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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 on business enterprise research in a panel of OECD countries. We contribute to the literature by explicitly distinguishing between the effects of a subsidy on R&D employment and expenditure, thereby accounting for a potential increase in scientists' wages. We employ instrumental variable regressions to address endogeneity problems of the subsidization. The results indicate that subsidies are effective in generating additional research expenditure. Expenditure for business research increases by roughly 20% more than employment. We take this as evidence that subsidies may raise scientists' wages given standard production functions.

1. Introduction

Research and development has been identified as one of the principal sources of economic growth.[1] It leads to the discovery of ideas and innovations, which in turn enhance productivity and generate growth. Empirical studies by Griliches (1979, 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 late 2002 at the Barcelona summit, heads of European governments agreed upon an initiative called "More Research for Europe". They wanted to see Europe's R&D investment rise from its current 1.9% of GDP to 3% by 2010, hence by about 50%.[2] This would close the current gap with the US, where R&D expenditure amounts to 2.8% of GDP and Japan (2.98%). This gap between Europe and the US and Japan is due to low R&D expenditure by firms in Europe. One way to increase R&D in firms is to subsidize them. However, it is unclear to what extent subsidies actually increase business research activity.

☆ The opinions expressed in this paper do not necessarily represent the views of the Deutsche Bundesbank or its staff.

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[1] See, e.g., Arrow (1962), Romer (1990) and Aghion and Howitt (1992) for theoretical and Griliches (1994) for empirical work.

[2] Moreover, the Barcelona target aims at a 50–50 split between private and public R&D, which underscores the importance of testing for crowding out effects.

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This paper investigates the effectiveness of subsidies to private business research at 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. Expenditure for business research increases by roughly 20% more than employment, which, in the dynamic specification, does not increase significantly. Under some assumptions this can be seen as evidence of higher wages for scientists.[3]

The effectiveness of subsidies to business R&D has been investigated extensively in the literature. David et al. (2000) and Klette et al. (2000) provide surveys. Most studies analyze the effectiveness of specific programs at the firm level. Our study complements the microeconometric evaluation studies with macroeconometric data. We try to capture whether the demand for R&D inputs due to large-scale subsidy programs leads to a significant increase in the wages of scientists. Previous evidence with household survey data by Goolsbee (1998) shows that the income of scientists and engineers in the U.S. did indeed increase substantially with aggregate subsidies to R&D in the entire economy, whereas the number of hours worked by each scientists remained almost constant. Goolsbee (1998) 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%.

Only a few studies investigate the effectiveness of subsidies to business R&D at the macroeconomic level. Levy and Terleckyj (1983) find that there is a positive impact of government contract R&D on private R&D investment in U.S. time series data. Kongsted et al. (2003) find a positive effect of public innovation support on Danish manufacturing research. Guellec and van Pottelsberghe (2003) confirm this result with panel data. They estimate that one dollar given to a firm results in 1.7 dollars of research. Levy (1990) finds a positive impact only in some countries of his panel, while in other countries no effect is found. All these studies 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 on R&D (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 find that expenditure reacts more strongly than employment to subsidies suggesting 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. Given the multitude of different subsidy programs even within individual countries, and in particular across our sample, we measure the subsidy rate to R&D as the ratio of public over private expenditure for R&D. The subsidy rate therefore captures the amount of subsidies that companies receive for each dollar privately spent. To isolate the effect of government policy changes on the subsidization rate we implement an instrumental variable estimator. We propose government revenue and the governments' investment budgets as instruments for changes of governments' subsidies.

A convenient byproduct of using the subsidy rate as the explanatory policy variable is that the omitted variable bias discussed by David et al. (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 is advantageous because 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.[4] The market for researchers can be diagrammed using demand and supply curves as presented in Fig. 1. As wages increase, more scientists and engineers will decide to work as researchers in firms. If the government's intention is to increase research in the business sector by subsidizing it, the relevant input factor for research output is 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.

2.1. Wage and employment effects

As shown in Fig. 1, an increase in the subsidy rate β leads to an increase in employment L and total expenditure $E^{\text{total}} = wL$ (which corresponds to the area $OLBw$). The

[3] Higher wages may well improve the quality of research output through higher effort (efficiency wages). Moreover, it increases the attractiveness of the profession potentially attracting brighter people.

[4] In Section 4.3 we discuss the role of capital in research.

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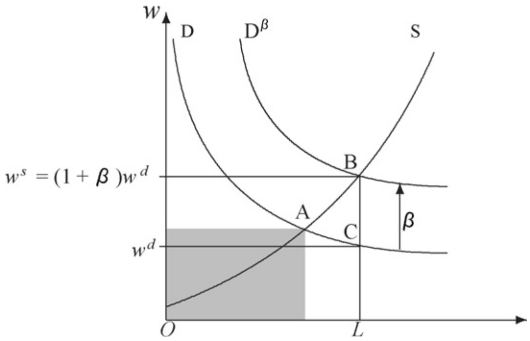

Fig. 1. Wage effect of R&D-subsidy.

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 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, thus 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 and supply curve. For example, the shaded area in Fig. 1 might be larger or smaller than the area $OLCw^d$, depending on the supply and demand elasticities of researchers. A regression analysis investigating the effect of subsidies on private research expenditure might therefore find an insignificant or even negative coefficient, even though the number of researchers has increased. A zero or even negative 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. In other words: even if private R&D spending is crowded out, overall spending and employment in the private sector can have increased.

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, that is, employees with university degrees, employed in research departments is rather small. In the most developed countries, like the US, Japan, Germany, and Great Britain, it is about 3%. In most of the other sample countries, it is less than 1%.[5] This would tend to support the idea of relatively elastic supply curves. However, Goolsbee (1998) found that in the U.S. 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-term effects*

Subsidies can have very different effects in the short and long terms. Beside the direct effect as discussed above, public aid to business R&D is likely to have further dynamic effects. David and Hall (2000, 1171 pp.) 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, the technology spillover effect, and the learning effect.

The first dynamic effect stems from the training of new scientists and engineers. Labor supply will be more elastic in the long term than in the short term. In the short term, 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 might increase in the subsidy rate depending on the respective elasticities. 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 et al. (2000) as well as by the whole R&D based growth literature (e.g., Barrio-Castro et al., 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.

A third dynamic effect results from learning by doing in the firm. Once research personnel is in place and trained, the firms's research productivity increases and it becomes more profitable for the firm to perform research (Klette and Moen, 1998).

The scientist training, the technology spillover, and the learning 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 underlying model.

[5] This number is computed by relating the OECD data on researchers in the business sector to the number of people with university degrees, as provided by de la Fuente and Domenech (2002). In the UK, 10.52% of the population hold a university degree or equivalent, while only 0.3% of the population works in private business R&D according to the OECD.

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2.3. Underlying model

Assume for the moment, that qualified labor (human capital) is the only input in research.[6] Let $\varphi(L_t)$ be the number of R&D projects that can be undertaken in the economy given that L_t scientists do research. Denote $\Pi_t(\cdot)$ as 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:

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

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:

$$w_t = g(L_t) \tag{2}$$

where w_t 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 $w = (1+\beta)w^d$. Solving the model for L_t and log-linearizing yields Eq. (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 $E_t^{\text{total}} = (1+\beta)w_t^d L_t$:

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

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

Since the coefficients c_1 and a_1 correspond to the elasticities of employment and expenditure with respect to $1+\beta$, the difference of the estimated coefficients correspond to the elasticity of the post-subsidy wage, i.e., $\varepsilon(w_t, 1+\beta) = a_1 - c_1$. Note that for small values of β, the elasticities with respect to $1+\beta$ approximate the semi-elasticities with respect to the subsidy rate β.

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, for example 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 on the other factors on the stock of knowledge A_t:

$$\varphi(L_t, A_t)$$

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

$$\dot{A}_t = \varphi(\cdot) - \delta A_t \tag{5}$$

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

$$\ln A_t = \gamma \ln A_{t-1} + (1-\gamma)\ln A^*(\beta_t, X_t, \pi_t) \tag{6}$$

where $\ln \gamma$ corresponds to the speed of convergence to the steady state as implied by the model parameters. $A^*(\beta_t, \pi_t)$ is the steady-state value of technology and is determined by the exogenous model parameters (β_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 linearize the zero profit condition $\varphi(L_t, A_t)\Pi_t(\cdot) = w_t^d L_t$ for $t, t-1$ and in the steady state, solve the linearized zero profit condition for $\ln A_t$, $\ln A_{t-1}$, and $\ln A^*$ and substitute in Eq. (6) to get

$$\ln L_t = \gamma \ln L_{t-1} + (1-\gamma)\ln L^*(\beta_t, \pi_t) \tag{7}$$

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

Table 1
Sample means in percent

	β	Researchers/population
Australia	4.45	0.12
Belgium	7.57	0.23
Canada	12.35	0.21
Germany	12.16	0.39
Denmark	10.37	0.28
Spain	10.96	0.07
Finland	4.58	0.35
France	24.74	0.27
UK	23.72	0.28
Italy	19.53	0.10
Japan	1.54	0.42
Netherlands	10.76	0.23
Norway	24.80	0.22
New Zealand	7.80	0.08
USA	32.52	0.30

β is the subsidization rate.

3. Data and measurement of the subsidy rate

The OECD (OECD, 2003b) provides cross-country data on the R&D performance in the business enterprise sector.[7] We used data for the time period 1981–2002 and the countries included in Table 1.[8]

As for our first endogenous variable, research employment, the OECD data covers all researchers in the business

[6] Romer (2000) points out that in university research only 5–7% is spent on equipment. Goolsbee (1998) argues that 60% of research expenditure is labor cost. The National Science Foundation (1995) documents that between 45% and 83% of total spending is wages and benefits of scientific personnel depending on how one counts overhead costs.

[7] According to the OECD classification, 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 R&D performing sectors in the OECD classification, see the Summary of Frascati Manual, (OECD, 1994, pp. 16–17).

[8] For some countries, missing observations made the inclusion in our sample impossible due to the fact that the Arellano and Bond (1991) estimator requires taking first differences.

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sector and all those providing direct services to the researchers (e.g., secretaries, clerical staff).[9] The other dependent variable, total R&D expenditure by the business sector is normalized to constant 1991 US$ in purchasing power parities. It includes expenditure in the business sector irrespective of the source of funding.

As for our main explanatory variable, the subsidy rate, a direct measure is not immediately available. There is a variety of subsidy programs, ranging from small scale targeted initiatives at the regional level to bigger pan-national programs. Condensing the different funding schemes into one number is difficult. One way is to measure the aggregate subsidization rate as the ratio of government subsidies for private sector R&D to the private sector's own finance of R&D. The OECD provides comparable data on expenditure on R&D in the business enterprise sector (BERD), which is financed through two main sources: Own finances (BERDb) and government subsidies (BERDg). Our measure of the subsidy rate is thus $\beta = \mathrm{BERDg}/\mathrm{BERDb}$.[10] It is a measure of average subsidization of the business enterprise sector by the government. Each private dollar of research expenditure is thus subsidized by β dollars from the government. The OECD statistics do not distinguish between different forms of channelling R&D subsidies to firms (grants, public procurement, etc.). In a recent study, Berube and Mohnen (2007) show that tax credits in combination with R&D grants lead to greater innovation success than the exclusive use of tax credits in a sample of Canadian plants. It is beyond the scope of this study to further differentiate between instruments. Further research in this direction is certainly highly relevant from a policy perspective.

The cross-country variation of the average subsidization rate β is substantial. It ranges between less than 2% in Japan to more than 30% in the U.S.A., with an unweighed average of 13.8%. Less than 1% 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% in Spain to 0.42% in Japan. 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 Fig. 2). The percentage of researchers in the population increased in almost all countries during the investigated period (Fig. 3).

The proposed measure of subsidization captures the amount of subsidy in relation to the private part of research and development spending. By construction, it should be unaffected by variations in prices, especially wages, as it is the ratio of two nominal variables. In this sense, β reduces the problem of spurious regression results present in earlier studies.

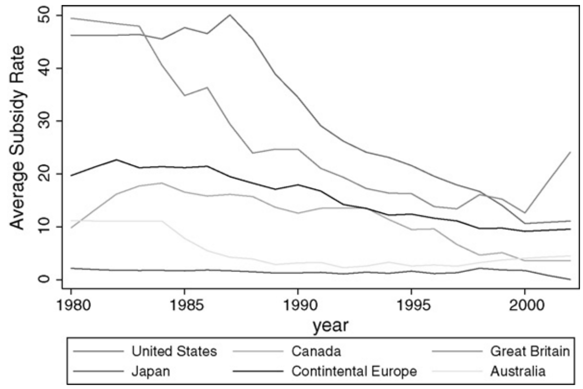

Fig. 2. Average subsidization of the business sector.

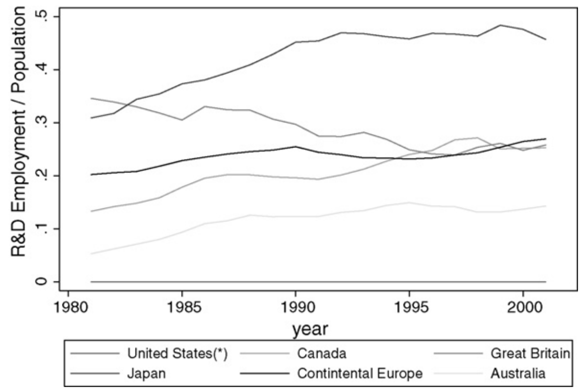

Fig. 3. Researchers in the business enterprise sector as a percentage of the population. Data for the USA* are researchers without supporting staff, and support staff and researchers otherwise.

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.[11] Higher GDP will lead to more research activity since the profit opportunity set increases. The openness of the economy is computed as the ratio of exports plus imports over GDP.[12] This 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 Eqs. (8) and (9). Besides the lagged dependent variable and the subsidization rate, we include GDP. The openness of the economy is added as an additional control variable:

$$\ln L_{it} = \gamma_l \ln L_{i,t-1} + c_1 \ln(1+\beta)_{it} + c_2 \ln GDP_{it} + c_3 \ln \mathrm{open}_{it} + \epsilon_{it} \quad (8)$$

[9] 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 (OECD, 2003b, Tables 27 and 30). For the USA, we took the number of researchers only, which is not problematic because of fixed effects.

[10] Data on β had missing observations. We therefore linearly interpolated right hand side variables in cases where only 1 year was missing. With two or more missing years, no interpolation was undertaken.

[11] The reference year for ppp is constant 1991 US$.

[12] The export and import data were taken from the OECD (2003a).

$$\ln E_{it}^{\text{total}} = \gamma_e \ln E_{i,t-1}^{\text{total}} + a_1 \ln(1+\beta)_{it} + a_2 \ln GDP_{it} + a_3 \ln \text{open}_{it} + \nu_{it} \quad (9)$$

4.1. Methodology

We use several different estimators for the regressions. As a first benchmark we estimated standard, fixed effect panel regressions.[13] In this version of the paper we do not report the fixed effect results.

A second set of regressions addresses the potential problem of endogeneity of the subsidization rate, where one has to ensure that it captures an exogenous policy impact. In particular, variations of the subsidization rate can result from changes in firms' privately funded expenditure on R&D even if there are no intentional changes in governments subsidy programs. In order to capture the effect of government policy changes on private research employment and expenditure, we instrument the subsidization rate β with variables capturing government policy changes. These variables should be exogenous to private sector research activity and at the same time be a good measure of government policy. We propose two sets of instruments fulfilling these criteria, and discuss their statistical properties at length in the results section along with tests for weak instruments.

The first set of instruments includes general government total tax and non-tax receipts (revenue),[14] and the government investment to government consumption ratio. While revenue is a very broad measure of government revenue and activity, it nevertheless provides valuable information for a specific government expenditure category, the subsidy to R&D. If subsidies constitute a fixed proportion of government revenue, subsidies will be correlated with government revenue. Moreover, it can be assumed, that in times of high government revenue, it will be easier to increase subsidies, while in times of low revenue, this relatively discretionary part of the public budget will be most strongly cut. Furthermore, government revenue is exogenous to research and development in the business sector, since the the overwhelming part of revenues comes from sources other than taxes on research. As a control of business cycle effects, we use cyclically adjusted revenue instead of general non-cyclically adjusted revenue.[15] The first set of instruments also includes lagged revenue. Moreover, we use the ratio of the investment budget over the consumption budget of the government.[16] This measures shifts of the government budget from investment to consumption and vice versa. Governments deciding to increase investment will likely also increase subsidies for R&D, with the overall objective of promoting growth relevant factors. The Lissabon and Barcelona summits identified R&D and public infrastructure as important factors for growth, which should both be promoted.

We tested, whether IV fixed effect regressions should be preferred over the standard fixed effect model with the Durbin–Wu–Hausman test (Davidson and MacKinnon, 1993, pp. 237–242) and had to reject the H_0 that the OLS parameter estimates are consistent for the employment and expenditure regressions. Thus, the enogeneity of β needs to be addressed in an instrumental variable estimation.

The first stage regressions confirm the validity of the instrument, as all proposed instruments positively and significantly affect the subsidization rate, β. Stock et al. (2002) present an excellent introduction to the problem of potentially weak instruments. Weak instruments can most easily be detected by the first stage F statistic, which should, as a rule of thumb, exceed 10 to have fairly good instruments. To test more formally, whether the instruments are weak, we also report the Cragg–Donald *F* statistic and compare it with the statistics provided in Stock and Yogo (2005). The instruments described above indeed suffer from a relatively weak connection to the instrumented variable. However, the test of overidentifying restrictions confirms the instruments' exogeneity (Sargan test). Fortunately, Moreira (2003) has developed a conditional likelihood ratio test for confidence tests, which are fully robust in the presence of weak instruments. We report the *p*-value of this statistic, which allows us to reject the null hypothesis of no influence of the subsidization rate on the dependent variable. Thus, even though the above discussed instruments are weak, we can trust our empirical results in Table 2, columns A–D.

As an alternative to the above (weak) instruments, we employ a second set of instruments (Table 2, columns E–H). Besides the government investment to consumption ratio, we also use the log of government expenditure for intramural government R&D (goverd). Thus, we use again a measure of government investment in capital and complement this measure by a more direct measure of government involvement in R&D. The *F*-statistic is now well above 10 and the Stock and Yogo (2005) statistics allow us to clearly reject the hypothesis of weak instruments. Also, the conditional likelihood ratio test by Moreira (2003) confirms the validity of the estimation results. Furthermore, the Sargan test confirms the exogeneity of these two instruments.

We next estimate the full dynamic model by including the lagged dependent variable. In a panel with fixed effects, a lagged dependent variable violates the strict exogeneity assumption. Baltagi (2001) points out that this renders the OLS estimator biased and inconsistent. The fixed effect (within) estimator will also be biased (Nickell, 1981). A large amount of literature has developed solutions to the described problems. Arellano and Bond (1991) developed a general method of moment (GMM) estimator. Their difference estimator is one of the most commonly employed GMM methods for dynamic panels. Moreover, in case of highly persistent variables, the system GMM estimator by Blundell and Bond (1998) is to be preferred over the difference GMM by Arellano and Bond (1991). Both GMM methods, however, rely on large sample asymptotics. They

[13] We estimated fixed instead of random effects regressions as indicated by the Hausman specification test (Greene, 2000, p. 576).

[14] Revenue is provided by the OECD (2004) database Code YRGTQ.

[15] The cyclically adjusted revenue is provided by OECD (2004) (code: YRGQA); we present the results for non-cyclically adjusted revenue, the results are similar for the cyclically adjusted part and available upon request.

[16] Government fixed capital formation, value, approp. account, code: IGAA over Government final consumption expenditure, value, appr. account, code CGAA.

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Table 2
Results of the static instrument variable regression analysis

	A ln(L)	B ln(E^t)	C ln(L)	D ln(E^t)	E ln(L)	F ln(E^t)	G ln(L)	H ln(E^t)
ln(1 + β)	**4.75**	**5.89**	**5.70**	**6.53**	**3.60**	**4.94**	**4.67**	**5.85**
	3.75	3.97	3.56	3.58	5.92	6.42	6.21	6.2
ln(GDP)	**2.24**	**2.91**	**2.21**	**2.87**	**1.97**	**2.73**	**2.04**	**2.79**
	8.51	9.44	7.72	8.78	13.98	15.33	12.8	13.98
ln(openness)			**0.74**	**0.58**			**0.63**	**0.54**
			3.71	2.55			5.53	3.76
Moreira (2003)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cragg–Donald F	4.457	4.457	3.484	3.484	22.90	22.90	18.42	18.42
Sargan test	0.343	0.186	0.205	0.124	0.56	0.61	0.23	0.36
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	232	232	232	232	255	255	255	255

Notes: Regressions A–D provide instrumental variable regressions with the revenue to GDP ratio, its lag, and the government investment to government consumption ratio as instruments. Regressions E–H use the government investment to government consumption ratio and the log of government intramural R&D expenditure as instruments. Estimation period is 1981–2002 in an unbalanced sample. t-Statistics are below the coefficients. L is the number of researchers, E^t are total expenditure on R&D. p-Value of Moreira (2003) conditional likelihood ratio test, p-value for Sargan test. F-Statistic for weak identification test for Stock and Yogo (2005) test.

require the number of cross-sections, N, to be much larger than the time dimension, T, as otherwise the number of instruments becomes very large compared to N.

Since we rely on a typical macro-sample, we do not employ the GMM methods typically employed in microeconometric studies. Using Monte Carlo simulations, Beck and Katz (2004) find that the nickel bias is low (2% or less) once $T = 20$, and they advise the use of the least-square dummy variable estimator (LSDV) and to include a lagged dependent variable if T is at least 20. Judson and Owen (1999) compare the performance of different dynamic panel estimators in typical macroeconomic datasets and conclude that for balanced samples the corrected least-square estimator (LSDVC) with country dummies and lagged dependent variable performs best. For unbalanced samples of our size, they recommend the one step difference GMM estimator by Arellano and Bond (1991). The bias reported by Judson and Owen (1999), for the coefficients on the independent variables, is minor in any of the estimators. Bruno (2005) extends the work of Bun and Kiviet (2003) and derives approximations to the bias of the LSDV dynamic estimator for unbalanced samples. He develops a biased corrected estimator (LSDVC) for unbalanced samples. For the dynamic estimations, we therefore present, following Beck and Katz (2004), the LSDV estimator, and, following the work of Bruno (2005) and Judson and Owen (1999) the LSDVC estimator.[17]

4.2. Estimation results

Table 2 presents our first set of statical regression results. As shown, both the number of researchers as well as expenditure for R&D are positively affected by the subsidy. We consistently find that the elasticity of expenditure is larger than the elasticity of R&D scientists. Moreover, GDP is positively connected with research. In regressions A–D, we perform instrumental variable regressions. While the instruments are weak, the conditional likelihood ratio test by Moreira (2003) shows, that the effect of the subsidy rate on research is robustly significant. We consistently find a larger coefficient for expenditure than for employment. Moreover, the difference in coefficient size is similar to the standard fixed effect OLS regression results amounting to roughly 20%. In columns E–H, we use different instruments as discussed above. The new instruments perform well on all three discussed statistics, the Sargan test, the F-statistic for the Stock and Yogo (2005) test, and the Moreira (2003) test. The results are consistent with the results from the previously used instruments and similar in magnitude. We again find that the elasticity is roughly 20% larger for expenditure than for employment.

In a next step, we turn to the dynamic instrumental variable regression analysis in Table 3. Regressions A–D present least-square dummy variable regressions, in which no bias correction is undertaken. Regressions E–G present bias-corrected (LSDVC) regression results.[18] All regressions, except E and F, use as instruments for the subsidization rate the instruments of regressions A–D in Table 2. As expected, the lagged dependent variable is highly significant. The coefficient size of the subsidization rate is now much smaller, documenting that the short-term impact is much weaker than the long-run effect of subsidies. We also compute the long-run steady-state effect of the subsidy on research. The coefficients on the long-run effect are similar in size to the static analysis. We again find that the impact on spending is larger than on employment, suggesting that even in the long-run, some price effects can be detected. Moreover, the estimated long-run coefficient in regressions G–H, which are bias corrected and instrumented, show that subsidies do not significantly affect the level of employment, but they have a very pronounced effect on the amount of research spending. Overall, these results suggest that spending increases are not necessarily driven by the amount of researchers, but potentially reflect wage increases.

Following the logic of our model, the estimates can be used to calculate the supply elasticity of researchers to

[17] Moreover, we also performed the one step difference GMM estimator following the results of Judson and Owen (1999) and found similar results, which are available from the authors.

[18] As starting values for the calculation of the bias correction we chose the estimates of the Blundell and Bond (1998) estimator.

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Table 3
Results of the dynamic regression analysis

	A ln(L)	B ln(E^t)	C ln(L)	D ln(E^t)	E ln(L)	F ln(E^t)	G ln(L)	H ln(E^t)
ln(1 + β)	**0.74**	**1.11**	**0.57**	**0.48**	**0.15**	**0.22**	**0.26**	**0.83**
	1.58	1.78	1.85	1.2	1.61	1.65	1.19	2.87
ln(GDP)	**0.34**	**0.54**	**0.25**	**0.21**	**0.05**	**0.00**	**0.02**	**−0.03**
	2.08	2.15	2.42	1.43	0.83	−0.05	0.38	−0.43
ln(openness)			**0.12**	**0.14**	**0.06**	**0.11**	**0.05**	**0.11**
			2.84	2.98	1.99	2.7	1.61	2.77
LDV	**0.82**	**0.76**	**0.82**	**0.84**	**0.93**	**0.93**	**0.94**	**0.94**
	15.41	10.44	19.53	18.26	31.27	27.33	35.96	33.23
ln(1 + β^{LT})	**4.16**	**4.55**	**3.25**	**2.98**	**2.18**	**3.14**	**4.24**	**13.91**
p-Value	0.02	0.00	0.01	0.11	0.11	0.11	0.28	0.09
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	218	218	216	216	218	218	220	220

Notes: Regressions A–D are LSDV, where β is instrumented with the weak instruments as in Table 1. Regressions E–H present the LSDVC estimator with the same instruments in G and H and no instruments in E and F. Estimation period is 1981–2002 in an unbalanced sample. *t*-Statistics are below the coefficients. L is the number of researchers, E^t are total expenditure on R&D.

wage changes:

$$\varepsilon(L_t, w_t) = \frac{\varepsilon(L_t, 1+\beta)}{\varepsilon(w_t, 1+\beta)} = \frac{c_1}{a_1 - c_1} \tag{10}$$

The elasticity of supply is around 0.5 in the last specification while in the other specifications it is larger.[19] The magnitudes are somewhat larger than those estimated by Goolsbee (1998), who finds a supply elasticity of 0.1–0.2. However, his estimations are based on data for the US 1968–94 and the explanatory variable includes the ratio of all federal R&D to GDP. As we have seen in the last section, subsidization rates were very high in the US, especially in the early parts of our sample. Goolsbee's investigated period covers a time of high military budgets, 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 defense 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.

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 at least 20% 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.[20] 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. If this is the case, our results would be evidence for a substantial effect of subsidies on scientists' wages.

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 for private firm research, which is provided by all OECD countries.

The present paper has investigated the effectiveness of public subsidies to business enterprise research in generating additional research. We explicitly distinguish between effects of the subsidy on aggregate employment and on aggregate expenditure. The results indicate that subsidies are effective in generating additional research. However, we also document that the effects on R&D employment are

[19] Except for specification E and F.

[20] 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.

quite weak in dynamic specifications, which take account of the strong persistency in R&D employment. The stronger increase of expenditure relative to employment can be interpreted such that subsidies affect wages of researchers. This result is in line with the results of Goolsbee (1998) who finds similar increases in wages using household survey data. However, it is also possible that the increase in R&D expenditure results from an increased capital intensity in research production. Also, a combination of the two effects is possible. An increase in wages probably reflects the fact that it takes considerable time to increase the supply of researchers in an economy since researchers are inelastic in supply. An increase in wages in turn is useful for the innovation process. First, it may increase the incentives of researchers to deliver better results. Moreover, it increases the attractiveness of this profession thereby attracting more bright people in the long run. However, policy makers should be aware that increasing R&D expenditure per se only partially feeds into a larger number of scientists and engineers.

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Appendix 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 is 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 Eq. (1) takes the form:

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

where $c(w^d, r)$ 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

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

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.[21] The parameter ν influences the labor income share in research production, which we call $\alpha(\nu, \sigma, w^d, r)$.

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

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

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

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

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

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

Rearranging these expressions gives Eq. (13). □ □

Eq. (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.

It is presumably difficult to investigate, at the macroeconometric level, whether capital and labor are substitutes or complements in the process of R&D. At least we are not aware of available data on capital—intensities in R&D. However, it does not seem very unrealistic to assume that capital and labor are complements in research.

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

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