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The Effectiveness of Subsidies Revisited: Accounting for Wage and Employment Effects in Business R+D

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The effectiveness of subsidies revisited: accounting for wage and employment effects in business R&D

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Abstract

The present paper investigates the effectiveness of public subsidies to business enterprise research in a panel of OECD countries. We contribute to the literature by explicitly distinguishing between effects of a subsidy on R&D employment and expenditure, thereby accounting for a potential increase in scientists' wages. The results indicate that subsidies are effective in generating additional research. We find that an increase in the direct subsidy rate of one percentage point leads to at least 1% more business R&D employment in the long run. Expenditure for business research increases by roughly 20-30% more than employment. We take this as evidence that subsidies also raise scientists' wages. In addition, we find that there exists significant crowding out of private research through university research. Research performed in public non-university institutions seems to have no effect on private research.

JEL: H25; H32; O31; O38; O57

Keywords: R&D; Government subsidy; Technology policy; Panel Data

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1 Introduction

Research and development has been identified as one of the principal sources of economic progress.[1] It leads to the discovery of ideas and innovations, which in turn enhance productivity and generate growth. Empirical studies by, for example, Griliches (1992) and Caballero and Jaffe (1993) indicate that there is too little private R&D because of market failure. These market failure arguments are probably the main reason why all OECD countries take public measures to increase research. In Europe, heads of governments agreed in late 2002 at the Barcelona summit upon an initiative called "More Research for Europe". They want to see Europe's R&D investment rise from its current 1.9% of GDP to 3% by 2010, hence by about 50%. This would close the current gap to the US, where R&D expenditure amounts to 2.8% of GDP and Japan (2.98%). The difference between Europe and the US and Japan is due to low R&D expenditure in firms in Europe. One way to increase R&D in firms is to subsidize private R&D investments. However, it is unclear to what extent subsidies actually increase business research activity. Even if R&D subsidies result in an increase of R&D spending of 50%, does this mean that R&D employment increases by 50% as well? Or does a significant fraction of the increased spending go into higher wages?

This paper addresses these issues and investigates the effectiveness of subsidies to private business research on a macroeconomic level using a panel data set of 15 OECD countries from 1981 to 2002. We disentangle the effects of direct subsidies to R&D on aggregate R&D employment and expenditure. We find that a 1 percentage point increase in the direct subsidy rate leads to at least 1% more business R&D employment in the long run. Expenditure for business research increases more than employment by roughly 20-30%. We take this as evidence that subsidies also raise scientists' wages. The effect is even stronger in the short run, when the increase in expenditure is 60% higher than the increase in employment. In addition, we find

[1] See, e.g., Romer (1990) and Aghion and Howitt (1992) for theoretical and Griliches (1994) for empirical work.

that private research is significantly crowded out by university research. Research performed in public non-university institutions seems to have no effect on private research.

The effectiveness of subsidies to business R&D has been investigated extensively in the literature. David, Hall, and Toole (2000) and Klette, Moen, and Griliches (2000) provide surveys. Most studies analyze the effectiveness of specific programs at the firm level. However, in order to evaluate broad, economy-wide policy measures (for example the initiative "More Research for Europe") the micro-econometric evaluation studies should be complemented by macro-econometric work for two reasons. First, there might be "migration" of scientists from a non-supported to a supported firm. This shows up as a positive effect of public support in firm level studies, especially if the non-supported firm is in the control group. Indeed, Berger (1993) shows that R&D spending among firms that cannot use R&D tax subsidies falls when subsidies rise. Second, an increase in the demand for R&D inputs due to large-scale subsidy programs can lead to a significant increase in the wages of scientists. Goolsbee (1998) provides empirical evidence of such an effect. He uses household survey data to show that the income of scientists and engineers in the U.S. increased substantially with aggregate subsidies to R&D in the entire economy, whereas the number of hours worked by each scientists remained almost constant. He concludes that simple evaluation studies might overstate the effects of government R&D spending on private R&D employment by as much as 30-50%.

There are only a few studies investigating the effectiveness of subsidies to business R&D at the macroeconomic level. Levy and Terleckyj (1983) find that there exists a positive impact of government contract R&D on private R&D investment in U.S. time series data. Guellec and Pottelsberghe (2003) confirm this result with panel data. They estimate that one dollar given to firms results in 1.7 dollars of research. Levy (1990) finds a positive impact only in a some countries of his panel, while in other countries no effect is found. All these studies have in common that they regress national private R&D expenditure on aggregate subsidy payments and a number of control variables.

We depart from this approach in two ways. First, in order to account for the potential increase in scientists' wages we run two separate regressions: one with R&D-employment and the other with total expenditure (i.e., private expenditure plus aggregate subsidy payments) as the dependent variable. Comparing the coefficients of the regressions allows us to assess whether the subsidy has a greater impact on expenditure than on employment. We interpret our finding that expenditure reacts more strongly than employment to subsidies as evidence that subsidies increase scientists' wages.

Our second departure from previous macroeconomic studies is to use the subsidy rate instead of aggregate subsidy payments as an explanatory variable. Governments can influence the decisions of private agents by changing relative prices through taxes and subsidies. Public subsidies for business R&D should therefore have an effect on private R&D investment only if they influence the cost of doing research at the margin. The reduction in marginal cost implied by subsidies is better captured by the subsidy rate than by aggregate subsidy payments. A convenient byproduct of using the subsidy rate as the explanatory policy variable is that the omitted variable bias discussed by David, Hall, and Toole (2000) is mitigated. They argue that the variation in private spending for R&D and in aggregate subsidy payments might both be driven by variation in the "technological opportunity set". Since technological opportunities for commercially attractive innovations are hard to control for, regressions of private on public R&D expenditure will tend to overstate the impact of subsidization. Using the subsidy rate, i.e., the ratio of public over private spending on R&D, as the explanatory variable has the advantage that it remains unaffected by the technological opportunity set. We thus estimate the impact of a change in the subsidization rate on research employment and total expenditure.

The remainder of the paper is organized as follows. The next section presents our theoretical framework. In section 3, we present the data. Section 4 gives the estimation results and further examines the effect of additional policy variables. The last section concludes.

2 Direct subsidies - a structural framework

David and Hall (2000) have argued that structural modelling of the "R&D black box" is necessary to better interpret the empirical estimates of subsidy effectiveness. In order to disentangle the effects on prices and quantities, we employ a model with labor as the only input in R&D.[2] The market for researchers can be diagrammed using demand and supply curves as presented in Figure 1. As wages increase, more scientists and engineers will decide to work as researchers in firms. The government's intention is to increase the number of researchers. A subsidy of β dollars for each dollar spent by private firms is paid. An increase in the subsidies will shift the demand curve for researchers outward from D to D^{β} as more research projects are profitable at the margin.

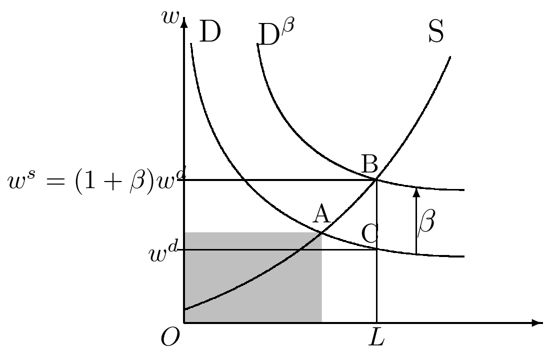

Figure 1: Wage effect of R&D-subsidy

2.1 Wage and employment effects

As can be seen in Figure 1, an increase in the subsidy rate β leads to an increase in employment L and total expenditure $E^{total} = w^s L$ (which corresponds to the area $OLBw^s$). The extent to which R&D subsidies lead to an increase in wages depends crucially on the wage elasticity of the supply of researchers. An increase

[2] In section 4.3 we discuss the role of capital in research. Note that most of the research expenditure is labor cost (see Goolsbee (1998) or The National Science Foundation (1995)).

in expenditure will be more pronounced relative to an increase in employment the lower the elasticity of supply of R&D-labor. Consider the extreme case of a totally inelastic supply of R&D labor. In such a case, R&D employment does not depend on the subsidization rate; total expenditure increases and private expenditure remains unchanged. In contrast, if the labor supply is totally elastic, total expenditure increases proportional to labor.

Interestingly, the effect of an increase of the subsidy rate β on private expenditure is ambiguous and depends on the slope of the demand curve (i.e., the shaded area in Figure 1 might be larger or smaller than the area $OLCw^d$). An insignificant coefficient in an empirical study that regresses private expenditure on public subsidies is therefore consistent with a positive effect of subsides on R&D employment.

A priori, it is not clear whether one should expect research-labor to be elastic or inelastic in supply. Firms face a large pool of university graduates and should be able to find additional researchers with relative ease. Moreover, the fraction of qualified labor - e.g., employees with university degrees - employed in research departments is rather small. In the most developed countries, e.g., the US, Japan, Germany, and Great Britain, it is about 3%, in most of the other sample countries, it is less than 1%. This would tend to support the idea of relatively elastic supply curves. However, Goolsbee (1998) finds for the U.S. that an increase of government subsidy payments leads to a considerable increase in the income of scientists, whereas the numbers of hours worked increased much less. His estimate for the supply elasticity of research-labor of about 0.1-0.2 corresponds to a very inelastic, steep labor supply curve. This implies that R&D is likely to be done by experienced and highly specialized scientists, who are not easy to find.

2.2 Short and long run effects

Subsidies can have very different effects in the short and long run. Beside the direct effect as discussed above, public aid to business R&D is likely to have further dynamic effects. David and Hall (2000, pp 1171) discuss the dynamic effects extensively. Our discussion focuses on the implications that we consider to be of special relevance at the macro level: the scientist training effect and the technology spillover effect.

The first dynamic effect stems from the training of new scientists and engineers. Labor supply will be more elastic in the long run than in the short run. In the short run, the number of qualified employees is fixed, since it takes some time for young people to get educated (and experienced) in those fields where new research opportunities arise. However, when young people decide on their field of study, they take into account expectations on future employment probabilities and salaries. As discussed above, the wage rate of scientists w^s increases in the subsidy rate. In the absence of knowledge spillover effects, the large long run elasticity of the labor supply will moderate the impact of the subsidy on the wage rate.

With respect to the demand for researchers, the main effect that is put forward by David, Hall, and Toole (2000) as well as by the whole R&D based growth literature (e.g., Barrio-Castro, Lopez-Bazo, and Serrano-Domingo (2002)) is the technology spillover effect. By developing a new technology, a firm heavily draws on the knowledge incorporated in existing technologies. Hence it could be that subsidized research helps to foster a new technology which in turn induces other firms to build on that technology. An often cited example is innovation in information technology, which was subsidized significantly in its early stages of development.

The scientist training and the technology spillover effect predict that the impact of public subsidies on R&D employment is larger in the long run than in the short run. In contrast, the impact of subsidies on wages might be bigger or smaller in the long run than in the short run. Increased demand through long run spillover effects reinforces the upward pressure on wages while an increase in the long run supply of scientists through training works in the opposite direction. Before turning to the empirical investigation of this question, we briefly formalize the outlined model.

2.3 Underlying Model

Let $\varphi(L_t, X_t^d)$ be the number of R&D projects that can be undertaken in the economy given that L_t scientists do research. X^d is a vector of variables representing technological opportunities or other variables that influence the productivity of researchers. Denote $\Pi_t(\cdot)$ the value of every innovation. It captures the state of demand for innovative goods and institutional conditions affecting the feasibility of appropriating innovation benefits.

The demand for research labor is determined by a free-entry or zero-profit condition that equalizes cost and returns to R&D:

$$\varphi(L_t, X_t^d)\Pi_t(\cdot) = w_t^d L_t \tag{1}$$

where w_t^d is the wage rate faced by private firms. Suppose that the supply of R&D personnel is given by an inverse supply function of the form:

$$w_t^s = g(L_t, X_t^s) \tag{2}$$

where X^s are shift variables and w_t^s is the wage rate received by researchers. Given that governments subsidize R&D labor at a rate β, the equilibrium is determined by the amount of research for which $w^s = (1+\beta)w^d$. Solving the model for L_t and log-linearizing yields Equation 3.

In order to disentangle the effects on prices and quantities we use the available information on R&D labor as well as on R&D expenditure. If we continue to assume that salaries are the only cost of research, total expenditure, i.e., that financed by public or private agencies, of R&D is $E_t^{total} = (1+\beta)w_t L_t$.

$$\ln L_t = c_1 \ln(1+\beta) + c_2 \ln X_t + c_3 \ln \pi_t \tag{3}$$

$$\ln E_t^{total} = a_1 \ln(1+\beta) + a_2 \ln X_t + a_3 \ln \pi_t \tag{4}$$

The elasticities of R&D-employment, pre- and post-subsidy wages with respect to the average subsidization rate are therefore straightforward to calculate. They are given by:

$$\begin{aligned}\varepsilon(L_t, 1+\beta) &= c_1 \\ \varepsilon(w_t^s, 1+\beta) &= a_1 - c_1 \\ \varepsilon(w_t^d, 1+\beta) &= a_1 - c_1 - 1\end{aligned}$$

In addition, estimates of the wage elasticity of the supply of researchers can be obtained. Using the upper coefficients,

$$\varepsilon(L_t, w_t^s) = \frac{\varepsilon(L_t, 1+\beta)}{\varepsilon(w_t^s, 1+\beta)} = \frac{c_1}{a_1 - c_1} \tag{5}$$

In order to allow for dynamic effects in our structural framework, we introduce the stock of knowledge as an additional variable in our model. Following the endogenous growth literature, e.g., Romer (1990) or Jones and Williams (2000), we assume that the number of R&D projects that can be successfully undertaken in the economy depends additionally to the other factors on the stock of knowledge A_t:

$$\varphi(L_t, X_t^d, A_t)$$

where φ is either increasing (most likely) or decreasing but convex in A_t. The evolution of the stock of knowledge over time depends on the existing stock of knowledge and on the newly created technologies, such that:

$$\dot{A}_t = \varphi(\cdot) - \delta A_t \tag{6}$$

where δ is the depreciation rate. Log-linearizing the model around the steady state ($\dot{A} = 0$) results in:

$$\ln A_t = \gamma \ln A_{t-1} + (1-\gamma) \ln A^*(\beta_t, X_t, \pi_t) \tag{7}$$

where $\ln \gamma$ corresponds to the speed of convergence to the steady state as implied by the model parameters. $A^*(\beta_t, X_t, \pi_t)$ is the steady state value of technology and is determined by the exogenous model parameters (β_t, X_t, π_t). If the latter stayed constant over time, A^* would be realized in the limit.

Since A_t is not observable, we can solve the linearized zero profit condition for $\ln A_t, \ln A_{t-1}$, and $\ln A^*$ and substitute in the last Equation 7 to get:

$$\ln L_t = \gamma \ln L_{t-1} + (1-\gamma) \ln L^*(\beta_t, X_t, \pi_t) \quad (8)$$

where $\ln L^*(\beta_t, X_t, \pi_t)$ is determined as in the static model, Equation 3. The dynamic model is thus straightforward to estimate through inclusion of the lagged dependent variable.

3 Data

We investigate the business enterprise sector, which is one of the four sectors of R&D performance.[3] The other three sectors are higher education, government, private non profit (PNP). The data on research employment in the business enterprise sector, subsidies to the business sector, research expenditure of the private sector financed by itself, higher education expenditure on R&D and government intramural expenditure on R&D are taken from OECD (2003b). The investigated number of OECD countries in the period 1981-2002 had to be somewhat reduced because of missing observations which made estimation impossible.[4] The included countries are shown in Table 1.

Research employment data covers all researchers in the business sector and all those providing direct services to the researchers (e.g., secretaries, clerical staff).[5]

[3]The business enterprise sector includes all firms, organizations and institutions whose primary activity is the market production of goods and services (other than higher education) for sale to the general public at an economically significant price, and the public enterprises and private non profit institutes mainly serving them. For a description of the other three sectors see Summary of Frascati Manual, (OECD 1994, pp 16-17).

[4]The Arellano and Bond (1991) estimator requires taking first differences.

[5]Data are expressed in full-time equivalents (FTE). One FTE may be thought of as one person-year. For the USA, only data on researchers without the supporting staff were available. However the correlation between researchers and (researchers + staff) is above 0.9 in countries where both indicators are available. About half of research employment consists of researchers. For the USA,

Expenditure on R&D in the business enterprise sector (BERD) is financed through two main sources: Own finances (BERDb) and government subsidies (BERDg). The ratio of the two, $\beta = \frac{BERDg}{BERDb}$, is a measure of average subsidization of the business enterprise sector by the government. Each private dollar of research expenditure is subsidized by β dollars from the government. Furthermore data on expenditure on R&D in the higher education sector (HERD) are available.[6] Government intramural expenditure on R&D (GOVERD)[7] and higher education expenditure were normalized by GDP, which is also taken from the OECD (2003b).[8]

The cross country variation of the average subsidization rate β is substantial. It ranges between less than 2 percent in Japan to more than 30 percent in the U.S.A. with an unweighed average of 13.8 percent. The high values for the US are also stressed by Goolsbee (1998) who emphasizes the role of the government sector in national R&D, where most of the public money is going to the defence sector. Less than one percent of the population work as researchers in the private sector in all considered countries. However these figures are quite heterogenous across countries ranging from 0.07 percent in Spain to 0.42 percent in Japan. Expenditure on R&D in the university sector and in the government sector represents less than 1 percent of GDP respectively in all investigated countries. The cross country variation is

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we took the number of researchers only, which should not be problematic because of fixed effects. Overall data for total employment were more readily available, and we thus chose total research employment.

[6] HERD is composed of all universities, colleges of technology, and other institutes of post-secondary education, whatever their source of finance or legal status. It also includes all research institutes, experimental stations, and clinics operating under the direct control of, or administered by, associated with higher education establishments.

[7] The government sector is composed of all departments, offices, and other bodies which furnish but normally do not sell to the community those common services, other than higher education, which cannot otherwise be conveniently and economically provided and administered by the state and the economic and social policy of the community.

[8] Data on β, HERD, and GOVERD had many missing observations. We therefore linearly interpolated right hand variables in the case of only one missing year. With two or more missing years, no interpolation was undertaken.

	β	$\frac{Researchers}{Population}$	$\frac{HERD}{GDP}$	$\frac{GOVERD}{GDP}$
Australia	4.45	0.12	0.36	0.41
Belgium	7.57	0.23	0.38	0.08
Canada	12.35	0.21	0.38	0.28
Germany	12.16	0.39	0.42	0.36
Denmark	10.37	0.28	0.36	0.28
Spain	10.96	0.07	0.20	0.16
Finland	4.58	0.35	0.46	0.37
France	24.74	0.27	0.36	0.51
UK	23.72	0.28	0.35	0.30
Italy	19.53	0.10	0.25	0.24
Japan	1.54	0.42	0.52	0.26
Netherlands	10.76	0.23	0.53	0.36
Norway	24.80	0.22	0.38	0.26
New Zealand	7.80	0.08	0.27	0.43
USA	32.52	0.30	0.37	0.26

Table 1: Sample means in percent. β is the the subsidization rate, $HERD$ is expenditure on R&D in universities, and $GOVERD$ is expenditure on R&D in the government sector.

between 0.2 for Spain and 0.52 for Japan in the case of university research. In the case of the government sector research, the range is between 0.08 percent in Belgium and 0.51 percent in France.

However the measures of R&D are not stable over time. In fact, the subsidization rates were quite disparate in the 1980s, converging to similar subsidization rates in the late 1990s (see Figure 2). The percentage of researchers in the population increased in almost all countries in the investigated period (Figure 3), while funding for government research institutes declined. Expenditure for university research, in contrast, increased in most countries with Sweden having the highest initial value while Spain is at the lower end, however increasing quickly.

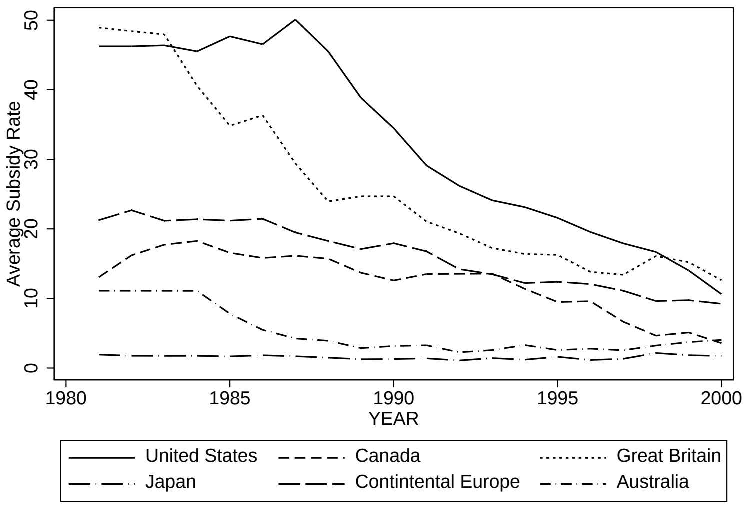

Figure 2: Average subsidization of the business sector.

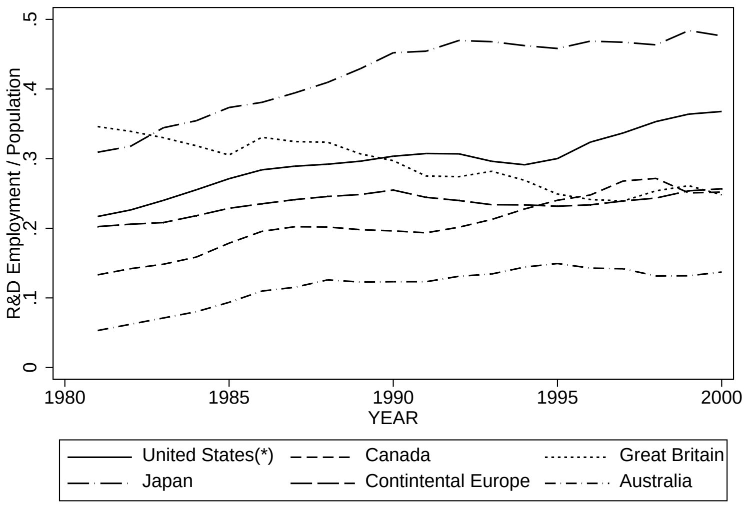

Figure 3: Researchers in the business enterprise sector as a percentage of the population. Data for the USA* are researchers without supporting staff, and support staff and researchers otherwise.

For the regression analysis, we further include control variables. Real GDP, measured in purchasing power parities presented by the OECD (2003b), is a broad measure of general economic activity. Higher GDP will lead to more research activity since the profit opportunity set increases. Conversely, higher research activity will positively affect GDP growth. The openness of the economy is computed as the ratio of exports plus imports over GDP. The export and import data were taken from the OECD (2003a). The openness of the economy is a measure for potential spillovers from one economy to the next and furthermore, accounts for additional profit opportunities abroad.

4 Determinants of R&D: Empirical evidence

We estimate the model presented in Section 2, or more precisely estimate equations 9 and 10. Besides the lagged dependent variable and the subsidization rate, we include GDP as a broad measure to capture economic activity and profit opportunities. The openness of the economy captures further profit opportunities abroad and also technology spillover effects. The separate estimation of the two equations allows us to disentangle the effect of changing subsidization rates on employment and total expenditure.

$$\ln L_{it} = \gamma_l \ln L_{i,t-1} + c_1 \ln(1+\beta)_{it} + c_2 \ln GDP_{it} + c_3 \ln openness_{it} + \epsilon_{it} \quad (9)$$

$$\ln E_{it}^{total} = \gamma_e \ln E_{i,t-1}^{total} + a_1 \ln(1+\beta)_{it} + a_2 \ln GDP_{it} + a_3 \ln openness_{it} + \nu_{it} \quad (10)$$

4.1 Methodology

We use three different estimators for the regressions. As a first benchmark we estimate standard, non-dynamic fixed effect panel regressions;[9] the results are presented in the first two columns of Table 2.

[9] We estimated fixed effect, not random effect regressions as the Hausman specification test (Greene 2000, p.576) results indicated.

We next estimate the dynamic model as presented in Section 2. If innovations depend on the existing stock of research, then last year's innovations influence those today. Research projects often extend over a period of several years. A high autocorrelation in the processes of research employment and expenditure can be expected. The estimation of a dynamic model is therefore appropriate.

In a panel with fixed effects, a lagged dependent variable violates the strict exogeneity assumption. Baltagi (2001) points out that the basic problem of including the lagged dependent variable is that it is, like the dependent variable, a function of the fixed effect. This renders the OLS estimator biased and inconsistent. The fixed effect (within) estimator will also be biased (Nickell 1981). Therefore Arellano and Bond (1991) proposed a General Method of Moment (GMM) estimator which overcomes these problems. It is now the standard method to estimate dynamic panels, for further details refer to Baltagi (2001, p. 131). The Arellano-Bond GMM procedure involves first differencing the model in order to remove fixed effects. The differenced equation is estimated, the lagged dependent variable is instrumented using all available lags of the variable in levels. The results of the Arellano-Bond estimation of the dynamic panel are presented in columns 3 and 4 of Table 2. The Arellano-Bond test that the average autocovariance in the residuals of order 2 is 0 could not be rejected at any conventional significance level. The Sargan test also confirms that the instruments are valid. Therefore the regressions pass two important specification criteria and the results can be readily interpreted.

In the last set of regressions, we account for the fact that GDP might not be an exogenous variable to R&D. Aghion and Howitt (1998) and Romer (1990) among others argue that technological progress constitutes one of the principal components of economic growth, thereby rendering GDP endogenous. We therefore instrument GDP with its own lags.

	Panel Fixed Effects		Arellano Bond		Arellano Bond GDP endogenous	
	(1) $\ln(L)$	(2) $\ln(E^{total})$	(3) $\ln(L)$	(4) $\ln(E^{total})$	(5) $\ln(L)$	(6) $\ln(E^{total})$
LDV			0.85	0.77	0.86	0.82
			(33.86)	*(26.23)*	*(37.67)*	*(31.92)*
$\ln(1+\beta)$	1.41	1.72	0.21	0.37	0.15	0.24
	(7.36)	*(7.26)*	*(2.32)*	*(3.01)*	*(2.08)*	*(2.41)*
$\ln(openness)$	0.37	0.21	0.09	0.15	0.09	0.15
	(5.38)	*(2.44)*	*(3.58)*	*(4.23)*	*(3.93)*	*(4.66)*
$\ln(GDP)$	1.44	2.03	0.22	0.43	0.18	0.27
	(22.17)	*(25.27)*	*(2.22)*	*(3.08)*	*(2.15)*	*(2.29)*
constant	-7.57	-18.13	0.00	0.00	0.00	0.00
	(-8.61)	*(-16.63)*	*(-0.85)*	*(-1.39)*	*(-0.93)*	*(-1.20)*
$\ln(1+\beta)^{long}$			1.40	1.65	1.06	1.36
(p-value)			*(0.02)*	*(0.00)*	*(0.03)*	*(0.01)*
R^2 (within)	0.73	0.76				
AR1 errors, $Pr > z$			0.38	0.08	0.59	0.18
AR2 errors, $Pr > z$			0.34	0.79	0.28	0.95
Sargan, $Pr > X^2$			1	1	1	1
Observations	258	258	198	198	198	198

Table 2: Estimation period is 1981-2001 in an unbalanced sample. z-statistics (t-statistics) are in italics. L is the number of researchers, E^{total} are total expenditure on R&D. The long run elasticity is the coefficient of $\ln(1+\beta)$ divided by 1 minus the coefficient of the lagged dependent variable (LDV). The p-value of the Wald test on significance of long run elasticity refers to H_0: the long-run effect is zero. Arellano-Bond test on average order 1 autocovariance in residuals (AR1 errors) with H_0 :The residuals are not autocorrelated. Arellano-Bond test on average order 2 autocovariance in residuals (AR2 errors) with H_0: The residuals are not autocorrelated. Sargan test of over-identifying restrictions (results from 2-step GMM with standard errors not corrected for heteroscedasticity), H_0: The over-identifying restrictions are valid.

4.2 Estimation Results

Table 2 presents the estimation results. The subsidy rate has a positive and significant effect on research employment in all specifications. An increase in the subsidization of one percentage point (since $\ln(1+\beta) \approx \beta$) leads to an increase of R&D employment of at least one percent in the long run.[10] A long run coefficient close to unity is obtained in the Arellano-Bond estimator with endogenous GDP (column 5). If GDP is not instrumented (column 3), the coefficient is 1.4. The estimates of the static fixed effects panel regression are very close to the long-run results of the Arellano Bond estimators. In the short run, the effect is much smaller. An increase in the subsidy rate of one percentage point leads to 0.21 % more research employment (0.15% if GDP is endogenous). Hence, our results support the view that dynamic effects are very important; roughly seven times larger than the immediate impact.

The effect on total expenditure for business R&D is stronger. In the Arellano-Bond regression with endogenous GDP, the short run coefficient of β is 60% higher than the corresponding one of the employment regression (0.24 compared to 0.15). In the long run, the coefficient of β is 1.36. This implies that research expenditure in the long run increases by 28% more than research employment. The huge increase in wages in the short run compared to the reaction of employment is thus mitigated but still substantial in the long run. The difference between short and long run is even more pronounced in the estimation with endogenous GDP (columns 5 and 6).

Our estimates can be used to compute wage-elasticities of labor supply in the research sector. According to Equation 5, it is 1.6 in the short and roughly 3.5 in the long run. The magnitudes are are much larger than that estimated by Goolsbee (1998). He finds a supply elasticity of 0.1 to 0.2. However his estimations were done using data for the US 1968-94 and inclusive of the ratio of all federal R&D

[10] Another way of interpreting the results is the following: Increasing the household wage relative to firm cost by one percent leads to a long-run increase in research employment of one percent. Evaluated at the sample mean, an increase in $\ln(1+\beta)$ of one percent corresponds to an increase of β of 0.995 percentage points. The average subsidization rate in our sample is $\beta = 13\%$.

to GDP. As we have seen in the last section, subsidization rates were very high in the US, especially in the early times of the sample. Goolsbee's investigated period covers a time of high military budgets, thus subsidies, due to the cold war, and therefore it is possible that the measured supply elasticities of researchers are lower. In addition, Goolsbee shows that the effect on wages is much higher in the aeronautical, mechanical, metallurgical, and electrical sectors, all recipients of high shares of defence spending. Most important, however, the supply elasticity calculated by Goolsbee measures the increase in an average scientist's working time due to higher wages. Our estimate, in contrast, takes into account the hiring of new scientists.

The control variables have the expected sign and coefficient magnitudes in all specifications. Openness and GDP have a a significant positive influence both on research employment and expenditure in the business enterprise sector. The coefficient on GDP is larger for total expenditure indicating that increases in GDP lead to higher wages for researchers.

4.3 The importance of capital in R&D

So far we have attributed differences in the reaction of expenditure and employment to changes in the wage rate. Since even in the long run, R&D expenditures increase by 20 to 30% more than employment, we interpret our findings as evidence that subsidies increase scientists' wages substantially. This interpretation is in line with the findings of Goolsbee (1998), who provides evidence for an increase in wages of roughly the same magnitude (even slightly higher) in a panel of household survey data.

Still, there is a different potential explanation for this finding, namely substitution towards capital. If labor and capital are substitutes in the process of R&D, and capital is supplied more elastically than labor, subsidization of R&D will lead to an increase in capital intensity that could explain the stronger response of R&D expenditure in our regressions. However, if capital and labor are gross complements as inputs to research, our estimate of the increase in wages, $a_1 - c_1$, even underestimates the true impact of subsidies on labor cost.[11] The intuition for this result is that the increase in expenditure (as measured by a_1) is a weighted average of the increase of labor and of capital cost. If capital is supplied elastically, capital cost does not increase at all, and labor cost must have increased by more than average cost. Hence, the observed increase in expenditure is a combination of a very strong increase in labor cost and no increase in capital cost. We explore this idea in more detail in appendix A.

We are not aware of any evidence on whether capital and labor are substitutes or complements in the production process of innovation. Estimating the elasticity of substitution is difficult because one requires data on the capital intensity of research. Such data is currently not available. Still, intuitively capital and labor are more likely to be complements in research. We therefore believe it safe to interpret our results as evidence for a substantial effect of subsidies on scientists' wages, thus confirming the findings of Goolsbee (1998).

4.4 Other policy variables

Instead of paying subsidies to business R&D, governments can use other policy instruments to foster research. A very direct way of increasing R&D is to fund research in the higher education sector (universities) or other public research centers. However, it is likely that research in these institutions also affects business R&D. On the one hand, research done in universities might increase the profitability of business research through positive spillover effects. It could also increase the education and therefore the supply of young researchers. On the other hand, universities and private research departments both employ educated scientist. Increased funding for universities might therefore induce upward pressure on scientists' wages, thereby

[11] Capital and labor are gross complements if the elasticity of substitution is smaller than one. Substitution towards one factor due to changes in the relative factor prices is overcompensated by an income effect.

leading to a crowding out of private research.

Table 3 looks at two further policy variables and estimates the effect of these variables on private research activity. First, we include expenditure on R&D in public research institutions (GOVERD) as a share of GDP. We find that GOVERD has no influence on private research. In regressions (3) and (4) the respective coefficient is insignificant.

A second variable with potentially important effects on private research is research done in the higher education sector (HERD). Regressions (2) and (4) in Table 3 show that the impact of university research on private research is negative and significant. This is indicative of crowding out of business R&D by university research; an effect also found by Guellec and Pottelsberghe (2003). A 10% increase in university research reduces private R&D employment by 0.4 % in the short run and by roughly 3% in the long run. This figure remains unchanged in both specifications.

Policy implications should, however, be carefully derived. University research is certainly important to provide firms with highly educated scientists. Additionally, well-designed cooperation between the public and the private sector is likely to have a positive impact on business R&D. What matters is not necessarily the pure quantitative measure of aggregate spending on university research, but also the quality of the institutions and similar structural variables. In our estimations we make use of time series variation only. The results measure thus the crowding out effect of increased spending in universities controlling for the structural variables in the fixed effect.

We can thus conclude that subsidies to R%D remain effective after concluding additional policy variables. The measured crowding out effect of business research by university research confirms the evidence of the previous sections, namely that scientists are in rather inelastic supply.

	(1) ln(L)	(2) ln(L)	(3) ln(L)	(4) ln(L)
LDV	0.86	0.86	0.86	0.86
	(37.67)	*(34.63)*	*(32.89)*	*(31.73)*
$\ln(1+\beta)$	0.15	0.24	0.14	0.23
	(2.08)	*(3.13)*	*(1.69)*	*(2.71)*
$\ln(HERD/GDP)$		-0.04		-0.04
		(-2.17)		*(-2.20)*
$\ln(GOVERD/GDP)$			0.01	0.01
			(0.25)	*(0.32)*
$\ln(openness)$	0.09	0.11	0.10	0.12
	(3.93)	*(4.81)*	*(3.55)*	*(4.27)*
$\ln(GDP)$	0.18	0.25	0.20	0.26
	(2.15)	*(2.76)*	*(2.11)*	*(2.70)*
constant	0.00	0.00	0.00	0.00
	(-0.93)	*(-0.94)*	*(-1.03)*	*(-1.00)*
$\ln(HERD/GDP)^{long}$		-0.29		-0.29
(p-value)		*(0.06)*		*(0.06)*
AR1 errors, $Pr > z$	0.59	0.58	0.48	0.18
AR2 errors, $Pr > z$	0.28	0.11	0.38	0.48
Sargan, $Pr > X^2$	1	1	1	1
Observations	198	192	196	192

Table 3: Estimation period is 1981-2001 in an unbalanced sample. z-statistics (t-statistics) are in italics. L is the number of researchers. β is the the subsidization rate, $HERD$ is expenditure on R&D in universities, and $GOVERD$ is expenditure on R&D in the government sector.The long run elasticity is the coefficient of $\ln(1+\beta)$ divided by 1 minus the coefficient of the lagged dependent variable (LDV). The p-value of the Wald test on significance of long run elasticity refers to H_0: long-run effect is zero. Arellano-Bond test on average order 1 autocovariance in residuals (AR1 errors) with H_0: The residuals are not autocorrelated. Arellano-Bond test on average order 2 autocovariance in residuals (AR2 errors) with H_0: The residuals are not autocorrelated. Sargan test of over-identifying restrictions (results from 2-step GMM with standard errors not corrected for heteroscedasticity), H_0: The over-identifying restrictions are valid.

5 Conclusions and policy implications

Research and development is an important contributing force for economic development and growth. There is empirical evidence that the amount of research undertaken in an economy is lower than the social optimum. One policy tool used to increase R&D is the provision of subsidies to private firm research, which is done by all OECD countries.

The present paper has investigated the effectiveness of public subsidies to business enterprise research in generating additional research. We thereby explicitly distinguish between effects of the subsidy on aggregate employment and aggregate expenditure. The results indicate that subsidies are effective in generating additional research. In fact, an increase of the subsidization rate by 1 percentage point will lead to an additional 0.2 percent researchers in the short run. As expenditure on R&D increases roughly by 60 % more than employment, we interpret this as evidence of wage increases. In the long run the subsidies' effect is stronger, an increase of the subsidization rate by 1 percentage point will lead to an additional 1% researchers. Expenditures increase by 20 to 30 % more than employment leading us to conclude that even in the long run the impact of subsidies on wages is substantial. Our results are in line with the findings of Goolsbee (1998) who finds similar increases in wages using household survey data. Policy makers should therefore be aware that increasing R&D expenditure per se only partially feeds into a larger number of scientists and engineers, as wages increase significantly.

Furthermore, we controlled for research expenditures in universities and government research institutes. While the latter have no effect on business enterprise research, the empirical results show that university research crowds out business research employment.

A Substitution towards capital

Certainly, researchers constitute the most important "input" to research and wages represent a large part of total spending. Employment in research departments is the only data on "quantities" used in research available at the macroeconomic level, since there are no data on capital in research. It is therefore a sensible approach just to investigate the reaction to a subsidy in terms of the number of employed researchers.

However, the subsidy could also affect the use of equipment, especially if capital goods are supplied more elastically than researchers. Government subsidies would then increase the capital intensity of research. In the following section we analyze the potential strength of this effect by incorporating capital into the model.

Suppose that R&D is a composite good Y which is produced with capital K and labor L. The zero profit condition that determines the demand for R&D remains unchanged, except for the fact that the composite Y instead of labor is the relevant input. Hence equation 1 takes the form

$$\varphi(Y, X_t^d)\Pi_t(\cdot) = c(w, r)Y \tag{11}$$

where $c(w, r)$ is the unit cost function in the production of Y and w and r the factor prices that firms face. In order to concentrate on the substitution effects we assume a constant elasticity of substitution σ. Therefore, the (standard) CES unit cost function is given by

$$c(w, r) = \left(\gamma^\sigma w^{1-\sigma} + (1-\gamma)^\sigma r^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{12}$$

If $\sigma > 1$ ($\sigma < 1$) capital and labor are gross substitutes (complements) in the sense that the demand for capital increases (decreases) if the wage rate increases. σ equal to unity corresponds to the Cobb-Douglas case.[12] The parameter γ influences the labor income share in research production, which we call $\alpha(\gamma, \sigma, w, r)$.

[12] If σ converges to infinity the corresponding production function is linear in L and K, and if $\sigma = 0$ it is Leontieff.

In this paper we find estimates for the reaction of total research expenditure and research employment with respect to a increase in the subsidy rate. Total research expenditure now corresponds to the sum of labor cost and capital cost. We can use the empirical estimates in order to calculate the increase in wages as a function of the elasticity of substitution σ and the labor share α.

Proposition 1 *Let* $a_1 = \varepsilon(E^{total}, 1+\beta)$ *and* $c_1 = \varepsilon(L, 1+\beta)$ *be the elasticities of total research expenditure and research employment with respect to* $1+\beta$. *Total expenditure is* $E^{total} = (1+\beta)c(\cdot)Y$ *where* $c(\cdot)$ *is the unit cost function as given by equation 12. Assume that capital is in perfectly elastic supply. Then, the elasticity of the wage rate* $w^s = (1+\beta)w$ *with respect to the subsidy rate is*

$$\varepsilon(w^s, 1+\beta) \quad = \quad \frac{a_1 - c_1}{\alpha + \sigma(1-\alpha)} \tag{13}$$

Proof: In order to proof this proposition, use the labor share in order to express labor expenditure as fraction of total expenditure, $w^s L = \alpha(\cdot)E^{total}$. Therefore $\ln w^s = \ln \alpha(\cdot) + \ln E^{total} - \ln L$. We have to differentiate this equation with respect to $\ln(1+\beta)$. The labor share for the CES production function is given by

$$\alpha(w,r) = \frac{\gamma^\sigma w^{1-\sigma}}{\gamma^\sigma w^{1-\sigma} + (1-\gamma)^\sigma r^{1-\sigma}}.$$

Given that we assumed capital to supplied elastically, differentiation of this equation with respect to $\ln(1+\beta)$ yields $\frac{d\ln\alpha}{d\ln(1+\beta)} = (1-\sigma)(1-\alpha)\frac{d\ln w^s}{d\ln(1+\beta)}$. Therefore

$$\frac{d\ln w^s}{d\ln(1+\beta)} = (1-\sigma)(1-\alpha)\frac{d\ln w^s}{d\ln(1+\beta)} + a_1 - c_1$$

Rearranging this expressions gives equation 13

q.e.d.

Equation 13 reveals that our estimate $a_1 - c_1$ gives the true increase in wages if $\sigma = 1$, i.e. the Cobb-Douglas-case, or if labor is the only input in research ($\alpha = 1$). We underestimate (overestimate) the true impact on wages if capital and labor are gross complements (substitutes) in research.

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