THE JOURNAL OF INDUSTRIAL ECONOMICS 0022-1821
Volume L December 2002 No. 4

DO R&D SUBSIDIES STIMULATE OR DISPLACE PRIVATE R&D? EVIDENCE FROM ISRAEL*

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In evaluating the effect of an R&D subsidy we need to know what the subsidized firm would have spent on R&D had it not received the subsidy. Using data on Israeli manufacturing firms in the 1990s we find evidence suggesting that the R&D subsidies granted by the Ministry of Industry and Trade greatly stimulated company financed R&D expenditures for small firms but had a negative effect on the R&D of large firms, although not statistically significant. One subsidized New Israeli Shekel (NIS) induces 11 additional NIS of own R&D for the small firms. However, because most subsidies go to the large firms a subsidy of one NIS generates, on average, a statistically insignificant 0.23 additional NIS of company financed R&D.

I. INTRODUCTION

DOES GOVERNMENT POLICY play a role in influencing the rate and direction of technological change? Most governments appear to believe so. A wide variety of instruments is used by governments to foster technological change: tax cuts, subsidies to R&D, the formation of R&D consortia and national R&D laboratories are but a few examples. In this paper we focus on the relationship between government subsidies to R&D and company financed R&D in Israel.

The Israeli experience is of interest because its high-tech sector boomed in the course of the last decade, both by national and international standards. Government R&D and innovation policies are perceived as crucial elements of this success story (Trajtenberg, 2002). Yet, there is no quantitative assessment of the effectiveness of these policies. This paper attempts to close the gap by focusing on the question: Are R&D subsidies stimulating or displacing company financed R&D in Israeli manufacturing

* In memory of Zvi Griliches, the driving force behind this project. I would like to thank Isabel Busom, Karnit Flug, Mark Schankerman, the editor and three anonymous referees for their valuable comments and suggestions that greatly improved the quality of the paper. All remaining mistakes are, of course, my own. I would like to extend my appreciation and thanks to Haim Regev for compiling the data set and to the Central Bureau of Statistics for making them available for academic research. Comments by seminar participants at the Research Department of the Bank of Israel and at the Hebrew University are gratefully acknowledged.

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firms? That is, is there an ‘additionality effect’ to R&D subsidies? The lessons learned from the Israeli case should be of interest to countries implementing or contemplating the use of subsidy schemes to promote R&D.[1]

An R&D subsidy can have a direct and an indirect effect on firm performance. The direct effect comes about through the increase in total R&D expenditures, holding company financed R&D constant. Griliches and Regev (2001) estimate the separate effects of subsidized and company financed R&D expenditures on output and productivity of Israeli manufacturing firms. Their findings point to significant and, in some cases, very large effects of subsidized R&D on output. The indirect effect operates through the response of company financed R&D expenditures to the subsidy. If the R&D subsidy displaces own R&D expenditures, the total effect on productivity may be lower than what the Griliches and Regev estimates suggest. On the other hand, if it stimulates own R&D expenditures, then the effects of the subsidy are magnified. Thus, an understanding of the relationship between R&D subsidies and company financed R&D is necessary for a correct assessment of the role of R&D subsidies in boosting productivity.

The precise way in which R&D subsidies are administered is likely to make a difference. In Israel, the largest R&D subsidy program is the one implemented by the Office of the Chief Scientist (OCS) at the Ministry of Industry and Trade. Firms apply for an R&D grant on a project by project basis. All firms intending to export part of the outcome of the R&D project qualify for participation in the program. The vast majority of the subsidies granted represents 50% of the agreed upon R&D budget. Thus, upon approval of the project, the firm commits to match, dollar-by-dollar, the subsidy received by the OCS. If the project is commercially successful, the firm pays the subsidy back in the form of royalties. Thus, the grant becomes a loan conditional on the success of the project.

The R&D subsidy can be viewed as lowering the private cost of the project. Receiving the subsidy may therefore turn an unprofitable project into a profitable one to be pursued by the firm. Or it may speed up the completion of a project already under way. If subsidized R&D involves setting up or upgrading research facilities (labs) then the fixed costs of *other* current and future R&D projects are lowered, increasing their probability of being undertaken. The learning and know-how gained in the subsidized project can also spill-over to *other* current and future projects thereby enhancing their prospects of success. For all these

[1] Finland, Norway, Spain and the U.S., to name just a few countries, have R&D support schemes that operate in a somewhat similar manner to the Israeli program.

reasons, the R&D subsidy can stimulate current and future private R&D expenditures.[2]

The standard rationale for government support of R&D is rooted in the belief that some form of market failure exists that leads the private sector to underinvest in R&D (Arrow, 1962). To a large extent, underinvestment in R&D occurs because the social benefits from new technologies are difficult to appropriate by the private firms bearing the costs of their discovery, and because imperfect capital markets may inhibit firms from investing in socially valuable R&D projects (Griliches, 1998; Romer, 1990). Publicly supported R&D ought to be augmenting or complementing private R&D efforts. It would therefore be surprising, and contrary to stated goals, if R&D subsidies were to substitute for private R&D.

Yet, some empirical evidence suggests that some substitution between private and government funded R&D does indeed occur. In the U.S., Wallsten (2000) showed that a subset of publicly traded, young, technological intensive firms, reduced their R&D spending in the years following the award of a Small Business Innovation Research grant, while Busom (2000) finds that in about 30% of the Spanish firms in her sample, public funding fully crowds out privately financed R&D. On the other hand, Klette and Moen (1998) conclude that the R&D subsidies were successfully targeted at firms that have significantly expanded their R&D expenditures, and that there is little tendency for crowding out in their sample of high-technology Norwegian firms.[3]

One way to rationalize the possibility of 'crowding out' is to argue that government bureaucrats are under strong pressure to avoid the appearance of 'wasting' public funds and, therefore, may tend to fund projects with higher success probabilities and with clearly identifiable results, i.e., projects that are likely to have high *private* rates of return. These are projects that could have been financed by the firm either from internal or external funds, suggesting that the R&D subsidies are in fact superfluous and may be crowding out private R&D resources. If, however, the funds released by the subsidy are invested in other R&D projects which, because of liquidity constraints, could not have been undertaken before these funds became available, the subsidy may be accomplishing its stated purpose, albeit in an indirect way.

Another channel through which publicly funded R&D projects may

[2] The terms 'company financed', 'private' and 'own' R&D expenditures are used interchangeably.

[3] In their review of a wide range of empirical studies, David, Hall and Tool (2000) conclude that drawing general conclusions about the effect of R&D subsidies is problematic because results differ considerably among the studies due to variation in samples and in econometric methodologies.

crowd out privately financed R&D is through their effect on the price of inelastically supplied R&D inputs (David and Hall, 2000). Suppose the subsidy does indeed turn an unprofitable project into a profitable one. Then, if the costs of hiring additional R&D personnel are high, the firm may decide to discontinue a previously profitable project. The commitment to undertake the subsidized project may crowd out other non-subsidized projects. This factor may be of importance in Israel because of the serious shortage of scientists and engineers in some high-tech areas.[4]

It is important to realize that from the firm's point of view, the R&D subsidy eases possible liquidity constraints because it is cheaper to apply for a government subsidy than to raise funds in the capital market. Thus, the firm views the R&D subsidy as a substitute source of financing and not necessarily as a stimulating force to do more R&D. Once a subsidy is received, and the firm commits to undertake the subsidized R&D project, the firm can adjust its portfolio of R&D projects, initiating new ones and/or closing old ones. Any analysis of the effect of the subsidy needs to take these changes into account.

As this discussion shows, the crux of the matter for evaluating the effect of the R&D subsidy is to know what the firm would have spent on R&D had it not received the subsidy. This counterfactual information, however, is not available. The estimation method used in this paper essentially attempts to estimate the missing expected counterfactual by the mean outcome of some group of firms.

Using data on Israeli manufacturing firms in the 1990s, we find evidence suggesting that the R&D subsidies granted by the OCS greatly stimulated company financed R&D expenditures for small firms but had a negative effect on the R&D of large firms, although not statistically significant. For the small firms, a subsidy of one New Israeli Shekel (NIS) first displaces private R&D by about 3 NIS, but subsequently increases R&D by about 14 NIS. Thus, overall, the private R&D of small firms increased by about 11 NIS. Because most subsidies go to the large firms, a subsidy of one NIS generates 0.23 additional NIS of company financed R&D on average. This estimate, however, is not significantly different from zero.

One interpretation of these results is that large firms get subsidies for projects that would have been undertaken even in the absence of the subsidy, whereas small firms do not. This differential effect of the subsidy may reflect a higher cost of raising capital by small firms than by large

[4] David and Hall (2000) also identify a set of 'second-order' crowding out effects which are more relevant to government R&D contracts that pursue specific (socially relevant) R&D projects than to R&D subsidies given to private firms to pursue their own, private, research agenda. For example, firms may decrease their own R&D in publicly funded areas because of anticipated lower returns due to the eventual disclosure of the outcomes of publicly funded R&D projects.

firms. The time pattern of the estimated effects also suggests that in the presence of some type of constraint (either capital or skilled labor), the commitment to undertake the subsidized R&D project may result in other R&D projects' being temporarily crowded out.

Section 2 describes the main features of R&D support in Israel and the data analyzed in this paper. Section 3 presents the main conceptual and empirical issues that arise in the estimation of the subsidy effect while Section 4 presents the empirical results. Conclusions close the paper.

II. R&D SUPPORT IN ISRAEL

II(i). *OCS Programs*

The Israeli government funnels its support of R&D projects through several channels. The most important source is the R&D grants given by the Office of the Chief Scientist (OCS) at the Ministry of Industry and Trade as mandated by the *Law for the Encouragement of Industrial Research and Development* of 1984.[5]

The main program administered by the OCS is the support of standard R&D projects. Qualifying firms submit grant applications for specific R&D projects. The OCS reviews the application and approves it if the project satisfies some specified criteria based on technological and commercial feasibility. About 70% of the applications are approved (Trajtenberg, 2002). In fact, the OCS is mandated by law to subsidize *all* eligible proposals; there is no ranking of the proposals. Moreover, the principle of 'neutrality' precludes the OCS from selecting projects according to technological field or any other such considerations.

If approved, the firm receives a grant from the OCS equal to a percentage of the estimated (and approved) project-specific R&D expenditure. This percentage varies between 30% and 66% depending on the circumstances. If the goal of the R&D project is to create a new project or industrial process or to make significant improvements in existing ones, the grant is 50% of the approved R&D expenditures. If it is just to improve an existing product, the grant is 30%. Exceptions to this rule are start-up companies which receive 66% of the approved R&D expenditure (up to $250,000 per year) during the initial two years, and firms in 'preferred' development areas receiving 60% of the approved R&D budget. The vast majority of the projects are supported at 50%: essentially, firms match the R&D subsidy dollar-by-dollar.

When a government-assisted R&D project results in a commercially successful product, the developers are obliged to pay royalties. The

[5] The purpose of the law is 'to encourage and support industrial R&D in order to enhance the development of local-based industry . . ., to improve Israel's balance of trade . . ., and to create employment opportunities in industry . . .'.

royalties are a percentage of the revenues derived from the project going from 3% during the first three years to 4–5% in later years. In any case, the royalties shall not exceed the amount of the grant plus interest. Thus, the grant or subsidy is, in fact, a loan to be paid back only if the project generates enough sales.

The OCS uses the proceeds of the royalties to fund future R&D projects. The share of royalties received out of total grants has been increasing very rapidly from about 10% in 1990 to 16% in 1995 and 32% in 1999, and is therefore becoming a very important element in the OCS annual budget for R&D support (Trajtenberg, 2002).

In addition to the 'standard' R&D grant, the OCS also gives grants for the execution of detailed feasibility studies regarding the marketing potential of R&D projects and funds the formation of business plans for start-up and young companies based upon the conclusions of the feasibility studies. Grants are also given to assist in the creation of beta-sites, mostly overseas, to test the new product in 'real life' situations. The OCS also implements bi-national programs supporting joint projects between companies or individual researchers.

A further two channels used by the government to fund R&D activities via the OCS is through the Magnet Program which supports the establishment of R&D consortia to carry out research in generic pre-competitive technologies, and through the establishment of technological incubators that enable novice entrepreneurs with innovative concepts to translate their ideas into commercial products. Starting in 1992, the government also proved instrumental in developing venture capital funds that play an increasingly pivotal role in the evolution of the high-tech industry in Israel.

The value of grants administered by the OCS in all its programs was 120 (current) million dollars in 1988; it increased steeply up to the mid 1990's and then leveled off at about 350–400 (current) million dollars per year. The number of firms applying for subsidies per year varied between 450 and 780 during 1990–1999, and over 6,600 projects have been approved since 1995.[6]

II(ii). *Description of the Data*

The data used in this paper are a subset of the data analyzed in Griliches and Regev (2001). The dataset is restricted to manufacturing firms doing R&D. More specifically, these are firms appearing at some point in the Surveys of Research and Development in Manufacturing conducted by the Central Bureau of Statistics during the period 1990–1995.[7] It includes

[6] See Trajtenberg (2002) for a detailed analysis of the OCS.

[7] Note that software and Internet firms are not included in the Israeli manufacturing sector.

TABLE I
AGGREGATE R&D EXPENDITURES AND SUBSIDIES IN MANUFACTURING

Year	Company R&D (1)	Subsidies (2)	Subsidy ratio $(3)=\frac{(2)}{(1)+(2)}$
1990	739.4	188.4	0.20
1991	776.7	206.1	0.21
1992	867.1	198.8	0.19
1993	1029.5	246.1	0.19
1994	1039.2	288.3	0.22
1995	1048.2	281.5	0.21

Figures in millions of 1990 NIS aggregated from firm-level data using sampling weights. The U.S. dollar-NIS exchange rate averaged 2.21 NIS per dollar during 1990.

firm-level data on sales, exports, employment, total R&D expenditures, R&D subsidies, and other characteristics on approximately 180–190 R&D-active firms per year.

The data on R&D subsidies are the data obtained directly from the Survey of Research and Development questionnaire. The survey breaks down the external sources of R&D support into three categories: (1) grants from the OCS at the Ministry of Industry and Trade, (2) financing from the bi-national Israel-American Fund, and (3) financing from other government sources. We consider all three sources together and label them 'R&D subsidies'. As mentioned in the introduction, the OCS subsidy program is the largest form of subsidization. During the sample period, grants from the OCS accounted for about 87% of all government support.

It is important to realize that the R&D expenditures and R&D subsidy data are at the firm level and may involve one or more projects. Moreover, there is no information in our dataset on firms that applied for subsidies and were denied. These firms cannot be distinguished from those that do not apply for subsidies.[8]

In Table I, we observe that company financed R&D expenditures increased in every year throughout the 1990–95 period, even though most of this increase occurred between 1992 and 1993. Their annual rate of growth was 7.2%. This pace was matched, on average, by the growth in R&D subsidies at 8.4% at an annual rate. As a result, the ratio of R&D subsidies to total R&D expenditures remained stable at about 20%.

The subsidy ratio in Table I does not differentiate among firms receiving and not receiving subsidies. The number of firms with positive R&D in the sample hovers around 165–195 per year and about 60% of them receive some kind of subsidy (Table II).

[8] The OCS database contains project level information and a list of denied applicants. These data have yet to be matched to the R&D surveys.

TABLE II
R&D PERFORMERS

Year	No. of firms doing R&D	% of firms receiving subsidy	Mean $\frac{\text{subsidy}}{\text{Total R\&D}}$ ratio for firms with subsidy > 0	Mean $\frac{\text{subsidy}}{\text{Private R\&D}}$ ratio
1990	183	59.6	0.31	0.58
1991	194	56.2	0.31	0.63
1992	184	63.0	0.28	0.46
1993	189	59.3	0.27	0.48
1994	185	57.8	0.27	0.57
1995	163	60.1	0.26	0.48
All years	1098	59.3	0.28	0.53

Among the supported firms, the mean subsidy ratio is about 30% in the first years of the sample but appears to be declining over time.[9] Median subsidy ratios (not shown) are almost identical to the mean ratios. Subsidized R&D represented, on average, 63% of company financed R&D in 1991, and was down to 48% in 1995. Thus, R&D subsidies constitute a significant portion of the R&D effort of manufacturing firms. Evidently, subsidies are not a marginal source of funding.

Most of the R&D activity in the manufacturing sector is undertaken by subsidized firms, highlighting the role of the OCS in the development of the Israeli high-tech sector.[10] Non-subsidized firms—about 40% of all R&D firms—account for only 10–15% of total R&D expenditures. Ninety-five per cent of all R&D is performed by firms in the electronics and chemical industries. It is therefore not surprising that essentially all R&D grants in the manufacturing sector are received by firms in these two industries.

The data reveal that subsidized firms are larger than non-subsidized firms. They spend, on average, about 5.5–8.5 millions of 1990 NIS in R&D, and employ around 400 employees.[11] Non-subsidized firms, on the other hand, spend considerably less in R&D—1.5–2.0 millions of 1990 NIS—and employ about half the number of workers of their subsidized counterparts. The differences persist, although less significantly, after controlling for firm size. Although suggestive, these differences are likely to be biased estimates of the subsidy effect because they do not account for the endogeneity of the R&D subsidy (see Section 3).

One of the distinguishing features of the R&D program in Israel is that the distribution of subsidies is highly skewed among R&D performers. Indeed, the largest 25% of the firms receive about 70–80% of all subsidies.

[9] Small firms (up to 100 employees) have mean subsidy ratios between 30 and 35%, while the mean ratio for larger firms (above 300 employees) is 25%.

[10] The following description of the data is based on tables appearing in the working paper version of this paper (Lach, 2000).

[11] The U.S. dollar-NIS exchange rate averaged 2.21 NIS per dollar during 1990.

On the other hand, small firms—employing less than 100 workers—receive at most 12% of all R&D subsidies, even though they represent about half the firms doing R&D. This suggests that the performance of the R&D subsidy program as a whole may be tied to the fortunes of the largest firms. It is, therefore, of interest to allow for a differential effect of R&D subsidies by firm size.

In short, about 60% of the R&D performers receive some kind of subsidy, which on average represents 30% of the firm's total R&D expenditures and, therefore, constitutes a significant source of funding for R&D projects. Subsidized firms are on average larger (in terms of employment and R&D size) and more R&D intensive than non-subsidized firms, and almost all subsidized firms belong to the electronics and chemical industries. Most of the R&D activity in the manufacturing sector is conducted by firms receiving some R&D subsidy, but the distribution of subsidies is highly skewed towards the largest firms.

III. THE R&D SUBSIDY EFFECT

As stated in the introduction, this paper examines the effect of R&D subsidies on the level of company financed R&D expenditures. Specifically, we ask whether receiving a subsidy stimulates or crowds out private R&D expenditures. We will deal first with some conceptual issues arising in the analysis of the effects of the R&D subsidy and them move on to the problems that arise in trying to measure and estimate these effects.

III(i). *Conceptual Issues*

A subsidy may stimulate private R&D expenditures for several reasons. The first one is, naturally, related to the 'matching' feature of the R&D subsidy program. Other things equal, this requirement should lead to an increase in private R&D expenditures by the subsidized firms. This is probably the rationale behind the subsidy scheme in Israel. Second, an R&D subsidy to a particular project may turn other potential R&D projects into profitable investments. This may happen when the subsidized project involves setting up or upgrading research facilities, lowering the fixed costs of other current (and future) R&D projects. Finally, there may also be a spillover of learning and know-how gained in the subsidized project to other current (and future) R&D projects, increasing their prospects of success and thereby their profitability. Thus, the spillover and 'cost-sharing' effects of the subsidy, in addition to the built-in matching incentives, should encourage further company financed R&D expenditures.

Sometimes, however, things can go *wrong*. If the firm would have undertaken a particular subsidized R&D project (at the same level of activity) even if the subsidy had not been granted, then the subsidy is superfluous from the granting agency's point of view. The subsidy would be fully crowding out private R&D expenditures. Thus, the matching features of the subsidy program would indeed guarantee an increase in company financed R&D only if the approved projects are those that would *not* have been undertaken without the subsidy. This vital piece of information is, of course, usually unknown to the granting agency (the OCS in Israel).

The reasoning above is based upon the implicit assumption that the firm does not readjust its portfolio of R&D projects after receiving a subsidy, i.e., that *other things are equal*. This is an overly strong and unrealistic assumption. For example, even when the subsidy is superfluous, the private funds released by the subsidy *could* be used in their totality to fund other R&D projects leaving private R&D expenditures unchanged. Moreover, suppose that receiving a subsidy carries some signal value which lowers the cost of new funds. Then the firm may start new projects or accelerate existing ones and thereby increase privately financed R&D expenditures. This may occur even if the subsidy to a particular project is superfluous.

On the other hand, private R&D expenditures may decrease even when the subsidized project would not have been undertaken without the subsidy. Suppose that the firm lacks enough skilled R&D workers or faces some liquidity constraints that make it very costly to implement the non-subsidized projects along with the subsidized project to which it is committed. The firm may find it profitable to discontinue some of the non-subsidized projects thereby contributing to a reduction in company financed R&D expenditures.

Thus, firms may react differently to the R&D subsidy depending, essentially, on their R&D portfolio and budget constraints. Theory alone cannot answer the question posed at the beginning of this section. Whether R&D subsidies stimulate or crowd out private R&D expenditures is, therefore, an empirical matter.[12]

[12] Note also that we restricted ourselves to the effect of the subsidy on the firm's own R&D expenditures. Subsidies may also carry implications towards other non-R&D activities, both contemporaneously and over time, and, through interfirm spillovers or rivalry channels, subsidies may have effects on other firms' R&D activities. These, however, are all *indirect* effects which are not the main goal of the R&D subsidy program (except for its effects on employment). If the *direct* effects on the subsidized R&D project are negative or not significant, the economic justification for continuing with the subsidy program in its present form is considerably undermined even if the indirect effects are quantitatively more important than the direct effects. There are more effective ways of generating the indirect effects than through R&D subsidies.

III(ii) *Measurement Issues*

For illustration purposes, we focus on the effect of receiving a subsidy on company financed R&D expenditures. In the empirical work, however, we also analyze the effect of the level of the subsidy on R&D. Let $D_{it} = 1$ represent the event of firm i receiving a subsidy in period t and let y_{it} denote the log of company financed R&D expenditures.[13] Let y_{it}^1 and y_{it}^0 be the log of company financed R&D expenditures when the firm received an did *not* receive a subsidy, respectively. Note that, for a given firm i, we either observe y_{it}^1 or y_{it}^0, but not both variables at the same time.

Suppose subsidies are received at time t and we wish to estimate their immediate impact on R&D expenditures. The 'gain' in company financed R&D expenditures from receiving a subsidy is $\Delta_{it} \equiv y_{it}^1 - y_{it}^0$. We would like to know Δ_{it} for each subsidized firm i because it measures the percentage difference between the observed R&D expenditure and the outlay that the firm would have incurred had it *not* received a subsidy—the 'what if' or counterfactual outcome. Of course, Δ_{it} cannot be computed because data on the counterfactual y_{it}^0 is missing for the subsidized firms.

We can, however, define an *average* effect and attempt to estimate its components. Let $E(y_{it}^1|D_{it} = 1, D_{it-1} = 0)$ be the average or expected R&D expenditures among firms that received a subsidy in period t but did not receive a subsidy in the previous period $t-1$. Similarly, let $E(y_{it}^0|D_{it} = 1, D_{it-1} = 0)$ be the expected R&D expenditures that would have been incurred by these same firms had they *not* received a subsidy at t. Then,

$$\begin{aligned} \text{(1)} \qquad \alpha &\equiv E(y_{it}^1 - y_{it}^0|D_{it} = 1, D_{it-1} = 0) \\ &= E(\Delta_{it}|D_{it} = 1, D_{it-1} = 0) \end{aligned}$$

The parameter α measures the average percentage change in company financed R&D expenditures between what was actually observed among firms that received a subsidy at time t and what these firms would have spent had the subsidy *not* been received.[14]

When $\alpha > 0$ the subsidy stimulates average company financed R&D. Using firm-level data, instead of project-level data, does not allow us to identify the precise mechanisms through which private R&D changes. As mentioned in Section 3.1, the increase in y may well be the result of the launching of new projects that would not have been undertaken without

[13] A drawback of using the binary indicator variable D to estimate the subsidy effect is that it does not reflect the size of the R&D subsidy. The use of logs is motivated, in part, by this scale problem. We will address this issue when analyzing the effect of the level of the subsidy instead of the effect of D.

[14] These expectations can be defined conditional on firms' characteristics (e.g., industry affiliation, size, technological area, etc.). The subsidy effect may, therefore, vary with these characteristics. This average subsidy effect is known in the evaluation literature as the 'effect of treatment on the treated'.

the subsidy, but it can also result from the use of the funds released by the receipt of the subsidy to fund a larger project that could not have been implemented before the subsidy funds became available.

When $\alpha = 0$, the subsidy does not, on average, displace nor stimulate private R&D expenditures. The firm adjusts its portfolio of R&D projects to accommodate the subsidized project which it is committed to perform. The trade-off between the subsidized and non-subsidized projects balances-off on average.

On the other hand, $\alpha < 0$ means that the subsidy is displacing—crowding out—private R&D effort. This can happen when, for example, some of the released resources from subsidizing a superfluous project are invested in non-R&D activities such as marketing, production, etc. A negative α may also occur when the subsidized project purely crowds out other non-subsidized projects due, for example, to the very steep costs of hiring new R&D personnel.

In short, the sign of α gives us information on the qualitative aspect of the relationship between subsidies and private R&D.[15]

Another possibility for assessing the effect of the R&D subsidy is to look at the performance of firms *after* the subsidy has been discontinued. That is, we could have compared the R&D expenditures of a firm without a subsidy to the expenditures the firm would have incurred had the subsidy been continued, $E(y_{it}^0 - y_{it}^1 | D_{it} = 0, D_{it-1} = 1)$. Doing this, however, is uninformative regarding the effectiveness of the subsidy program. To see this, assume that the flow of R&D subsidies stops because the project is completed. Then the effect being estimated is the effect of the outcome of the R&D project, and not the effect of the subsidy itself. Knowledge of what a firm would have done were the subsidy to be continued tells us nothing on whether the subsidized project would have been undertaken in the first place in the absence of the subsidy.

III(iii). *Estimation Issues*

The estimation problem is that data on firms receiving support identify $E(y_{it}^1 | D_{it} = 1, D_{it-1} = 0)$ but cannot identify the counterfactual $E(y_{it}^0 | D_{it} = 1, D_{it-1} = 0)$. The estimator of the parameter α essentially attempts to estimate the expected counterfactual by averaging the R&D expenditures of some group of firms.

We illustrate this basic estimation problem by analyzing the most naive estimator of α. Suppose we use the mean R&D expenditures of the non-supported firms, $E(y_{it}^0 | D_{it} = 0, D_{it-1} = 0)$, as an estimator of the counter-

[15] Note that when $\alpha = 0$, *total* R&D expenditures (private plus subsidized) increase by the size of the subsidy, whereas when $\alpha > 0$ ($\alpha < 0$) total R&D expenditures increase by more (less) than the subsidy.

factual $E(y_t^0|D_t = 1, D_{t-1} = 0)$. We then estimate α by the sample analogue of (1),

$$\hat{\alpha}_t^D = y_{.t}^{01} - y_{.t}^{00} \tag{2}$$

where the means are taken over the two groups of firms defined by the subsidy status in period t, conditional on *not* having received a subsidy at $t-1$.[16]

The estimator $\hat{\alpha}_t^D$ is the *simple difference* in mean own R&D expenditures by support status. Of course, this estimator is unbiased as long as the estimator of the counterfactual is unbiased. This occurs when y_{it}^0 is mean independent of D_{it}, conditional on $D_{it-1} = 0$,

$$E(y_{it}^0|D_{it} = 1, D_{it-1} = 0) = E(y_{it}^0|D_{it} = 0, D_{it-1} = 0) \tag{3}$$

i.e., there are no systematic differences in R&D expenditures between subsidized and non-subsidized firms.

As observed in Section 2, however, the two groups of subsidized and non-subsidized firms differ in many aspects (e.g., in size and industry affiliation) that are most likely to affect both the level of R&D expenditures directly and the probability of receiving a subsidy. Thus, the difference in mean R&D by support status is not only capturing the causal effect of the subsidy but also part of the effect of the excluded determinants of R&D and D.

For example, if R&D subsidies are biased towards firms in electronics, and in this area R&D expenditures are much larger than in other research fields then the bias term would be positive and the simple difference in means by support status overestimates the casual effect of the R&D subsidy. In the same vein, suppose that liquidity-constrained firms are more likely to apply for—and to receive—an R&D subsidy *and* to tighten their R&D expenditures. Then we would expect the bias term to be negative and the simple difference in means by subsidy status will underestimate the causal effect of the R&D subsidy. In these examples, the independence assumption of R&D expenditures and subsidy support status cannot be sustained. The correlation between subsidies and R&D is not causal; it is due to a third factor affecting both decisions. Therefore, assumption (3) is overly strong and is bound to fail in the data.

The above examples suggest that if one could 'control' or 'account' for the firm's industry, or for the firm's cash-flow, the simple difference in mean R&D expenditures by support status would be an unbiased estimator of α. Indeed, if controlling for firms' characteristics through the use of appropriate covariates eliminates all the differences in potential own R&D expenditures among supported and non-supported firms then the

[16] The superscripts denotes the subsidy status in period $t-1$ and t, respectively.

missing counterfactual can be consistently estimated by the mean R&D expenditures of the non-subsidized firms. This is the 'selection on observables' assumption whereby selection into the R&D subsidy program is based on a set of observable variables that are controlled for. This approach is implemented by essentially computing (2) at each value of the covariates.

In general, however, we do not have data on all the relevant covariates. In particular, there are *unobservable* characteristics that cannot be controlled for which may lead to the failure of the 'selection on observables' assumption. For example, the technological state of the firm is likely to affect R&D expenditures and may also affect the probability of receiving an R&D subsidy. In order to overcome this identification problem inherent in non-experimental data, we need to impose restrictions on the process generating the data.

A first restriction is to assume linearity of the conditional expectation function $E(y|x, D)$, where x is a vector of covariates and D is the subsidy indicator. A second restriction is to assume that the unobserved characteristics can be decomposed into a firm-specific and time-specific effect. This leads to an error-component specification. These assumptions imply that we can write,

$$y_{it} = x_{it}'\beta + \alpha D_{it} + \theta_i + \lambda_t + \eta_{it} \tag{4}$$

where x_{it} is a vector of covariates, θ_i is the firm-specific effect, λ_t is a time-specific component common to all firms, and η_{it} is an *i.i.d.* zero mean random variable assumed to be mean independent of x_{it}.

Under certain conditions, it can be shown that the coefficient of D in (4) is indeed equal to the parameter defined in (1).[17] Taking first differences of model (4) removes firm-specific effects and, conditioning on not having received a subsidy at $t-1$, i.e., on $D_{it-1} = 0$, implies that the expected difference between the *growth rates* of subsidized and non-subsidized firms is

$$\begin{aligned} &E(\Delta y_{it}|\Delta x_{it}, D_{it} = 1, D_{it-1} = 0) - E(\Delta y_{it}|\Delta x_{it}, D_{it} = 0, D_{it-1} = 0) \\ &\quad = \alpha + E(\Delta\eta_{it}|\Delta x, D_{it} = 1, D_{it-1} = 0) - E(\Delta\eta_{it}|\Delta x, D_{it} = 0, D_{it-1} = 0) \end{aligned} \tag{5}$$

It is clear now that, conditional on Δx_{it} and on $D_{it-1} = 0$, α is identified provided $\Delta\eta_{it}$ is mean independent of D_{it},

$$E(\Delta\eta_{it}|\Delta x_{it}, D_{it} = 1, D_{it-1} = 0) = E(\Delta\eta_{it}|\Delta x_{it}, D_{it} = 0, D_{it-1} = 0) \tag{6}$$

This condition is implied by the requirement that η_{it} and η_{it-1} be mean independent of D_{it} (conditional on Δx and on $D_{it-1} = 0$). The *difference-in-difference* (DID) estimator of α is the sample version of (5).

[17] See the appendix to the working paper version of this paper in Lach (2000).

The contrast between assumptions (3) and (6) is that the latter allows for firm-specific unobserved effects θ_i (e.g., unobserved managerial skills or time-invariant efficiency levels) and economy-wide shocks λ_t to affect both the level of company financed R&D expenditures and the support status of the firm. We can do this because the additivity assumption in (4) implies that 'same-firm' differences eliminate the firm-effects terms while 'same-period' differences eliminate the time effects from the bias. In other words, the panel features of the data and the error component assumption permit us to relax the 'selection on observables' assumption to allow for correlation between (time-invariant) firm-specific and time-specific effects and the subsidy dummy variable D.

This issue is closely related to the bias in the estimation of α attributed to the self-selection of firms into the application process of the R&D subsidy program (Busom, 2000). Not all firms apply for a subsidy. Firms decide to apply for a subsidy on the basis of their expected profitability of applying relative to not applying. Because grants are repaid only if success is achieved, it is possible that firms working in riskier R&D areas will be more likely to apply for subsidies. For this and other reasons, firms receiving an R&D subsidy may not constitute a random sample of firms from the population of R&D doers. Because the characteristics that make a firm a recipient of an R&D subsidy are likely to be correlated with the determinants of own R&D effort, we need to control for this potential source of correlation.

DID with covariates goes some ways towards solving this problem. First, it accounts for common observed covariates affecting the decisions to apply for a subsidy, to be granted one, and to do R&D. Second, it also takes account of permanent (time-invariant) differences between successful and unsuccessful applicants, and non-applicants. Thus, if one believes that part of the self-selection mechanism works through the observed covariates (e.g., industry, size) and that, given these covariates, what determines whether or not a firm is granted a subsidy are firm characteristics that stay more or less constant during the sample period (such as the degree of risk in the R&D area in which the firm is involved), then the DID estimator is an acceptable estimation procedure.

The *DID* approach handles the problem caused by the notion that more 'successful' firms may be receiving more R&D subsidies and doing more R&D. If the 'success' profile of the firm is more or less constant during the sample period then it differences-out in the *DID* estimator. *DID* fails, however, when receiving an R&D subsidy is associated with the unexpected development of a particularly good idea which also leads to more R&D expenditures. In this case, the *DID* estimator is likely to be upward biased. In general *DID* does not control for idiosyncratic factors affecting simultaneously the level of R&D expenditures and the probability of receiving a subsidy, i.e., when D_{it} is correlated with η_{it}.

Some of the features of the subsidy program, however, suggest that selection bias may not be a very serious problem in the Israeli context. First, the OCS is mandated by law to subsidize *all* eligible proposals. Second, what makes a proposed project 'eligible' is to satisfy a set of basic technological and commercial feasibility criteria. In particular, the selection procedure at the OCS is non-competitive, i.e., there is no ranking of the proposals. All in all, about 70% of all applications are approved (Trajtenberg, 2002).[18]

IV. EMPIRICAL RESULTS

The *DID* estimator equals the difference between the mean R&D change between $t-1$ and t among the supported and non-supported firms, conditional on x and on not having received a subsidy at $t-1$. A convenient way to control for different values of x, is to estimate α from (4) in two consecutive years using panel data estimation methods. Specifically, we need data for two periods, a 'pre-treatment' period and a 'post-treatment' period. A fixed-effects estimator of (4) generates consistent estimators of α and β provided the identifying assumptions hold.

To improve the precision of the estimator, we pool the data over the 6 years of data in the sample using only observations for which $D_{it-1}=0$. For example, for the year 1991 we use data on firms not receiving a subsidy in 1990, for the year 1992 we select firms that did not receive a subsidy in 1991, and so on. There are 325 such observations over the years 1991–1995 whereas the original sample has 1,098 firm-year observations (see Table II). These observations correspond to 136 firms. 183 of the 325 observations belong to 67 firms that never received a subsidy during the five years 1991–95. Similarly, 8 observations belong to 8 firms receiving a subsidy every year during 1991–95 (but not in 1990).[19] Thus, about half the firms in this sample received a subsidy at least once. Because this is the sample upon which our estimates are based, Table III presents statistics on the main variables of interest.

Firms spent on average about 2 million NIS with the larger firms—firms with more than 300 employees—spending about 5 times as much as the smaller firms. The average level of R&D subsidies is only 31,000 NIS for

[18] We only observe recipient and non-recipient firms in the data. A recipient firm is one that applied and was accepted to the subsidy program, the non-recipient firm may have applied for a subsidy and been denied or may not have applied at all. The data at hand do not allow us to distinguish between denied applicants and non-applicants. See also footnote 8.

[19] The remaining 134 observations are distributed as follows: 46 belong to 16 firms receiving a subsidy only once, 45 belong to 17 firms receiving a subsidy two times, 25 belong to 15 firms receiving a subsidy three times, and 18 belong to 13 firms receiving a subsidy four times during 1990–95.

TABLE III
SAMPLE WITH $D_{it-1} = 0$

	All Firms		Small Firms		Large Firms	
Variable	Nobs	Mean (St.D.)	Nobs	Mean (St.D.)	Nobs	Mean (St.D.)
Own R&D expenditures	325	2071.2 (3600.5)	272	1230.2 (4234.4)	53	6386.8 (11670.1)
R&D Subsidies	325	62.7 (585.2)	272	31.4 (139.6)	53	223.6 (1414.4)
Employment	325	187.1 (273.0)	272	87.7 (72.4)	53	697.1 (347.0)
Sales	322	545.1 (976.5)	270	209.3 (245.0)	52	2288.4 (1410.6)

R&D expenditures and subsidies in thousands of 1990 NIS, sales in million of 1990 NIS.
The U.S. dollar-NIS exchange rate averaged 2.21 NIS per dollar during 1990.
Small (large) firms have less (more) than 300 employees.

the smaller firms but jumps to 223,000 NIS for the larger firms. The high standard deviations point to the large variations across firms in these two variables.

Table IV presents the first set of estimates on α based on model (4) using employment and sales to control for the effect on R&D of observable firm characteristics that may be correlated with the probability of receiving an R&D subsidy. Industry affiliation and other constant-over-time variables drop out in the estimation. The size variables—employment and sales—may capture some of the effect of liquidity constraints.[20]

In columns (1)–(3), the subsidy effect comes in negative and of considerable size—about -16%—but statistically not significantly different from zero at conventional significance levels. The subsidy does not appear to have any effect on private R&D expenditures.[21]

Not surprisingly, larger firms spend more on R&D expenditures but the size elasticity of R&D is well below unity implying that company financed R&D by employee decrease with the size of the firm. To test whether there is a difference in the subsidy response of large and small firms, a term interacting the subsidy and a 'large firm' dummy for firms with more than 300 employees—was added to the regression. The estimated coefficient of this interaction term (not shown) was -0.099 but not significantly different from zero. Splitting the sample into small and large firms (columns (4) and (5)) does not alter the picture much: the estimated subsidy effects are negative but very imprecisely estimated. Nevertheless, the estimated α is much more negative for the larger firms.

[20] Klette and Moen (1997) relate optimal R&D expenditures to expected profitability (proxied by sales) and subsidies. Because employment and sales are highly collinear usually only one of the regressors comes in positive and significant.

[21] The year-to-year estimates of equation (4) appear in Table 9 of the working paper version of this paper (Lach, 2000). Although, there is much variation across the years in the estimates, these are qualitatively the same as those in the pooled sample.

TABLE IV
POOLED DID ESTIMATES-SUBSIDY DUMMY
$\log R\&D_{it} = x'_{it}\beta + \alpha D_{it} + \theta_i + \lambda_t + \eta_{it}$
Sample includes only observations for which $D_{it-1} = 0$

	(1)	(2)	(3)	(4) Small firms	(5) Large firms
D	−0.162 (.156)	−0.165 (.156)	−0.142 (.156)	−0.158 (.162)	−0.236 (.557)
Log(Employment)	—	0.172 (.194)	0.160 (.203)	−0.200 (.227)	1.413** (.831)
Log(Sales)	—	—	0.232 (.158)	0.261 (.166)	0.306 (.783)
Within R^2	0.036	0.040	0.051	0.051	0.203
Nobs	325	325	320	269	51

Standard errors in parentheses. Year and firm dummies included.
A *(**) indicates different from 0 at 5(10)% significance level.

Note that the 'within' R^2—where firm variables are taken in deviation from their time mean—are about 4–5% indicating that most of the within-firm variation in own R&D expenditures is largely unrelated to changes over time in scale (except maybe for the large firms) or to the receipt of R&D subsidies.[22]

Partly because of the disappointing fit of this simple model and partly because we want to exploit the availability of complete data on the subsidies we now expand the basic framework to account for the level of the subsidy received.

As in Wallsten (2000), we use the levels of R&D expenditures and of the R&D subsidy, and not their natural logarithms, to capture the hypothesized 'one-to-one' additionality relationship between them. We will omit the sales variable from the regression because it is highly correlated with employment (their simple correlation coefficient in the sample used is 0.91). Table V presents these results.

Note first that the fit of the model is very much improved. More importantly, the estimates now reveal that for every subsidized NIS received, the firm reduces its own expenditures on R&D by about 2.5 NIS, on average. This is a large and significant displacement effect. The effect is more precisely estimated for the smaller firms (at about 3 NIS of private R&D displaced per subsidized NIS) than for the larger firms whose estimated displacement effect, even though numerically larger, is not significantly different from zero.

This large negative effect may reflect the fact that once the subsidy is received the firm is committed to implement the subsidized project. In an economic environment characterized by serious skilled R&D labor shortages, as was typical in Israel during the sample period, this commitment may lead firms to temporarily scale down other non-subsidized R&D projects. The estimates suggest that this disinvestment

[22] The standard R^2's (not shown) were in the order of 90%.

TABLE V
POOLED ESTIMATES-SUBSIDY LEVEL
$R\&D_{it} = x'_{it}\beta + \alpha(subsidy_{it}) + \theta_i + \lambda_t + \eta_{it}$
Sample includes only observations for which $D_{it-1} = 0$

	(1)	(2)	(3) Small firms	(4) Large firms
Subsidy	−2.678* (1.268)	−2.586* (1.162)	−2.930* (.625)	−4.591 (8.002)
Employment	—	17.573* (2.921)	24.209* (6.073)	14.117 (9.681)
Within R^2	0.039	0.198	0.228	0.144
Nobs	325	325	272	53

Standard errors in parentheses. Year and firm dummies included.
A *(**) indicates different from 0 at 5(10)% significance level.

was large enough for private R&D expenditures to decrease considerably after the subsidized project was started.

This interpretation of the large negative subsidy effect would be more credible if the crowding out effect is indeed temporary. Indeed, as suggested in Section 3.1, the effect of the subsidy may be spread over several periods. This suggests that lags of the subsidy should be added to the regression in order to capture the full effect of the subsidies on private R&D.[23] Table VI adds one lag of the subsidy indicator to the regression.[24]

The results change dramatically. For the smaller firms, a one NIS subsidy does indeed displace private R&D expenditures by about 3.0 NIS but this substitution is completely reversed later on. A year after receiving the subsidy, own R&D expenditures increase on average by 13.5 NIS. These two estimates are quite precisely estimated. Adding both estimates we get a strong and significant stimulating effect of the R&D subsidies of 10.8 NIS. For the larger firms, the immediate displacing effect is larger than the subsequent stimulus but neither both effects, nor their sum (−3.29) is significantly different from zero.[25,26]

These estimates reinforce the interpretation advanced after Table V, namely, that upon receiving an R&D subsidy, a small firm scales down other R&D projects during the first year of the project in order to focus on

[23] Moreover, usually (subsidized) R&D projects are conducted over a number of years and the grant money is transferred to the firm accordingly.

[24] This requires selecting a sample where firms did not receive a subsidy at $t-2$, i.e., $D_{it-2} = 0$. That is, for the year 1992 we use firms that did not receive a subsidy in 1990, and so on. A second lag was not significant and generated essentially the same contemporaneous and one-lag estimates of the subsidy effect presented in Table VI.

[25] The standard deviation of the sum of the effects in the small firms sample is 3.87 and in the large firms sample is 5.28.

[26] Because the sample is changed we rerun the regressions in Table V using the same sample used in Table VI: the estimates of α are essentially unchanged. The estimates of the subsidy effect corresponding to the specifications in columns (1) to (4) in Table V are −2.33 (1.02), −2.29 (0.99), −2.55 (0.91) and −4.70 (4.00), respectively.

TABLE VI
POOLED ESTIMATES-SUBSIDY LEVEL
$R\&D_{it} = x'_{it}\beta + \alpha_0(subsidy_{it}) + \alpha_1(subsidy_{it-1}) + \theta_i + \lambda_t + \eta_{it}$
Sample includes only observations for which $D_{it-2} = 0$

	(1)	(2)	(3) Small firm	(4) Large firms
Subsidy	−2.832* (1.091)	−2.779* (1.063)	−2.832* (.879)	−6.702 (6.278)
$Subsidy_{-1}$	4.293 (2.916)	4.319 (2.841)	13.640* (3.848)	3.409 (8.089)
Employment	—	8.381* (3.281)	18.846** (10.293)	19.405** (9.824)
Within R^2	0.104	0.158	0.262	0.324
Nobs	208	208	169	39

Standard errors in parentheses. Year and firm dummies included.
A *(**) indicates different from 0 at 5(10)% significance level.

the subsidized project. This effect, however, is merely temporary and, for the smaller firms, the level of private R&D expenditures is significantly increased by a factor of 11 from what it would have been in the absence of the subsidy. No statistically significant effect can be discerned for the larger firms.

Taking into account that about 75% of the subsidies given by the OCS go to large firms, the average effect of a subsidized NIS is to increase own R&D expenditures by 0.23 NIS ($10.8 \times \frac{1}{4} - 3.29 \times \frac{3}{4}$). Total R&D expenditures increase, of course, by 1.23 NIS. This is not a large effect. Moreover, it is not significantly different from zero because of the very imprecise estimated effect for the large firms.[27] Taken at face value, these estimates suggest that in order to increase private R&D activity, the subsidy funds should be redirected to the small firms.

V. CONCLUSIONS

This paper analyzes the effects of R&D subsidies on company financed R&D using data on Israeli manufacturing firms during 1990–1995. The R&D subsidy effect is defined as the average change in company financed R&D expenditures between what was actually observed among firms that received a subsidy and what these firms would have spent had the subsidy not been received.

We posit a variety of channels through which the subsidy operates. Some of these channels affect private R&D positively and some affect it negatively. The paper focuses on estimating the net effect of the subsidy on private R&D; the distribution of these effects through the different channels is left for future research.

The empirical approach uses a DID-type estimator to estimate the effect

[27] Its standard deviation is 6.5 assuming zero covariance between the estimates in the two sub-samples.

of receiving an R&D subsidy and of its level on company financed R&D expenditures. We find evidence suggesting that the R&D subsidies granted by the OCS greatly stimulated company financed R&D expenditures for small firms but had a negative effect on the R&D of large firms, although the latter is not statistically significant. For the small firms, a subsidy of one NIS increases their R&D by about 11 NIS. These estimates suggest that subsidy funds should be diverted towards the small firms. Currently, because most subsidies go to the large firms, a subsidy of one NIS generates, on average, a statistically insignificant 0.23 additional NIS of company financed R&D. The estimates suggest that private R&D activity could be increased by shifting subsidy funds to small firms.

One interpretation of these results is that large firms get subsidies for projects that would have been undertaken even in the absence of the subsidy, whereas small firms use the subsidies to fund projects that would not have been undertaken without them. This differential effect of the subsidy may reflect a higher cots of raising capital by small firms than by large firms. The time pattern of the estimated effects also suggests that in the presence of some type of constraint (either capital or skilled labor), the commitment to undertake the subsidized R&D project may result in other R&D projects being temporarily crowded out.

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