0.002 (0.684)	0.005 (0.003)	-0.003 (0.572)
$\ln y_t$	0.212 (0.005)	-0.230 (0.604)	0.472 (0.000)	0.071 (0.857)
$\ln L_t$	-0.308 (0.001)	0.182 (0.588)	-0.429 (0.000)	0.065 (0.837)
R^2	0.956	0.955	0.955	0.953

P-values of H_0 that the corresponding parameter significantly differs from 0 are in round brackets and are based on heteroskedastic-consistent standard errors.

Table 1: Econometric results

2SLS with OLS and 3SLS with SUR estimates) generally decreases the size of the estimates. In the R&D equation the subsidy variable even becomes insignificant at a 5% level. This is also true for the R&D equation with fixed effects. As such, we can tentatively conclude that if possible simultaneity between private and public R&D decisions is not corrected for, the effect of subsidies on firms' R&D tends to be slightly overestimated. The same conclusion goes for the no-fixed-effects estimates of the output elasticity of both labor stocks if simultaneity between output and R&D decisions of firms is not taken into account. Turning from single equation to system methods (compare SUR with OLS and 3SLS with 2SLS) generally yields slightly more efficient estimates, so it should be possible to take advantage of efficiency properties of system estimators, specification errors are absent and are not transferred from single equations to the system.

Further, including fixed firm effects decreases the estimates of the lagged

	OLS	2SLS	SUR	3SLS
output elasticities with sector dummies				
K	0.2869 (0.000)	0.3253 (0.000)	0.2758 (0.000)	0.3251 (0.000)
L	0.5260 (0.001)	0.4631 (0.009)	0.5241 (0.001)	0.4635 (0.009)
R	0.1515 (0.002)	0.1543 (0.005)	0.1795 (0.000)	0.1550 (0.005)
output elasticities with firm dummies				
K	0.0781 (0.035)	0.0693 (0.219)	0.0730 (0.014)	0.0888 (0.123)
L	0.4600 (0.000)	0.4887 (0.005)	0.4737 (0.000)	0.4648 (0.006)
R	0.0888 (0.008)	0.2438 (0.002)	0.1713 (0.000)	0.2409 (0.002)
$\frac{\partial \ln \mathbf{R}}{\partial \ln \mathbf{IWT}}$ ***with sector dummies***				
	0.0415 (0.002)	0.0315 (0.100)	0.0378 (0.027)	0.0318 (0.097)
$\frac{\partial \ln \mathbf{R}}{\partial \ln \mathbf{IWT}}$ ***with firm dummies***				
	0.0079 (0.015)	-0.0041 (0.681)	0.0074 (0.004)	-0.0051 (0.568)

P-values of H_0 that the corresponding parameter significantly differs from 0 are in round brackets.

Table 2: Long-run estimates

dependent variables in both equations, without making them insignificant. This was to be expected, since the lagged dependent variables represent the individual history of the firms, which is also partly measured by the firm dummies, such that correlation between lagged dependent variables and fixed effects usually is high. In the output equation, when allowing for firm effects in the non-instrumental variables estimations, the coefficient of the lagged dependent variable also declines, which results in a decline in the long-run output elasticities. The short-run coefficient of capital also declines, which could be an indication that the capital stock is more correlated with the firm-specific effects compared to R&D and non-R&D labor. On the other hand, the non-R&D labor coefficients sharply increases, so one would also expect that part of the influence of the lagged dependent variable would now be capture in this coefficient. When having a look at the correlations between firm constants and the other variables, the above results are confirmed. Capital indeed is more correlated with the fixed effects, as is labor with (lagged) output. From these results one would argue that the firm effects in the output equation are to be interpreted, not only as technological opportunities, but also as 'capital opportunities'. These capital opportunities could e.g. include access to financial markets. Probably also the fact that the non-personnel-investment part of the R&D stock is included in the 'ordinary' capital stock, such that part of the technological opportunities were captured in capital, can explain these results[14].

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[14] In Hall and Mairesse (1995) an opposite result has been found, i.e. their R&D stock variable seemed to be more correlated with the fixed effects than 'ordinary' capital.

As in the R&D equation the size of the short-run coefficient of the government support variable does not change when introducing fixed effects, we would expect that the subsidy variable is not highly correlated with the firm effects. Since the lagged dependent variable coefficient declines, the size of the (long-run) coefficient of the government support variable also declines. Note that in both equations the fixed effects can be (partly) interpreted as technological opportunities, but one should be aware of that the opportunities are of a different kind. In the output equation these constants are interpreted as firm-specific exogenous technologies that make output grow when all production factors are assumed to remain constant. In the R&D equation, the firm effects represent (exogenous) growth of R&D employment, when all other right-hand-side variables do not change. Turning back to the R&D equation, we observe that the absolute values of the control variables $\ln y$ and $\ln L$ have increased significantly by the introduction of the fixed effects.

The consequence of applying instrumental variables techniques to the fixed effects estimations of the R&D equation are quite clear-cut, in the sense that all right-hand-side variables except for the lagged dependent, become insignificant. We should be careful in interpreting this result, as it is not unlikely that introducing firm effects ànd instrumental variables techniques is too much of a good thing as both tackle simultaneity issues. The fixed effects should correct for the omitted latent variables part, while the instrumental variables technique should correct for general simultaneity issues, including omitted latent variables. We realize that both methods tackle the issues in different ways. As such, consequences for the estimates of correcting for simultaneity in the fixed effects estimations of the output equation are hard to interpret. The estimated output elasticity of R&D increases importantly when correcting for simultaneity between output and R&D personnel, which is against the expectations of a positive influence of output on personnel, but consistent with the negativeness of the output variable in the R&D equation. Since the latter is not significant (and even not positive in the 3SLS estimations), no clear-cut conclusions can be drawn from this observation.

In log-log specifications it is assumed that across observations elasticities of the left-hand-side variable(s) with respect to the right-hand-side variables, i.e. the estimated parameters, are constant, but not the marginal effects. In the output function the elasticities can be interpreted in the usual straightforward way, but with respect to the R&D function some further considerations are necessary. Indeed, policy makers usually are concerned with questions as ‘how much additional personnel is employed in the firm when financing an R&D employee?’. To be able to answer this question we need to calculate the long-run marginal effects of the IWT variable on the amount of R&D

personnel according to the following formula:

$$\frac{\partial \bar{R}}{\partial \bar{I}WT} = \frac{\hat{\theta}_1}{1-\hat{\theta}_0}\frac{\bar{R}}{\bar{I}WT}.$$

$\bar{R}$ and $\bar{I}WT$ stand for the long-run values of total R&D personnel and total subsidized R&D personnel respectively. Replacing these long-run values by their respective means enables us to calculate the marginal effects for different groups of firms. $\bar{R}$ and $\bar{I}WT$ are respectively equal to 46.5 and 3.7 in the underlying data set. If relying on the total estimations with sector dummies, the marginal effect would thus be about 0.40, and only significant at the margin, while if relying on the fixed effects estimations the effect would be between 0 and 0.10. We have to be very careful when interpreting the results, though, since the subsidies granted to firms in this data set represent only 66% of the total budget of IWT. This is because many firms have missing values on R and other variables and are thus not taken into account in the analysis. An even more important remark in this context is that we have required each firm to have at least 4 time observations on all variables to enter the analysis, as to make sure that any change in parameter estimates can be traced back to a change in estimation method, and not to a change in the sample, as suggested in Hall and Mairesse (1995). Consequently, starting and relatively young firms and firms that did not answer the R&D surveys at least a number of times, are neither taken up in the analysis. Thus, the firms that remain in the analysis mainly are relatively large R&D spenders which are well known by IWT and have a tradition in applying for government projects and answering R&D surveys. Results should also be interpreted in this context.

3 Conclusion

In the paper we have estimated an R&D equation, focusing on the effects of government support for R&D on private R&D incentives, and an output equation, representing a production function where an R&D stock variable enters the equation to represent the knowledge stock. For this purpose, we used a panel data set of Flemish innovative firms covering the period 1992-1999. The first main result is that in the production function, the R&D stock, measured by R&D employment, has been found to be quite high and significant, even with inclusion of fixed firm effects, which is similar to the one found in Hall and Mairesse (1995). Secondly, we found evidence for substitution effects between privately and publicly financed R&D personnel. Our results indicate that when ignoring fixed firm effects, about 60% of the publicly financed R&D would serve as a substitute for private R&D. When taking into account firm effects, almost complete substitution prevails. It should be realized though, that these results refer to a specific sample of relatively large R&D spenders, having a tradition in applying for government subsidies, and should not be extrapolated to all innovative firms, let alone to the whole population of firms.

The novelty of the study lies within the combination of a few approaches. First, we have used R&D employment to represent the R&D stock because of disadvantages related to the estimation of an R&D stock using R&D expenditures. Further, we have attempted to correct for possible simultaneity in both equations, i.e. between private and public R&D decisions and between private R&D and private production decisions, yielding (slightly) lower estimates than without correcting. Finally, as a first step towards a system approach in the study of the R&D and innovation landscape, we have used system estimation methods and we have been able to take advantage of their efficiency properties.

References

M. Almus and D. Czarnitzki. The effects of public R&D subsidies on firms' innovation activities in a transition economy: the case of Eastern Germany. ZEW Discussion paper 01/10, Centre for European Economic Research (ZEW), Mannheim, 2001.

L. Braein, A. Hervik, E. Nesset, and M. Rye. The Norwegian systemic approach to impact estimation of R&D subsidies: focus on additionality and the contra-factual problem. In P. Boekholt, editor, *Innovation policy and sustainable development: can innovation incentives make a difference? Contributions to a six countries programme conference, February 28-March 1, 2002*, pages 67–85, 2002. IWT studies nr. 40.

I. Busom. An empirical evaluation of the effects of R&D subsidies. *Economics of Innovation and New Technology*, 9(2), 2000.

H. Capron and M. Cincera. Exploring the spillover impact on productivity of world-wide manufacturing firms. *Annales d'Economie et de Statistique*, 49/50:565–87, 1998.

D. Czarnitzki and A. Fier. Do R&D subsidies matter? evidence for the German service sector. ZEW Discussion paper 01/19, Centre for European Economic Research (ZEW), Mannheim, 2001.

P.A. David and B.H. Hall. Heart of darkness: public-private interactions inside the R&D black box. *Research Policy*, 29(9):1165–84, 2000.

P.A. David, B.H. Hall, and A.A. Toole. Is public R&D a complement or a substitute of private R&D? *Research Policy*, 29(4):467–529, 2000.

T.B. Fomby, R.C. Hill, and S.R. Johnson. *Advanced econometric methods.* Springer-Verlag, New York, 1984.

Luke Georghiou. Impact and additionality of innovation policy. In P. Boekholt, editor, *Innovation policy and sustainable development: can innovation incentives make a difference? Contributions to a six countries programme conference, February 28-March 1, 2002*, pages 57–65, 2002. IWT studies nr. 40.

Z. Griliches. Productivity, R&D and basic research at the firm level in the 1970's. *American Economic Review*, 76(1):141–54, 1986.

B.H. Hall. The stock market's valuation of R&D investment during the 1980's. *American Economic Review*, 83(2):259–64, 1993.

B.H. Hall and J. Mairesse. Exploring the relationship between R&D and productivity in French manufacturing firms. *Journal of Econometrics*, 95: 263–93, 1995.

S. Lach. Do R&D subsidies stimulate or displace private R&D? Evidence from Israel. NBER Working paper series 7943, National Bureau of Economic Research, Cambridge, 2000.

F.R. Lichtenberg. The relationship between federal contract R&D and company R&D. *American Economic Review*, 74(3):73–8, 1984.

F.R. Lichtenberg and D. Siegel. The impact of R&D investment on productivity — new evidence using linked R&D–lrd data. *Economic Inquiry*, 29 (2):203–28, 1991.

W. Meeusen and W. Janssens. Substitution versus additionality: econometric evaluation by means of micro-economic data of the efficacy of R&D subsidies to firms in the Flemish region. CESIT Discussion paper 2001/01, University of Antwerp, 2001.

M.I. Nadiri and I.R. Prucha. Estimation of the depreciation rate of physical and R&D capital in the U.S. total manufacturing sector. *Economic Inquiry*, 34(1):43–56, 1996.

S. Suetens and J. Larosse. Evaluation of R&D policy in Flanders. In N. Gretzmacher, G. Hutschenreiter, and W. Polt, editors, *Changing strategies for business R&D and their implications for science and technology policy*, pages 74–82, 2002. Proceedings of the tip workshop in Vienna, February 25, 2002.

O. Toivanen and P. Niininen. Investment, R&D, subsidies and credit constraints. mimeo, 2000.

S.J. Wallsten. The effects of government-industry R&D programs on private R&D: the case of the small business innovation research program. *Rand Journal of Economics*, 31(1):82–100, 2000.