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Business R&D and the Interplay of R&D Subsidies and Market Uncertainty

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Non-technical Summary

The literature suggests that public research and development (R&D) subsidies may reduce market failures affecting private R&D investment caused by incomplete appropriability of knowledge and financial constraints due capital market imperfections. Drawing on the insights from the real options approach to investment under uncertainty, this paper shows that public R&D subsidies may increase R&D spending through an additional mechanism: subsidies can mitigate the disincentive to invest in R&D stemming from market uncertainty. Although public R&D subsidies do no act directly to reduce demand uncertainties, they can offset the incentive effect of these uncertainties by increasing the expected return to the firm's R&D investment.

Using a sample of German manufacturing firms, we show that market uncertainty indeed reduces R&D investment, and that R&D subsidies mitigate the effect of uncertainty. Controlling for financial constraints and a variety of other factors, our results hold even though some of the knowledge generated from a firm's own R&D investment spills over to other firms and economic actors.

Moreover, there are two notable implications of our analysis. First, public policies intended to increase private R&D investment can achieve this objective by reducing the degree of uncertainty in the demand for innovative products. Second, our results suggest that private firms may be using public R&D subsidy programs to fund their most uncertain projects. It is widely known that program administrators have a difficult problem picking proposals that have high social returns but insufficient private returns. While probably unintended, these administrators may still be stimulating private R&D by reducing the effect of uncertainty on private project returns.

Business R&D and the interplay of R&D subsidies and market uncertainty [1]

by

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ABSTRACT

The literature suggests that public research and development (R&D) subsidies may reduce market failures affecting private R&D investment caused by incomplete appropriability of knowledge and financial constraints due capital market imperfections. Drawing on the theory of investment under uncertainty, this paper argues that public R&D subsidies increase business R&D investment through an additional mechanism – mitigating the effects of market uncertainty on R&D investment in markets for new products. Using a sample of German manufacturing firms, we show that market uncertainty indeed reduces R&D investment, and that R&D subsidies mitigate the effect of uncertainty. Our findings suggest that public policies aimed at increasing business R&D investment can achieve this objective by reducing the degree of uncertainty in the demand for innovative products.

Keywords: Real Options Theory, Uncertainty, R&D, Censored Regression

JEL Classification: O31, O33, C25

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1 Introduction

Since business investment in research and development (R&D) is a critical factor driving innovation and economic growth, it is important to understand how public policies like R&D subsides influence private incentives for R&D investment. There is now a sizable literature on how public R&D subsides might "correct" for underinvestment in business R&D resulting from market failures such as incomplete appropriability of the returns to knowledge generated through R&D investment or various capital market imperfections leading to financing constraints.[2] Drawing on the theory of investment under uncertainty, this paper argues that public R&D subsidies increase business R&D investment through an additional mechanism – mitigating the effects of market uncertainty on R&D investment in markets for new products.

The real options approach to investment under uncertainty predicts that firms invest less in irreversible capital as uncertainty in expected future cash flows increases (Pindyck 1991; Dixit 1992; Dixit and Pindyck 1994). R&D investment is highlighted in this literature as a particularly relevant example of irreversible capital since a large proportion of R&D supports the salaries of research personnel and cannot be recouped if projects fail. In light of the fact that the output of R&D is inherently uncertain, firms can avoid large losses by waiting for new information about future market demand and forgoing investment when this information is unfavorable. Hence, the incentive to invest in R&D today is lower because it involves exercising or "killing" the option to productively invest at any time in the future.

[2] The seminal papers are Nelson (1959) and Arrow (1962). David, Hall and Toole (2000) survey the empirical literature related to public R&D subsidies. Hall (2002) surveys the literature on financing constraints due to capital market failures.

The basic contribution of this paper is to point out that public R&D subsides can mitigate the deleterious incentive effect of market uncertainty on firm-level R&D investment and to test this possibility using firm data. Although public R&D subsidies do not act directly to reduce demand uncertainties, they can offset the incentive effect of these uncertainties by increasing the expected return to the firm's R&D investment. Controlling for financial constraints, we find R&D subsides offset the dampening effect of demand uncertainties even when some of the knowledge generated from a firm's own R&D investment "spills over" to other firms and economic actors. One implication from our analysis is that public policies intended to increase R&D investment can achieve this objective by reducing the degree of uncertainty in the demand for innovative products. Our findings support the use of demand-side incentive mechanisms such as purchase precommitments as suggested in a stream of research on spurring medical innovation and vaccines development by Kremer (2000, 2001a, 2001b).

The remainder of the paper is organized as follows. Section 2 briefly summarizes the necessary literature that is used to elaborate the main hypotheses we test in this analysis. Section 3 introduces the data. The empirical results are presented in Section 4 and the final section concludes.

2 Literature and Hypotheses

2.1 Incomplete R&D Appropriability and Financing Constraints

The best known rationales for public R&D subsides are incomplete R&D appropriability and firm financing constraints. Nelson (1959) and Arrow (1962) argued that private incentives for investment in R&D may lead to underinvestment because the knowledge generated through R&D activities is non-excludable. Other economic actors may "capture" part of the value created from the original R&D investment for use in their own innovative activities. When this happens, the social return is greater than the private return and private firms under-invest in R&D from a social perspective. Moreover, this incentive problem is even more acute for projects that involve more “basic” or “fundamental” research and knowledge generation since valuable applications stemming from this type are more difficult to foresee.

Public R&D subsides are seen as one way to increase overall investment in R&D in order to compensate for underinvestment due to incomplete appropriability. However, implementing this policy response is quite challenging and controversial. Ideally, public agencies would only grant subsidies for projects where the private return is insufficient to induce investment but the social return exceeds the R&D cost of investment. Two main problems are identified: first, it is unclear whether the government can select those projects that promise high social return, but costs prevent private investment. Second, once public support programs are in place each firm has incentive to apply for grants for any kind of R&D project, as marginal cost of subsidies are zero (aside of application cost). Thus firms might simply substitute private for public funding. This potential crowding out effect has been subject of numerous empirical studies. David et al. (2000) and Klette and al. (2000) surveyed the literature and find that micro-econometric studies yield mixed results. For instance, David et al. report nine out of nineteen studies find crowding-out effects. With the availability of better micro firm-level databases and new econometric methods, scholars tend to find that crowding out effects are rejected in more recent studies (see, for instance, Almus and Czarnitzki 2003; Duguet 2004; Czarnitzki and Licht 2006; González et al. 2006; Hussinger 2003; and Toole 2007). Mixed evidence is found by Lach (2002) and Görg and Strobl (2006), though.[3]

In addition to the incomplete appropriability argument, the literature on financial constraints points out that capital market imperfections also lead to private underinvestment in R&D. A

[3] A detailed discussion of these studies is beyond the scope of this paper. We refer the reader to a recent survey by Aerts et al. (2006).

survey by Hall (2002) summarizes the findings as follows: Due to asymmetric information between borrowers and lenders a financing gap for R&D emerges. Potential lenders like banks are reluctant to fund R&D due to the inherent risk, even if the borrower has argued that there are high expected returns. Since R&D is an expense, the investment is sunk. Unlike investment in physical capital there is no capitalized value in firms' balance sheets which can be used as collateral in credit negotiations. Thus R&D has to be primarily financed by internal financial resources. This causes a financing gap especially for small and medium-sized firms that do not have sufficient cash-flow to finance R&D. Surprisingly the financial constraints literature attempts to test for the existence of financial constraints, but ignores the presence of R&D subsidies in most cases. Exceptions are Hyytinen and Toivanen (2005) and Czarnitzki (2006) who combine the discussion about financial constraints and R&D subsidies. Each of these studies finds that R&D subsidies reduce the underinvestment problem stemming from financial constraints.

Hypothesis 1: R&D subsidies increase R&D investment in recipient firms.

2.2 Market uncertainty

In the theoretical literature, the direction of the effect of uncertainty on investment is ambiguous. One strand of research suggests that greater uncertainty will increase the investment of a risk-neutral competitive firm since the marginal value of capital is a convex function of the uncertain market price (Hartman 1972, Abel 1983). Another strand of the literature emphasizes the role of irreversibility of investment. When investment is irreversible, firms incur an additional opportunity cost by giving up the option to wait for more information. This line of research suggests that greater uncertainty will reduce the investment of a risk-neutral firm since the marginal value of capital is a concave function of the uncertain market price (McDonald and Siegel 1986; Bertola 1988; Pindyck 1988; Pindyck and Dixit 1994; Carruth et al. 2000).

Among the varieties of capital investment a firm might undertake, R&D investment is probably the most sensitive to changes in market uncertainty. R&D investment has a large human and tacit knowledge component making it one of the most irreversible types of capital investment. Thus, it is likely that R&D investment is delayed and thereby reduced as market uncertainty increases.

To our knowledge, there are only two empirical studies that investigate the relationship between market uncertainty and R&D investment. Using annual data for nine OECD countries over the period 1982-1992, Goel and Ram (2001) relate the share of R&D and non-R&D investment in GDP to indicators of aggregate inflation uncertainty, real interest rates, and the growth of GDP. The separate categories of investment, R&D and non-R&D, are intended to capture differences in the degree of irreversibility of the underlying investment decisions. They measure uncertainty using 5-year moving averages of each country's inflation rate in both standard deviation and level form. The results show that both versions of uncertainty reduce the share of R&D in GDP but have no significant impact on the share of non-R&D investment in GDP. Since irreversibility is one of the required characteristics for creating a positive option value for waiting, their results are consistent with real options investment behavior.

Because most shocks relevant to R&D investment will be firm-specific and are smoothed out in aggregate data, Czarnitzki and Toole (2006) use firm-level data to shed light on how uncertainty influences R&D investment. Their sample is a cross-section of 489 German manufacturing firms. They use survey data to construct an informative measure of market uncertainty based on the firm's own innovative experience in product markets – the variance of sales from new product introductions. Controlling for the firm's subjective assessment of expected demand growth and a variety of other factors, their results show that market uncertainty significantly reduces R&D investment. Further, the impact of uncertainty is greater for smaller firms than it is for larger firms.[4]

Hypothesis 2: Greater uncertainty is associated with lower levels of firm R&D investment since firms choose to hold back on exercising their investment options.

The main contribution of this paper is to point out that public R&D subsides can mitigate the deleterious incentive effect of market uncertainty on firm-level R&D investment. R&D subsidies do not act directly to reduce demand uncertainties, but they can offset the incentive effect of these uncertainties by increasing the expected return to the firm's R&D investment. Therefore, market uncertainty should affect R&D investment of subsidy awardees less than R&D investment of non-supported firms.

Hypothesis 3: R&D subsidies mitigate the deleterious incentive effect of market uncertainty for recipient firms.

3 Data

The data source for our research is the Mannheim Innovation Panel (MIP) which is an annual German innovation survey conducted by the Centre for European Economic Research (ZEW). It represents the German part of the Community Innovation Survey, which is part of the harmonized innovation survey conducted by EU member states. It covers both public and

[4] While there appear to be no further empirical studies of the relationship between R&D investment and uncertainty at the firm level, several researchers have investigated the broader relationship between firm investment (mostly physical assets) and various measures of uncertainty. Examples are Bulan (2005), Leahy and Whited (1996), Guiso and Parigi (1999), Von Kalckreuth (2000).

private firms of all sizes in Germany. We use the 1999 and 2001 survey for the manufacturing sector. The surveyed data correspond to the years 1998 and 2000, and are supplemented with time series information on company sales achieved with newly introduced products. These data are obtained from previous annual surveys that have been conducted since 1993, which are used to construct our measure of market uncertainty.[5]

Our sample is a pooled cross-section of 1,059 "innovative" manufacturing firms. Although we have two years, we cannot make use of panel econometrics, as most firms are only observed once: the 1059 observations correspond to 798 different firms. Only 31% of firms are observed in both years. Hence, we can only perform pooled cross-sectional regressions. An innovative firm is defined to be a company that introduced at least one new product into a market during the previous six years, 1992-1997 and 1995-1999, respectively. We assume firms use their prior market experience as innovators to form their expectations about future market uncertainty. This indicator of uncertainty is separate and distinct from their subjective assessments of future market growth potential (or innovative opportunities). Since past sales information on new product introductions is used to construct our market uncertainty measure, we must restrict our sample to those firms with at least three new product sales observations in the pre-sample period (these do not need to be consecutive).

The dependent variable is R&D expenditure at the firm level (RD_i) in millions of DM (1.9583 DM = 1 EUR). Although we consider only previous product innovators, we find that about 29% of the firms in the sample did not conduct R&D in 1998 or 2000. This fact itself may reflect a reaction to high levels of market uncertainty already. Our econometric analysis

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[5] The survey questionnaire changes over time as it addresses topics of interest in current innovation policy. The panel structure can only be used for certain core questions on innovation indicators that are surveyed annually.

takes this into account by modeling the censored distribution of R&D. Above zero, the distribution of R&D spending is quite skewed and this motivates our logarithmic specification (ln$R\&D_i$). Since we cannot take the log of the censored observations at $R\&D_i$ = 0, we set those observations to the minimum observed positive R&D value in the sample and interpret this observed minimum as the censoring point in the regression models.

Market uncertainty (*UNCER*) is measured as the variance of the share of sales (in %) achieved with new products per year in the pre-sample period from 1992 to 1997 (for observations of R&D in 1998) and 1995 to 1999 (for R&D in 2000) at the firm level. The number of observations available for each firm varies from three to six years:

$$UNCER_i = \frac{1}{T_i} \sum_{t=1}^{T_i} \left(\text{sales}_{it}^* - \overline{\text{sales}_i^*} \right)^2 ,$$

where sales^*_{it} denotes the share of sales achieved with new products in firm *i* in year *t*. This variable accounts for the volatility of revenue from new market introductions. Consistent with the real options theory, higher expected demand volatility should delay R&D investment and thereby have a negative impact on the level of R&D investment.

R&D subsidy awards are measured by a dummy variable indicating whether the firm received R&D subsidies either from local government agencies, the German federal government or the European Commission (*GOV*). In our sample, 33% of firms received R&D grants from public sources.

To test how market uncertainty facing the firm is influences by the receipt of a public R&D subsidy, we include an interaction term of the uncertainty measure with *GOV*. Instead of using the variable UNCER in the regression model, we group it by subsidy receipts: *UNCER*GOV* measures the effect of uncertainty in subsidized firms, while *UNCER**(1-*GOV*) refers to non-subsidized firms.

Market type, the degree of competition, and capital intensity may also influence the firm's investment decision. We control for market type using eleven industry dummies variables. To measure the degree of competition, we include each market's concentration using the Herfindahl index based on shares of market sales (*HHI*). In addition, the market share on the 3-digit industry level is calculated (*SHARE*). Capital intensity (*KAPINT*) is measured as physical assets (in million DM) per employee to account for the fact that firms in more technology-intensive sectors may have a higher propensity to conduct R&D than those in more labor-intensive sectors.

With regard to other firm characteristics, we include controls for firm size, liquidity constraints, and governance structures. The number of employees controls for heterogeneity in size with respect to the propensity to conduct R&D. In our sample, 17% of observations are large firms with more than 500 employees. The median firm size in our sample is 125 employees. We also control for liquidity constraints since these may be confounded with the effects of uncertainty. The literature on financing innovation generally finds that liquidity constraints reduce R&D investment (Hall 2002). We use the firm's credit rating as a proxy for the firm's access to credit markets (*CR*). The credit rating is obtained from Creditreform which is the largest German rating agency. We use the rating in period *t*-1 in order to avoid endogeneity problems.[6] The rating is an index ranging from 100 to 600, where 600 hundred is the worst basically corresponding to bankruptcy of the firm.

Corporate governance structures are included by two indicator variables. The first variable captures whether the firm is associated with a group of companies (*GROUP*). Such firms may have better access to capital through the parent company. The second variable denotes subsidiaries of foreign parent companies (*FOREIGN*). They may be less likely to conduct

R&D, as this is often done in the headquarters of multinational companies. 40% of the sampled firms belong to a group, and 11% of those have a foreign parent company.

With German data it is also important to control for the firm's location in Eastern Germany. Since the German re-unification in 1990, Eastern Germany has been transitioning from a planned economy to a market economy. As a result, the former large firms in the German Democratic Republic (the so-called "combinates") were either closed-down or have been privatized and split into several independent companies. The vast majority of these firms were founded after 1990. Most are small and many are struggling to survive. As such firms may behave different from Western German companies that were not subject to the market shock of the re-unification, we include a dummy variable *EAST* in the regressions. About 35% of firms in the sample are located in Eastern Germany.

One time dummy controls for other changing macroeconomic time effects. Table 1 below presents descriptive statistics of all variables used (for convenience the index *i* indicating firm level variables is omitted).

[6] For some firms, there was no rating available for the preceding year. In such cases we use ratings from one or two years earlier.

Table 1: Descriptive statistics (1,059 observations)

Variable	Mean	Std. Dev.	Min	Max
$R\&D_t$ (in million DM)	10.441	94.968	0	1990
$UNCER_t$ (uncertainty measure)	0.064	0.082	0	0.5
GOV_t (R&D subsidy dummy)	0.329	0.470	0	1
EMP_t (number of employees)	636.104	3080.949	5	43118
$EAST_t$ (location dummy)	0.348	0.477	0	1
$KAPINT_t$ (Physical assets in million DM/ EMP)	0.083	0.104	0.002	1.509
HHI_{t-1} (industry concentration)	47.227	67.864	3.441	427.702
CR_{t-1} (credit rating index)	213.114	69.797	100	600
$SHARE_{t-1}$ (market share)	0.008	0.036	0.0001	0.846
$D2000_t$ (year dummy)	0.536	0.499	0	1
$GROUP_t$ (group dummy)	0.398	0.490	0	1
$FOREIGN_t$ (foreign parent company)	0.106	0.308	0	1

Note: 11 industry dummies not presented.

4 Empirical Results

Table 2 presents our regression results. We consider two versions of equation to be estimated: model A excludes the interaction term of uncertainty and R&D subsidies in order to test the baseline hypotheses 1 and 2 suggesting that subsidies increase R&D investment and market uncertainty reduces investment. Model B implements the interaction term among subsidies and uncertainty to test our third hypothesis that public R&D subsidies dampen the disincentive for R&D investment caused by market uncertainty. First, we estimate homoscedastic Tobit models. However, since the presence of heteroscedasticity can lead to inconsistent coefficient estimates, we performed several tests. We applied Lagrange Multiplier tests on basis of the homoscedastic models to select variables potentially causing heteroscedasticity,[7] which were subsequently implemented into heteroscedastic regressions where we consider the variance σ_i of observation i being of the form $\sigma_i = \sigma \exp(w_i'a)$ with z denotes the vector of variables in the heteroscedasticity term and a the additional coefficients to be estimated. The LM-tests suggests we use industry dummies and size dummies (based on employment) in the variance function. Table 2 also presents a Likelihood ratio test on heteroscedasticity. It turns out that homoscedasticity is rejected.

In Model A, R&D subsidies show a positive sign and are significantly different from zero. This finding is in line with results found earlier for German data by Almus and Czarnitzki (2003) and Hussinger (2003). It confirms that subsidies yield higher R&D spending at the firm level and that full crowding-out effects are not present, on average. The impact of public R&D subsidies on firm R&D investment is not due to relaxing the firm's financial constraints since the regression includes a control for each firm's credit rating, *ln(CR)*. As for our second hypothesis, market uncertainty is negative and very statistically significant. This finding is consistent with the results in Czarnitzki and Toole (2006) and supports the real options viewpoint that greater market uncertainty reduces firm investment. It is also consistent with the findings of prior research analyzing the effects of uncertainty on overall firm capital investment.

In Model B of Table 2 the effect of market uncertainty is allowed to depend on whether or not the firm received an R&D subsidy. As predicted in hypothesis 3, we find that market uncertainty has no significant impact on the level of R&D investment once the firm has received a public R&D subsidy. For those firms with no subsidy, market uncertainty continues to be associated with lower firm R&D investment. The perspective that public R&D subsides mitigate the deleterious incentive effect of market uncertainty is reinforced by the fact that these subsides continue to increase firm R&D investment, as shown by the coefficient on *GOV*. The dummy variable *GOV* remains positively significant.

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[7] See e.g. Greene (2000: pp. 912-914) for technical details.

Table 2: Tobit regressions on ln(*R&D*) at the firm level

Variable	Model A		Model B	
	homo-scedastic	hetero-scedastic a)	homo-scedastic	hetero-scedastic a)
ln(*EMP*)	1.085 ***	1.018 ***	1.090 ***	1.014 ***
	(0.085)	(0.082)	(0.085)	(0.082)
UNCER	-4.564 ***	-4.449 ***		
	(1.257)	(1.204)		
*UNCER*GOV*			-1.318	-1.413
			(2.007)	(2.017)
*UNCER**(1-*GOV*)			-6.543 ***	-5.984 ***
			(1.603)	(1.473)
GOV	2.620 ***	2.795 ***	2.336 ***	2.546 ***
	(0.202)	(0.206)	(0.242)	(0.244)
EAST	-0.568 ***	-0.633 ***	-0.586 ***	-0.653 ***
	(0.221)	(0.223)	(0.222)	(0.224)
KAPINT	-0.553	0.069	-0.585	0.046
	(0.898)	(0.901)	(0.902)	(0.901)
ln(*HHI*)	0.050	0.072	0.044	0.063
	(0.102)	(0.103)	(0.102)	(0.103)
SHARE	2.463	2.805	2.676	3.052
	(2.497)	(2.550)	(2.474)	(2.551)
ln(*CR*)	-0.381	-0.349	-0.360	-0.350
	(0.378)	(0.391)	(0.379)	(0.391)
D2000	-1.343 ***	-1.353 ***	-1.333 ***	-1.352 ***
	(0.171)	(0.175)	(0.172)	(0.175)
GROUP	0.119	0.214	0.136	0.219
	(0.214)	(0.215)	(0.213)	(0.215)
FOREIGN	0.110	0.144	0.073	0.108
	(0.299)	(0.306)	(0.299)	(0.306)
Intercept	-8.752 ***	-8.075 ***	-8.770 ***	-7.871 ***
	(2.319)	(2.274)	(2.329)	(2.276)
Test on joint significance of 10 industry dummies ($\chi^2(10)$)	125.83***	123.46***	125.31***	124.92***
# of observations	1059	1059	1059	1059
Log-likelihood	-1955.91	-1934.19	-1954.16	-1932.03
McFadden R^2	0.167	0.176	0.168	0.177
LR-test on heteroscedasticity ($\chi^2(15)$)		43.44***		40.64***

Note: Standard errors in parentheses. *** (**, *) indicate a significance level of 1% (5, 10%).
a) Heteroscedasticity term includes 10 industry dummies and 5 size dummies (based on the number of employees)

The other covariates show the expected sign, but several turn out to be insignificant: As expected firm size related positively to R&D spending, as indicated by the positive and significant coefficient of ln(*EMP*). Firms located in Eastern Germany invest less in R&D than Western German firms, all else constant. As shown by the time dummy, R&D investment levels did, on average, reduce from 1998 to 2000 conditional on the other covariates. There are large differences in R&D investment among industries, which is shown by the test of joint significance of the industry dummies. Highest investment (conditional on the other covariates) is achieved in industries as 'medical, optical and precision instruments', 'automotives', 'chemicals including pharmaceuticals' and 'machinery and equipment'. The credit rating has the expected negative sign showing that firms with poor credit invest less in R&D, perhaps due to financial constraints. However, the estimated coefficient is statistically insignificant.

Finally, it should be noted that R&D subsidies are often considered as endogenous in policy evaluation studies, as governments cherry-pick the recipients, and thus the receipt of subsidies may be correlated with unobserved capabilities of the firm. Hence, the subsidy dummy would be correlated with the error term in the regression model. Correcting for endogeneity would be desirable in our study as well, although we do not focus on the evaluation of some particular treatment effect. The major problem in such an exercise is the typical lack of a valid instrumental variable. As we have no good candidate that affects the probability to receice a subsidy but not R&D either, we only performed a rough test. We omit the insignificant variables in the equations estimated above, and regress *GOV* on the full set of variables available (except the uncertainty measure) including some cross-products of variables with firm size. Then we calculate the estimated probability and use that instead of *GOV* in the regressions. Predicting the probability from exogenous variables yields that the estimate is asymptotically uncorrelated with the error in the R&D equation. This procedure obviously conforms to 2SLS for the Tobit case (see e.g. Gourieroux, 2000). We find that the results on the effect of subsidies and uncertainty as shown in the tables above hold.

5 Conclusions

Drawing on the insights from the real options approach to investment under uncertainty, this paper shows that public R&D subsidies can mitigate the disincentive to invest in R&D stemming from market uncertainty. Although public R&D subsidies do no act directly to reduce demand uncertainties, they can offset the incentive effect of these uncertainties by increasing the expected return to the firm's R&D investment. Controlling for financial constraints and a variety of other factors, our results hold even though some of the knowledge generated from a firm's own R&D investment spills over to other firms and economic actors.

Moreover, there are two notable implications of our analysis. First, public policies intended to increase private R&D investment can achieve this objective by reducing the degree of uncertainty in the demand for innovative products. While not tested empirically, Kremer (2000, 2001a, 2001b) and others have used this insight to argue that purchase precommitments and R&D prizes may be a valuable mechanisms for stimulating R&D investment and innovation in areas ignored by private firms such as HIV vaccines. Second, our results suggest that private firms may be using public R&D subsidy programs to fund their most uncertain projects. It is widely known that program administrators have a difficult problem picking proposals that have high social returns but insufficient private returns. While probably unintended, these administrators may still be stimulating private R&D by reducing the effect of uncertainty on private project returns.

While this research provides the first systematic evidence that public R&D subsidies mitigate the effect of market uncertainty on private R&D investment, there are a number of caveats. First, our measure of uncertainty is based on prior firm experience. If firms form their expectations of future market uncertainty through different means, then our measure is weakened. Second, we cannot control for firm fixed effects in our cross-sectional data.

Fixed effects would provide a better control for managerial investment tastes, particularly their tastes for risk. Third, market uncertainty is only one form of uncertainty that may influence R&D and other capital investments by the firm. Richer data would permit us to investigate more sources of uncertainty. Fourth, our data do not allow us to perform more sophisticated econometric tests that would rule out potential sources of endogeneity such as firm's choice to apply to the public program.

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