The R&D Investment-Uncertainty Relationship: Do Strategic Rivalry and Firm Size Matter?[1]

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Abstract

This paper uses a real options perspective to augment a standard R&D investment model and implement a firm-level empirical analysis to assess the practical significance of market uncertainty and its interactions with strategic rivalry and firm size. We use a measure of firm-relevant market uncertainty along with panel data and find that firms invest less in current R&D as uncertainty about market returns increases. The effect of firm-specific uncertainty on R&D investment is smaller in markets where strategic rivalry is likely to be more intense. Furthermore, holding access to financing constant, the effect of uncertainty on R&D investment is attenuated for large firms.

Keywords: Real Options Theory, Uncertainty, R&D, Strategic Rivalry, Firm Size

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1 Introduction

Economists view research and development (R&D) expenditure as an investment decision that is commonly understood by applying models of physical capital investment. The development of real options models offers a new perspective for understanding the determinants of R&D expenditure. These models highlight the influence of uncertainty when investments are at least partially irreversible and decision makers are able to choose the timing of their investments (Dixit and Pindyck 1994; Abel and Eberly 1996; Abel et al. 1996).

Real options models are a natural starting point for understanding how uncertainty influences R&D investment decisions. R&D investments satisfy the irreversibility criterion of the real options paradigm because the bulk of R&D expenditures support the salaries of research personnel and cannot be recouped if projects fail (Grabowski 1968; Dixit and Pindyck 1994). However, unlike the canonical real options model of a monopolist evaluating a single investment project, most private R&D investment is undertaken strategically by large multi-project firms. The influence of market uncertainty on investment may be different in these circumstances. For instance, the decision makers of large multi-project firms may respond less to uncertainty due to greater flexibility in R&D capacity utilization (Pindyck 1988). Strategic rivalry may introduce the threat of pre-emption and restrict the decision makers' choices about when to invest (Kulatilaka and Perotti 1998; Weeds 2002).

This paper uses a real options perspective to augment a conventional R&D investment framework and implements a firm-level empirical analysis to assess the practical significance of market uncertainty and its interactions with strategic rivalry and firm size. A number of theoretical and empirical studies examine these interrelationships in the case of physical capital investment (see, for instance, Bloom et al. 2007; Bulan 2005; Ghosal and Loungani 1996, 2000;

Grenadier 2002; Novy-Marx 2007). For R&D investment, only a handful of empirical studies explore the effects of uncertainty and none have examined how strategic rivalry and firm size affect the relationship between uncertainty and R&D investment.

In line with prior studies, we find that current R&D investment falls as market uncertainty increases. We also find that the effect of firm-specific uncertainty on R&D investment is smaller in concentrated markets and in markets with a smaller number of competitors. This result is consistent with real options models involving oligopolistic competition where pre-emption erodes the option value of waiting (Grenadier 2002; Weeds 2002). Furthermore, R&D investment by large firms is less responsive to uncertainty even after controlling for potential financial constraints. Large firms have inter-related and ongoing R&D projects and this allows R&D assets to be transferred to alternative uses within the firm. This flexibility suggests that size confers valuable marginal "operating options" that offset the effect of uncertainty without relying on the belief that large firms have greater access to financing. However, our current database is not detailed enough to pinpoint the exact source of greater flexibility and our firm size result is consistent with other possibilities. For instance, large firms may have greater flexibility in project design and selection.

2 Prior Literature

In this paper, we apply a conceptual framework that generalizes a standard, but rather simple model of firm-level R&D investment behavior. The conventional model, which is described by Grabowski and Baxter (1973) and Howe and McFetridge (1976), postulates that in each planning period the firm chooses the level of R&D investment that equates the marginal return to R&D (*mrr*) with the marginal cost of R&D capital (*mcc*). This model is related to Tobin's "marginal q" in which it is optimal for a firm to invest when the marginal valuation of an addition unit of R&D capital in the current period exceeds its marginal cost.[2] The condition determining the optimal level of R&D investment in this static model is:

(1) $mrr_t = mcc_t$

In the decades since this simple model was postulated there have been a number of significant advances in the theoretical literature on investment.[3] Although a survey of these developments is beyond the scope of this paper, an important contribution by Abel et al. (1996) shows the equivalence between the q-theory of investment and more recent real options models using a dynamic (two period) framework. Their analysis shows how investment decisions are related to future opportunities and costs. Using our notation their investment optimality condition can be written as:

(2) $mrr_t = mcc_t - \gamma R_t + \gamma E_t$

In this dynamic setting, mrr_t now represents the expected present value of current and future marginal revenue products of capital evaluated at the current level of capital. The mcc_t term is the current marginal cost of purchasing a unit of R&D capital. Gamma is the firm's discount factor. The second term on the right-hand side, R, adjusts for "reversibility" options which take into account changes in the opportunities and costs associated with disinvestment at some point in the future. Because purchasing a unit of capital today creates the opportunity to

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[2] This formulation leads to a reduced form model in which the level of R&D investment is regressed on a variety of explanatory variables related to R&D returns (*mrr*) and the cost of capital (*mcc*). See David et al. (2000) for a review of this model.

[3] For instance, refer to Dixit and Pindyck (1994), Abel and Eberly (1996, 1999). Butzen and Fuss (2002) and Carruth et al. (2000) survey the literature on investment under uncertainty.

sell this unit in the future, the marginal value of this option reduces the effective cost of capital today. The final component, *E*, adjusts for "expandability" options which take into account changes in the opportunities and costs associated with investment at some point in the future. Because purchasing a unit of capital today extinguishes the option to purchase this unit in the future, the marginal value of this option increases the effective cost of capital today. The value of an expandability option is commonly referred to as the option value of waiting.

In the literature, R&D investment is typically considered to be a completely irreversible type of capital investment since a large proportion of R&D supports the salaries of research personnel that cannot be recouped if projects fail (see, for instance, Grabowski 1968; Dixit and Pindyck 1994, p. 424). Under this assumption, the value of the reversibility option in equation (2) is zero and only the expandability option influences optimal R&D investment. So, in addition to the factors that influence *mrr* and *mcc*, factors that change the option value of waiting will also affect the incentive for current R&D investment.

Holding other factors constant, their comparative static results suggest increases in uncertainty reduce the incentive for current R&D investment by increasing the marginal value of expandability options – increasing the option value of waiting. Higher uncertainty leads to a higher trigger threshold for investment. Theoretically, however, the current *level* of investment remains ambiguous because higher uncertainty may also increase the probability of reaching a given threshold (see, for instance, Dixit and Pindyck 1994, page 369; Abel and Eberly 1996;

Sarkar 2000; Lund 2005; Bloom et al. 2007).[4] In light of the theoretical ambiguity, the direction of the effect of uncertainty on current R&D investment must be investigated empirically.

Our review of the empirical literature identified only four published articles that examine the effect of uncertainty on R&D investment.[5] Using cash flow volatility as a proxy for firm-specific uncertainty, Minton and Schrand (1999) found higher levels of volatility are associated with lower R&D investment for a sample of public firms in the US. Analyzing a sample of OECD countries, Goel and Ram (2001) found that greater uncertainty, measured as the standard deviation in a country's inflation rate, reduces the share of R&D in GDP, but has no significant effect on the share of non-R&D investment in GDP. In two recent papers, Czarnitzki and Toole (2007, 2011) examined cross-sectional and panel data on innovative firms in the German manufacturing sector to explore how public subsidies and patenting interact with product market uncertainty. Using past revenue volatility as a proxy for uncertainty, they found that current R&D investment falls as firm-specific uncertainty increases. R&D subsidies and patents were found to partially offset the effect of uncertainty on the firm's R&D decision and thereby increase current R&D investment.

None these papers, however, examine the possibility that competition through strategic rivalry could influence how uncertainty affects current R&D investment.[6] Some theoretical

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[4] The presence of growth options or investment lags in R&D would also offset the negative effect of expandability options (Kulatilaka and Perotti 1998, Ban-Ilan and Strange 1996). Also see Abel and Eberly (1999).

[5] Bloom (2007) considers how adjustment costs may differ between R&D and fixed capital investment and presents some simulation results. There is also a growing empirical literature on the relationship between fixed capital investment and uncertainty at the project and firm levels. Recent contributions include Bulan et al. (2009), Baum et al. (2008), Bloom et al. (2007), Bulan (2005).

[6] Theoretical models incorporating strategic considerations are reviewed by Gilbert (2006) for the industrial organization literature and by Smit and Trigeorgis (2004) for the financial economics literature.

models show that strategic rivalry erodes the option value of waiting (Grenadier 2002). Using a real options model with R&D competition, Weeds (2002) finds that the incentive for current investment depends on the relative magnitudes of the option value of waiting and the expected value of pre-emption. In her model the disincentive for current R&D investment due to higher uncertainty is offset as strategic rivalry increases. In contrast, Novy-Marx (2007) presents a model in which firm heterogeneity in scope and size leads to different opportunity costs of investment. Heterogeneity prevents firms from competing directly over investment opportunities and the option value of waiting remains even if competition drives oligopoly rents to zero. In this case, heterogeneity reduces (or eliminates) the expected value of pre-emption and the disincentive for current R&D investment due to higher uncertainty is not offset by strategic rivalry. In this paper, we empirically investigate whether strategic rivalry offsets the value of expandability options.

The influence of firm size on the investment-uncertainty relationship is also an unsettled issue. Empirical studies of fixed capital investment suggest this distinction may be important. Ghosal and Loungani (2000) postulate that greater uncertainty exacerbates existing capital market imperfections due to asymmetric information (also see Himmelberg and Petersen 1994). Higher uncertainty leads to higher costs of external funds and forces small firms to reduce current investment more than large firms. Using industry-level data, they find that uncertainty reduces investment in industries dominated by small firms and has no significant effect in industries dominated by large firms. Bulan (2005) connects firm size directly to factors that affect option values by suggesting large firms possess more market power or have greater irreversibility of capital. Contrary to Ghosal and Loungani, she expects large firms to reduce current investment more than small firms as uncertainty increases. In her analysis of fixed capital investment, large firms appear to respond more to uncertainty, but the difference between large and small firms is not statistically significant.

A more appealing possibility is that large firms possess more valuable marginal "operating options" than small firms. The existence and value of an operating option derives from the flexibility a firm obtains when purchasing an additional unit of capital. Pindyck (1988) presents a model of irreversible investment and capacity choice that allows for flexibility in capacity utilization. Each unit of installed capacity gives the firm an infinite number of options to produce or not, one for each future time period. When applied to R&D investment, flexibility in the utilization is likely to be greater for large firms. With many inter-related and ongoing R&D projects, large firms have the option to shift R&D personnel and equipment across projects within the firm in response to changes in market conditions. Pindyck (1988) shows that greater uncertainty increases the value of a firm's marginal operating option and increases the incentive for current investment.[7] This offsets the negative effect on current investment acting through expandability options. Intuitively, R&D investment by larger firms should respond less to a given change in uncertainty because they hold more valuable operating options. We examine how firm size interacts with uncertainty in the empirical analysis.

[7] In equation (2), the mrr_t term captures this effect when it is convex. (See Abel et al. (1996), footnote 13, page 763. Dixit and Pindyck (1994) also discuss the offsetting effects of operational flexibility, page 195-199, chapter 6).

3 Data and Empirical Model

3.1 Data

Our data come from the Mannheim Innovation Panel (MIP) which is an annual survey conducted by the Centre for European Economic Research (ZEW), Mannheim, Germany, since 1992. The MIP is the German part of the European-wide Community Innovation Surveys (CIS) designed to collect harmonized data on innovation in the European Community following the guidelines of the OSLO manual, the international guidelines for collecting innovation data from the business sector (Eurostat and OECD, 2005).[8] The surveys yield a representative sample of the German manufacturing sector each year covering firms with five or more employees.

From the MIP surveys, we construct a panel database consisting of 870 "innovative" firms from Germany's manufacturing sector observed between 1995 and 2001. The panel is unbalanced because firms do not respond to the survey in every year. An innovative firm is defined as a company that introduced at least one new product in the pre-sample period, that is, before the firm enters the panel database.[9] We require each firm to be observed at least three times before entering our sample. We use these pre-sample years to generate some of the explanatory variables including our proxy for the firm's perceived uncertainty in the market for innovations. Our final sample has 2,929 firm-year observations with the following structure: 21% of firms are observed twice, 24% three times, 21% four times, and the remaining 35% are

[8] For a detailed description of the CIS, see e.g. Eurostat (2004).

[9] For the MIP survey, a new product is defined as "a product whose technological characteristics or intended uses differ significantly from those of previously produced products. Such innovations can involve radically new technologies, can be based on combining existing technologies in new uses, or can be derived from the use of new knowledge" (Olso Manual, page 31, www.oecd.org/dataoecd/35/61/2367580.pdf).

observed between 5 and 7 times. A breakout of our sample by industry aggregates is presented in Table A.1 in the appendix.

The log-level of current R&D investment for firm *i* at time *t*, $\ln R\&D_{it}$, is our dependent variable. The distribution of R&D investment is skewed above zero and this motivates our use of the logarithmic specification. Since we cannot take the log of the censored observations at $R\&D_i = 0$, we set those observations to the minimum observed positive value of R&D in the sample and interpret this minimum as the censoring point in the regression models. R&D is measured in millions of Deutsche Mark (1.95583 DM = 1 EURO). Consistent with what one would expect from real options behavior, one-third of the innovative firms with positive R&D in the past have at least one observation with zero R&D investment in subsequent years. Since our sample has a number of smaller private firms (the median number of employees per firm is 110), R&D investment is intermittent.[10] In the regression models, we account for the censored distribution of R&D using a Tobit model.

We assume firms use their past market experience as innovators to form their expectations about future market uncertainty. Market uncertainty is measured by the coefficient of variation of past sales. We distinguish two components of past sales since our data allow us to explicitly account for sales of new products introduced in the most recent three years and sales of established products. The survey requests the respondents to classify their total sales as follows:

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[10] This is consistent with real options behavior because the trigger values for investing and abandoning projects are higher and lower, respectively, than those predicted from standard net present value analysis. See Novy-Marx (2007) for a discussion of the implications from intermittent and lumpy investment behavior in a real options theoretical model. (Also see Abel and Eberly 1996; Bloom et al. 2007)

(a) sales of products new to the market,

(b) sales of products that are not new to the market, but are new to the firm including significant improvements of existing products, and

(c) sales of marginally improved products and unchanged products.

We use the sum of (a) and (b) as our definition for "new product sales" and calculate the coefficient of variation, *UNC_NEW*. The coefficient of variation of older, more established product sales, *UNC_OLD*, is based on definition (c) from above.

Before calculating the uncertainty measures for each firm-year, we made two adjustments to a firm's sales volume. The first adjustment eliminates firm size effects. This adjustment takes the firm's sales in a particular year and divides it by the number of employees at the firm in that year. The second adjustment eliminates possible differences in trends, diffusion patterns, or product life-cycle characteristics of particular industries. For instance, new product diffusion is expected to be more rapid in the electronics industry than in the steel industry due to differences in consumer and/or producer behavior or product characteristics within those industries. To make this adjustment, we first calculated the average of sales per employee across all the firms in the industry for each year. Then, we divided the individual firm's sales per employee by the industry average sales per employee. After these two adjustments, we calculated the coefficient of variation across time for each firm. The number of observations available for calculating the coefficients of variation for each firm relied on available pre-sample data for which we have three to nine years available ($s = 1,\ldots,S$, with S ranging between 3 and 9): [11]

[11] For the regression models presented below, we performed robustness checks to test the sensitivity of our results to the length of the pre-sample period used. This did not materially affect our results. If desired, these results can be obtained from the authors.

$$(3) \qquad UNC_{it} = \frac{\sqrt{\frac{1}{S}\sum_{s=1}^{S}\left[Z_{i,t-s} - \left(\frac{1}{S}\sum_{s=1}^{S}Z_{i,t-s}\right)\right]^2}}{\frac{1}{S}\sum_{s=1}^{S}Z_{i,t-s}}, \qquad \text{with } Z_{it} = \frac{\frac{R_{it}}{L_{it}}}{\frac{1}{n_j}\sum_{i=1}^{n_j}\frac{R_{it}}{L_{it}}},$$

where Z_{it} in the formula is calculated as follows: R_{it}, which denotes the volume of new or established product sales of firm *i* in year *t*, is divided by L_{it}, the number of employees in firm *i* in year *t*. The resulting firm-level sales per employee (R_{it} / L_{it}) is normalized by the average sales per employee in firm *i*'s respective industry *j*.

In prior work, we "validated" this uncertainty measure by examining its correlation with other survey results where firms reported the degree of competitive and demand uncertainty in their main product market (Czarnitzki and Toole 2011). The correlation coefficient between our uncertainty measure and the external survey data is 0.43 for the competitive uncertainty and 0.45 for the demand uncertainty. These results are generally supportive of our measure as a proxy for uncertainty. Finding even a moderate degree of relatedness is reassuring as these alternative measures were drawn from two independent datasets and represent two completely different approaches to measuring firm-level uncertainty.

Since we are interested in how strategic rivalry and firm size affect the R&D investment-uncertainty relationship, we created interaction variables between uncertainty and indicators of strategic rivalry and firm size. For strategic rivalry, we would like an indicator that reflects the threat of pre-emption a firm faces from its rivals when it considers investing in product innovation. Perhaps not surprisingly, a systematic measure of rivalry has not been identified or used in the empirical literature. Microeconomic theory suggests that monopolistic or oligopolistic product markets with a small number of sellers are likely to involve strategic interdependencies that increase the threat of pre-emption. One systematic, but imperfect, indicator that generally increases as the number of sellers becomes smaller is the Herfindahl-Hirschman Index (HHI). For the eighty-three industries in our sample, HHI indexes were obtained from official German industry statistics produced by the German Monopolies Commission. These are calculated based on shares of total domestic and international sales by German firms at the 3-digit NACE level, called ln(*HHI*) in the tables below.[12] We define industries in the upper quintile of the HHI distribution as highly concentrated and we expect these industries to be more oligopolistic in nature and exhibit greater strategic rivalry.

Admittedly, there are several potential problems with using the HHI index as an indicator of strategic rivalry. Most product markets in Germany involve imports and exports, but the German Monopolies Commission does not include foreign firms in its calculation of the HHI indexes. This omission may produce an HHI index that over-estimates or under-estimates seller concentration. Further, the HHI indexes are calculated using the standard NACE industry classification scheme. As a result, the HHI index for a particular firm may not accurately reflect the true concentration or number of strategic competitors it faces in its main product market. Finally, an increase in the HHI index may also reflect an increase in the disparity of the sales distribution within an industry and not simply a smaller number of sellers.

In light of these limitations, we searched for a second indicator of strategic rivalry to use as a robustness check. In the 2003 wave of the Germany CIS survey, firms were asked to report the number of competitors, both domestic and foreign, in their main product market.

[12] NACE is the industry classification system used in the European Community. It is similar to the North American

Respondents could choose from among four possibilities: no competitors, one to five competitors, six to fifteen competitors, and greater than fifteen competitors. Assigning a rank metric to each of these categories (one to four), we calculated the average rank across all respondent firms in each 3-digit NACE industry to produce a distribution of the rank metric across industries. We identified industries in the lowest quartile of this distribution (i.e. those with the fewest reported competitors) and created a dummy variable equal to one for firms in those industries, called *D(Rivalrous)* in the tables (see Nickell 1996 for a similar use of survey data to measure competition using the number of competitors). We expect these industries to be oligopolistic in nature and likely to involve strategic rivalry.

Firm size is measured using the number of employees in the firm. We define a firm as large when it has more than 500 employees. In our sample, 14.7% of the firms are large. We checked the cut points for concentration and firm size for robustness and this is discussed in the results section below.

From the investment literature, the capital asset pricing model (CAPM) suggests a negative relationship between non-diversifiable or systematic uncertainty and firm-level investment to the extent that firm-level returns are correlated with aggregate volatility (see, for instance, Leahy and Whited 1996). Since our sample has a large proportion of private firms, we cannot follow the standard approach of calculating firm specific "betas" and constructing a proxy of systematic uncertainty. As an alternative, we generated an uncertainty measure at the 3-digit NACE industry level from official statistics from the German Monopolies Commission.[13] We

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Industry Classification System (NAICS) used in the U.S.

[13] As we do not have information about employment at this detailed industry level, we do not normalize industry sales by the number of employees, but the number of firms active in that industry in a given year.

calculated the coefficient of variation for total industry sales (UNC_IND_{it-1}). This is included in our regressions as a control for systematic uncertainty which could influence firm-level R&D investment.

Another potential confounder in the relationship between investment and uncertainty is the risk aversion of the firm. If firms are risk-averse, then investment is expected to fall as uncertainty increases independent of any real options investment behavior. To control for this possibility, we postulate that each firm's risk preferences should be strongly reflected in its recent innovation strategy. That is, firms with an aggressive product innovation strategy should be the *least* risk-averse firms, while those following a conservative innovation strategy should be the most risk-averse. The firm's innovativeness (*PASTINNO*) is calculated using its average share of new product sales in the pre-sample period (the same period over which we calculate our uncertainty measure). In addition, the firm-specific effect in the panel data models should help control for risk preferences to the extent these are time constant in our sample period.

To control for firm-level innovation capabilities we used the firm's lagged patent stock per employee, $PSTOCK_{i,t-1}/EMP_{i,t-1}$, where the stock is calculated with data from the German Patent and Trademark Office. Those data cover German patents including EPO priority applications with German coverage since 1978. We cumulated each firm's patents from 1978 forward using a 15% annual obsolescence rate of knowledge (see e.g. Griliches and Mairesse, 1984, or Hall, 1990, for details). Firms with more productive R&D capabilities are expected to invest more in current R&D.

Our specifications control for access to internal and external financial capital. For the availability of internal capital, we used a measure of the firm's average price-cost margin, (*PASTPCM*), in the pre-sample period:[14]

$$(4) \qquad PASTPCM_{i,t-1} = \frac{1}{S}\sum_{s=1}^{S} PCM_{i,t-s}$$

with *PCM* = (Sales – staff cost – material cost + R&D) / Sales.

As a proxy for access to external credit, we used the firm's credit rating in period *t*-1 from Creditreform, the largest German credit rating agency.[15] The rating is an index ranging from 100 to 600, where 600 is the worst rating and essentially corresponds to bankruptcy.

Table 1 presents descriptive statistics of all variables. Note that all time-variant variables enter the right-hand side of the regressions as lagged values, so that they can be treated as predetermined. We also include aggregate industry, region, and annual time dummy variables in all regressions to capture differences in investment opportunities by industry, region, and time.

>>> Insert Table 1 about here <<<

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[14] See Collins and Preston (1969), or Ravenscraft (1983). Scholars who have used such measures to test for financial constraints typically add back R&D to PCM, as R&D is an expense and reduces profits in the period. If the firm would have decided not to invest in R&D, PCM would have been accordingly higher and is therefore corrected by current R&D in most empirical studies (see e.g. Harhoff, 1998). Note that many scholars used cash-flow instead of PCM (e.g. Fazzari et al., 1998), but unfortunately such information is not available to us. As the majority of firms are small and medium-sized privately owned companies, they are not obliged to publish their financial data.

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

3.2 Empirical Model

Annual firm-level R&D investment is a "corner solution" dependent variable because R&D investment can be zero with positive probability and it is roughly continuously distributed for strictly positive values. As discussed above, we set the firm-year observations with zero R&D to the minimum observed positive value in the sample in order to use the log of current R&D as our depended variable. In most of the regression analysis, we account for the censored distribution of R&D using a Tobit model. For the main results presented in Table 2, we use both pooled cross-sectional and random effects Tobit estimators. The model can be written as:

$$(5) \quad \begin{aligned} & y_{it} = \max\left(0, x_{it}\beta + c_i + u_{it}\right), \quad i = 1,2,\ldots,N, \;\; t = 1,2,\ldots,T \\ & u_{it} \mid x_i, c_i \sim N\left(0, \sigma_u^2\right) \end{aligned}$$

where y_{it} is the dependent variable (ln$R\&D_{it}$), x_{it} denotes the set of regressors, β the parameters to be estimated, and c_i the unobserved firm-specific effect, and u_{it} is the error term. First, we assume that $c_i = 0$, which allows us to estimate a pooled cross-sectional model where we adjust the standard errors for firm clusters to account for the panel structure of the data. The pooled model has the advantage that it does not maintain strict exogeneity of the explanatory variables. While consistency requires that u_{it} is independent of x_{it}, the relationship between u_{it} and x_{is}, $t \neq s$, is not restricted (see Wooldridge, 2002: 538). The model allows for feedback from R&D in period t to the regressors in future periods. For instance, the pooled model would allow for follow-on R&D in response to an increase in patents per employee at time t. In the second version of the model, we apply a random-effects Tobit panel estimator allowing $c_i \neq 0$.[16] This

[16] As described in the text, the uncertainty measures are calculated using moving time windows for each firm. As such, these measures do not vary sufficiently within firms to use a fixed effects or a correlated random effects

estimator explicitly models an unobserved firm-specific effect, but requires both strict exogeneity and independence between c_i and the explanatory variables, x_{it}. Due to these stronger assumptions, the random effects estimator is not necessarily superior to the pooled cross-sectional estimator, but imposes a different set of assumptions.

For the main results we assume our key explanatory variable, firm-specific volatility of new product sales (*UNC_NEW*), is independent of the error term in the R&D equation. However, it is likely that a firm's past sales volatility reflects aspects of the firm's own behavior and the behavior of other agents in the market. This suggests that our uncertainty measure might be endogenous if it is correlated with unobservable factors influencing the firm's current R&D decision. Some firm-specific characteristic or an omitted variable that is correlated with our uncertainty proxy and current R&D investment would be the most likely source of endogeneity.

To address this possibility we instrument for the explanatory variables in the R&D equation that might be endogenous. This group includes the new and old firm-specific uncertainty measures (*UNC_NEW*, *UNC_OLD*), any interaction terms, and the risk aversion proxy (*PASTINNO*). For each firm in our sample, exogenous instruments were constructed from data on every other firm in its 3-digit NACE industry except itself. Other firms in the industry will face similar supply and demand shocks, but the uncertainty and risk preferences of those firms will not be directly influenced by the focal firm's own characteristics such as its management practices that might be a source of endogeneity. To form these instruments, we went back to the full MIP database covering the years 1992 through 2005 and selected all

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estimator. To address this limitation, we use instrumental variables (IV) estimators with instruments that are unrelated to firm specific characteristics as robustness checks.

innovative firms with at least three years of new product sales data. The coefficients of variation for new and established product sales were calculated using Equation (3) for each firm and, after excluding the sample firm of interest, the average values were taken for each industry and year. A similar procedure was followed to construct the instrument for *PASTINNO*. The full set of instruments used in the analysis is composed of these IVs and their interactions with the industry dummy variables. Table 3 reports the IV regression results using both a pooled IV Tobit estimator and a linear IV random effects panel estimator.[17]

4 Results

Table 2 presents our baseline regression results. We consider three versions of the empirical specification: model A excludes the interaction variables between market uncertainty, industry concentration, and firm size. Model B examines how the R&D investment-uncertainty relationship is mediated by greater industry concentration which we interpret as indicating greater strategic rivalry. Model C looks at how the R&D investment-uncertainty relationship differs between large and small firms. In models B and C we estimated separate slope coefficients of uncertainty for each group of interest. In model B, the groups are concentrated versus less concentrated industries. In model C, the groups are large versus small firms.

Using both pooled and random effects Tobit estimators, model A finds that uncertainty in the market for new products significantly reduces firm-level R&D investment. This reaffirms and builds on earlier results found in Czarnitzki and Toole (2011).[18] It is also consistent with

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[17] A linear random effects IV panel estimator is used because estimating a Tobit random effects IV panel estimator with multiple endogenous variables is computationally infeasible.

[18] Czarnitzki and Toole (2011) argued that patenting mitigates the effect of market uncertainty on R&D investment by providing the firm with a legal right to prevent imitation in the product market. All the regression results

Minton and Schrand (1999) who found that cash flow volatility is associated with lower R&D investment for a sample of publicly traded U.S. firms. Uncertainty in the market for established products (*UNC_OLD*) is negative, but not significantly related to current R&D investment in any of the regression models in Table 2.

The results for the control variables show similar patterns across all three models. Both the employment and patent stock per employee covariates are positive and significant in all regressions. This suggests that larger firms and firms with more productive R&D operations invest more than smaller and less productive firms. Somewhat mixed results are found for our proxy for firm risk preferences ($PASTINNO_{it\text{-}1}$), firm price-cost margin ($PASTPCM_{it\text{-}1}$), and the direct effect of industry concentration, ($HHI_{i,t\text{-}1}$). The positive coefficient for *PASTINNO* suggests that less risk averse firms invest more in R&D; however, it is only significant when firm-specific effects are included in the specification. A firm's price-cost margin, which captures access to internal funds or possibly its market pricing power, is only significant in the pooled regressions when firm-specific effects are not modeled. The Herfindahl index is negative and significant in the pooled version of Model B, but insignificant in all five other specifications presented in Table 2. When significant, higher industry concentration appears to reduce current R&D investment. Industry-level uncertainty, which is the proxy for CAPM systematic risk, is never significant and neither is a firm's credit rating.

Model B looks at how strategic rivalry influences the firm-level R&D investment-uncertainty relationship. When the distribution of Herfindahl index is partitioned at the eightieth percentile, both models show that firms in upper quintile respond less to uncertainty. The Chi-

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presented in Table 2 continue to hold when this effect is included. Strategic rivalry and firm size capture separate squared test reported at the bottom of Table 2 shows a statistically significant difference across the two groups. If other cutoff points in the distribution of concentration are chosen, the firm-level responses to uncertainty become increasingly similar. We re-estimated the model using the 70%, 60% and 50% quantiles of HHI as cutoff points. The difference in the estimated slopes coefficients decreases as the cutoff point is moved downwards in the distribution. While the estimated coefficient for more concentrated markets is still slightly smaller in absolute value when the sample is split at the median of HHI, there is no statistically significant difference among them anymore. Both estimated coefficients approach the value of the non-interacted slope coefficient for uncertainty in model A.

The upper quintile of the HHI distribution contains many industries that are often characterized as oligopolies such as basic chemicals, milled grains, agricultural machinery, optical instruments, the manufacture of aircraft and spacecraft, and so forth. We believe these concentrated industries involve more intense strategic interaction and rivalry. Under this interpretation, our empirical results are consistent with theoretical models that predict strategic interactions erode the option value of waiting (Grenadier 2002; Weeds 2002; Kulatilaka and Perotti 1998).[19] To our knowledge, our analysis is the first to empirically examine how the R&D investment–uncertainty relationship is influenced by strategic rivalry. The results are mixed in

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and additional mechanisms explaining how firms react to market uncertainty.

[19] Note that strategic interaction as we have measured it does not completely erode the option value of waiting as Grenadier's model predicts. Since the option value of waiting is still relatively large for high concentration industries, our evidence appears to be more consistent with the model presented by Novy-Marx (2007). However, our empirical analysis is not a formal test of the differences between these models.

the literature studying the physical capital investment–uncertainty relationship (Bulan et al. 2009; Bulan 2005; Ghosal and Loungani 1996, 2000).[20]

Some readers may be concerned that we use the dummy D(HHI > Q_{80}) instead of using ln(HHI_{it-1}) for the interaction term. We re-estimated the model using the dummy D(HHI > Q_{80}) as a separate independent regressor instead of using ln(HHI_{it-1}) which conforms to the usual specification when including an interaction term. The results are very similar to those reported in Table 2. The dummy D(HHI > Q_{80}) has a negative coefficient in most models and is only statistically significant in one of the pooled models.

We also re-estimated the model investigating the effect of concentration at the lower tail compared to the upper tail of the HHI distribution. The specification included one slope parameter for the upper quintile of the HHI distribution, one for the lower quintile, and one for the remaining medium concentration. The results are virtually the same as presented in model B in Table 2 (therefore we omit a detailed presentation). The reaction to uncertainty by firms in industries in the upper quintile of concentration is significantly lower than those in industries with medium concentration. The reaction in low concentration industries is not different from the medium concentration industries.

Model C examines how firm size influences the R&D investment-uncertainty relationship. The regression results show that large firms respond less to market uncertainty than do small firms. The Chi-squared test shows a statistically significant difference across the two groups. This result is consistent with the findings of Ghosal and Loungani (2000) who examined

[20] Bulan et al. (2009) study the effects of competition on real estate investment. In their analysis, they capture strategic interaction between developers by identifying the competitors for each project using neighborhood

industry-level data on how physical capital investment responds to uncertainty. However, our work does not support their explanation that asymmetric information problems associated with uncertainty restrict access to financing for small firms more than it does for large firms. Our models hold financial constraints constant by controlling for internal cash flow and access to external financing. In our models, firm size must be capturing some form of managerial or operational flexibility that helps to offset market uncertainty related to product innovation. The precise nature of this additional flexibility is difficult to pin down. We postulate that large firms have greater flexibility in R&D asset utilization and this creates more valuable marginal operating options that help offset uncertainty. However, we cannot rule out other possibilities such as greater flexibility in project selection or multi-market diversification. We explored the firm size effect further by estimating a separate slope coefficient for the group of smallest firms, that is, firms with less than 50 employees (details not presented in Tables). It turns out that these do not differ significantly from those firms with 50 to 499 employees, but the largest firms still react significantly less to uncertainty than the medium-sized firms.[21]

>>> Insert Table 2 about here <<<

We also calculated marginal effects for both models, that is, dE(Y|X)/dx. The estimated marginal effects at the mean of uncertainty amount to -1.68 and -2.68 for large versus small

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"markets" defined as encompassing a 1 or 2 kilometer radius. They find that the effect of uncertainty on investment is less in markets with more competing projects, which can be interpreted as more strategic rivalry.

[21] We also estimated the model by replacing ln(EMP) with the LARGE FIRM dummy in the regressions to conform with the usual specification when using interaction terms. The coefficient of the dummy LARGE FIRM is positive and significant at the 1% level and the results concerning the uncertainty measures hold as reported in Table 2.

firms (significantly different at 1% level), and -1.87 and -2.67 for highly concentrated industries vs. others (different at 5% level). As these numbers are somewhat difficult to interpret economically, we illustrate the impact of uncertainty on R&D over the range of the uncertainty distribution in Figure 1. It can be seen that the slope of the curve (the marginal effect) is more negative for smaller firms and for firms in less concentrated industries compared to their respective control groups over a large range of the distribution.

>>> Insert Figure 1 about here <<<

4.1 IV Regression Results

Table 3 reports the results using instrumental variables for the firm's own volatility of new product sales (*UNC_NEW*), its volatility of old product sales (*UNC_OLD*), its risk preferences (*PASTINNO*), and the interaction variables between uncertainty, concentration and firm size. As before, Model A finds that firms reduce current R&D investment as uncertainty in new product markets increase. Relative to Table 2, the magnitude of the IV coefficient is larger in the pooled model and about the same as previously found in the random effects model. Uncertainty in established product markets is now marginally significant in the random effects version. *PASTINNO*, which was significant in the random effects model, is no longer significant due to a four-fold increase in its standard error and only a two-fold increase in its magnitude. The magnitudes of the coefficients for the price-cost margin and patents per employee become considerably smaller and insignificant in the IV results.

The IV results for Model B are not as favorable. In the pooled model, the coefficient estimate for high concentration markets is still notably smaller in absolute value, but this difference disappears in the random effects version. In both versions, the separate coefficient estimates for high versus low concentration markets are no longer significantly different as can be seen from the statistics reported at the bottom of the table. We suspect these results reflect the weaknesses of the Herfindahl-Hirschman Index (HHI) as an indicator of strategic rivalry and we explore this possibility further using the number of reported rivals as alternative in Table 4. The results for the other covariates are broadly consistent with those reported in Table 2 with the exception of the internal funds variable (i.e. price-cost margin). In the IV specifications, the magnitude of the coefficient for price-cost margin falls by almost 60% and becomes insignificant.

The IV versions of Model C continue to show that R&D investment by large firms responds less to market uncertainty than R&D investment by small firms. In both the pooled and random effects versions the coefficient estimates for large firms are smaller in absolute value. The Chi-squared test at the bottom of the table finds significant differences between the large and small firm coefficients at the 1% level. Volatility of old product sales (*UNC_OLD*) is marginally significant in the random effects version, but the proxy for risk preferences (*PASTINNO*) is insignificant in both versions. The results for the other covariates are broadly consistent with those reported in Table 2 with the exception of patents per employee which is insignificant in the IV results.

4.2 Alternative Measure of Strategic Rivalry

In light of the weaknesses of the HHI index as an indicator of strategic rivalry, we re-estimated all of the versions of Model B from Tables 2 and 3 using an alternative indicator that captures the number of rivals in the firm's main product market. Industries with a smaller number of competitors are oligopolistic in nature and likely to involve strategic interdependence and rivalry. As described in Section 3, we defined a dummy variable equal to one for firms in industries with the fewest reported competitors, called *D(Rivalrous)* in the tables.

Table 4 presents both non-IV and IV regression results for Model B. Uncertainty in new product markets (*UNC_NEW*) is interacted with *D(Rivalrous)* to estimate separate slope coefficients for industries with more versus less strategic rivalry. For the non-IV models in columns (2) and (3), the results are quite similar to those found using the HHI index in Table 2. Firms in industries with greater strategic rivalry react less to market uncertainty. This suggests that rivalry erodes the option value of waiting as predicted by some theoretical models such as Weeds (2002). The difference in the coefficient estimates between the two groups of industries is statistically significant at the 1% level.

The IV models reported in columns (4) and (5) use instrumental variables for the interactions involving (*UNC_NEW*), the volatility in established product markets (*UNC_OLD*), and the risk aversion proxy (*PASTINNO*). Unlike Model B in Table 3 that used HHI, the rivalry indicator using the number of competitors provides clear and significant results. The option value of waiting for R&D investment is completely offset for firms in industries with high strategic rivalry. These firms show no significant reaction to uncertainty while firms in industries with little to no strategic rivalry reduce their R&D investment in response to uncertainty. The difference in the coefficient estimates is significant at the 1% level. Most of the other results are similar to those reported in Table 3 except for the following exceptions. The proxy for risk preferences (*PASTINNO*) is significant in the random effects version, which is similar to the finding in Table 2. The price-cost margin is significant in both the pooled and random effects versions. Finally, *D(Rivalrous)* is negative and significant. Holding other factors constant, this suggests that firms in industries with fewer product market competitors invest less in current R&D.

5 Conclusions

Research and development (R&D) expenditure is a form of investment because it produces new knowledge that is cumulative and contributes to innovation and productivity in future time periods. Models of physical capital investment are frequently used to understand the incentives that drive R&D investment (Hall and Hayashi 1989). However, most empirical work on R&D investment relies on a simple investment model that ignores the insights from real options models. Real options models incorporate the opportunities and costs of future investment and disinvestment and draw attention to potentially important influence of uncertainty on the incentives for investment. This paper uses these insights to augment a standard R&D investment model and empirically examine the R&D investment-uncertainty relationship based on a firm-level panel database.

We find that firms respond less to uncertainty in markets where strategic rivalry is likely to be greatest. This result is consistent with real options models that predict the option value of waiting is eroded by the strategic value of pre-emption, but where the option values are not completely offset.

Our results also show that large firms react less to market uncertainty than small firms. Because we include controls for access to internal and external financing, we do not interpret this result as reflecting asymmetric information problems in capital markets that differentially affect small firms when uncertainty is high as in Ghosal and Loungani's (2000) study of physical capital investment. Instead, the models strongly suggest that large firms possess some kind of flexibility in R&D asset utilization, project design or selection that small firms do not enjoy. We believe Pindyck's (1988) analysis of flexibility in capacity utilization is most appropriate. Large firms possess more valuable marginal operating options that offset the option value of waiting. The fact that large firms are better able to weather market shocks may have important implications for the evolution of market structure and the distributions of firm size across industries; however, at this point in the research, it is not possible to draw conclusive predictions.

There are a number of issues that remain for future research. First, we must emphasize that we study innovative firms in the manufacturing sector. One must be cautious and not generalize our findings to non-innovative firms or to other sectors like services or agriculture. At this point, more research is needed before valid generalization can be done. Second, while our firm-level panel data make a significant step forward in the analysis of firm-specific uncertainty, the time series dimension of our data is not rich enough to model the dynamics of the R&D investment-uncertainty relationship. Third, the development of empirical measures that capture economies of scope at the firm-level would allow researchers to analyze the mechanisms driving down real options values for large firms in greater detail.

Appendix

Table A.1: Sample description by industry

Industry	Number of firm-year obs.	Avg. R&D (mil.DM)	Avg. employment	Avg. R&D/ empl. (in thsd.)
Food, Tobacco	160	0.23	183.39	0.88
Textiles, Clothing, Leather	142	0.40	322.66	1.24
Wood, Paper, Printing/Publishing, Furniture	308	1.22	305.68	1.37
Chemicals	248	18.23	871.03	10.05
Rubber, Plastics	267	0.64	212.23	2.91
Non-metallic mineral products	160	0.88	255.21	2.28
Metal production and processing	436	0.87	295.53	1.63
Machinery	485	4.66	448.99	5.31
ICT equipment, electronics	273	39.07	1274.01	9.08
Medical and precision instruments, optics	321	11.55	579.67	12.52
Vehicles	129	46.23	1118.63	7.31

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Table 1: Descriptive Statistics (2929 firm-year observations)

Variable	Mean	Std. Dev.	Min	Max
$R\&D_{it}$	9.655	97.078	0	3000
$UNC\_NEW_{i,t-1}$	0.958	0.685	0.015	3
$UNC\_OLD_{i,t-1}$	0.519	0.369	0.009	2.449
$UNC\_IND_{i,t-1}$	0.118	0.106	0.009	1.067
$PASTINNO_{i,t-1}$	38.849	25.650	0.125	99.167
$PASTPCM_{i,t-1}$	0.275	0.138	-0.373	0.827
$EMP_{i,t-1}$	514.721	2512.381	1	45000
$PSTOCK_{i,t-1}/EMP_{i,t-1}$	0.018	0.045	0	0.370
$HHI_{i,t-1}^{(1)}$	47.4	66.606	3.213	432.041
$RIVALROUS_i$	0.236	0.425	0	1
$RATING_{i,t-1}$	214.907	64.416	100	600
Large [$D(EMP_{i,t-1}>500)$]	0.147	0.355	0	1

Note: 10 industry dummies and 6 time dummies not shown. (1) The HHI index should be multiplied by 10 to be consistent with standard reporting that uses a maximum HHI of 10,000.

Table 2: Baseline Regressions of ln($R\&D_{it}$):

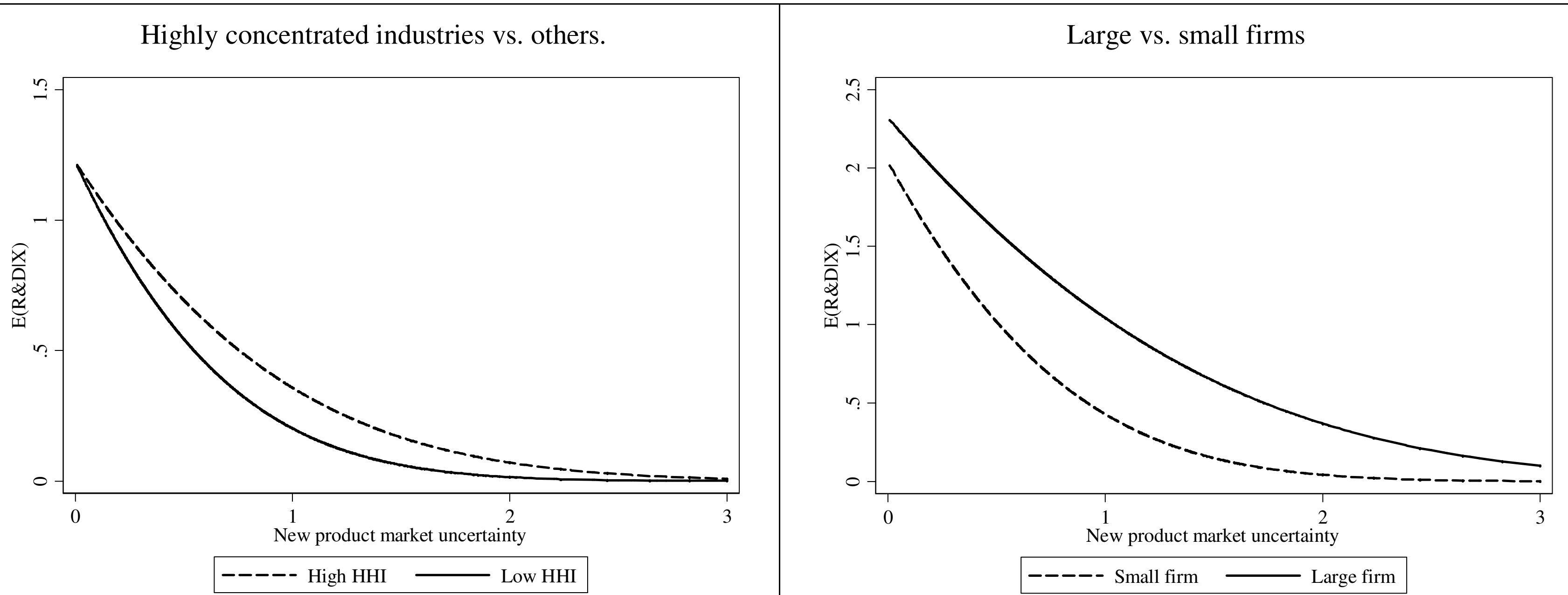
	Model A		Model B		Model C	
Variable	Pooled Tobit[a)]	RE Panel Tobit	Pooled Tobit[a)]	RE Panel Tobit	Pooled Tobit[a)]	RE Panel Tobit
$UNC\_NEW_{i,t-1}$	-4.125***	-3.026***				
	(0.331)	(0.318)				
$UNC\_NEW_{i,t-1}$ * D(HHI $_{i,t-1}$ > Q_{80})			-2.888***	-2.052***		
			(0.517)	(0.440)		
$UNC\_NEW_{i,t-1}$ * D(HHI $_{i,t-1} \leq Q_{80}$)			-4.358***	-3.219***		
			(0.330)	(0.323)		
$UNC\_NEW_{i,t-1}$ * LARGE FIRM					-2.609***	-1.446***
					(0.610)	(0.512)
$UNC\_NEW_{i,t-1}$ * SMALL FIRM					-4.362***	-3.289***
					(0.336)	(0.323)
$UNC\_OLD_{i,t-1}$	-0.334	-0.286	-0.401	-0.348	-0.379	-0.319
	(0.440)	(0.439)	(0.437)	(0.438)	(0.438)	(0.437)
$UNC\_IND_{i,t-1}$	0.160	0.598	0.865	1.152	-0.701	0.232
	(1.540)	(1.179)	(1.540)	(1.197)	(1.570)	(1.184)
$PASTINNO_{i,t-1}$	0.014	0.023**	0.014	0.023**	0.013	0.022**
	(0.009)	(0.010)	(0.009)	(0.009)	(0.009)	(0.009)
$PASTPCM_{i,t-1}$	2.975**	1.310	2.097**	1.393	1.786*	1.222
	(0.981)	(0.972)	(0.981)	(0.967)	(0.976)	(0.965)
ln($EMP_{i,t-1}$)	1.471***	1.554***	1.489***	1.561***	1.280***	1.363***
	(0.099)	(0.101)	(0.098)	(0.100)	(0.110)	(0.111)
$PSTOCK_{i,t-1}/EMP_{i,t-1}$	9.641***	9.891***	9.724***	9.942***	9.471***	9.577***
	(2.181)	(2.607)	(2.187)	(2.599)	(2.171)	(2.593)
ln($HHI_{i,t-1}$)	-0.106	0.021	-0.410***	-0.242	-0.127	-0.003
	(0.145)	(0.138)	(0.166)	(0.160)	(0.144)	(0.137)
ln($RATING_{i,t-1}$)	0.211	-0.208	0.166	-0.234	0.355	-0.104
	(0.610)	(0.527)	(0.609)	(0.525)	(0.603)	(0.525)
Intercept	-13.291***	-13.466***	-12.042***	-12.448***	-12.960***	-12.915***
	(3.783)	(3.171)	(3.771)	(3.178)	(3.736)	(3.157)

Table 2 continued

Joint significance of industry dummies ($\chi^2(10)$)	74.99***	84.16***	71.71***	79.89***	81.13***	89.53***
Joint significance of time dummies ($\chi^2(6)$)	122.43***	135.41***	122.55***	138.11***	120.70***	133.84***
Joint significance of regional dummies ($\chi^2(9)$)	17.27**	15.90*	19.19**	17.40**	19.70**	18.05**
Joint test on difference of slope coefficients of UNC_NEW variables ($\chi^2(1)$)			9.41***	10.05***	9.29***	15.61***
Log-Likelihood	-6084.35	-5881.41	-6073.67	-5876.46	-6070.67	-5873.68
McFadden-R^2	0.154	0.183	0.156	0.183	0.156	0.184

Note: Standard errors in parentheses. *** (**.*) indicate a significance level of 1% (5%. 10%). 2929 firm-year observations covering 1995-2001.
a) Standard errors are clustered at the firm-level (870 clusters).

Figure 1: Estimated effects of new product market uncertainty on R&D investment



Note: High concentrated industries are above the upper quintile of the HHI distribution. All covariates except new product market uncertainty are taken at their median values. Unlike employment as shown in the right panel of this figure, HHI is not significant as covariate in the regression. Therefore we restricted its independent impact to zero for this illustration.

Note: Large firms have more than 500 employees. In order to draw this curve we used reference firms that have +/- 100 employees above or below the cutoff. i.e. the small firm has 400 employees and the large firm 600. All covariates except new product market uncertainty are taken at their median values.

Table 3: IV Regression Models of $\ln(R\&D_{it})$

	Model A		Model B		Model C	
Variable	Pooled IV Tobit	RE Panel IV Linear	Pooled IV Tobit	RE Panel IV Linear	Pooled IV Tobit	RE Panel IV Linear
$UNC\_NEW_{i,t-1}$	-5.712***	-2.908***				
	(1.188)	(1.126)				
$UNC\_NEW_{i,t-1}$ * $D(HHI_{i,t-1} > Q_{80})$			-5.196***	-2.605***		
			(1.005)	(1.034)		
$UNC\_NEW_{i,t-1}$ * $D(HHI_{i,t-1} \leq Q_{80})$			-6.008***	-2.509***		
			(1.066)	(0.980)		
$UNC\_NEW_{i,t-1}$ * LARGE FIRM					-4.639***	-2.244**
					(1.101)	(1.031)
$UNC\_NEW_{i,t-1}$ * SMALL FIRM					-6.768***	-3.920***
					(1.149)	(1.081)
$UNC\_OLD_{i,t-1}$	-2.077	-3.281*	-1.129	-3.351*	-2.231	-3.002*
	(2.070)	(1.898)	(1.785)	(1.709)	(1.826)	(1.721)
$UNC\_IND_{i,t-1}$	0.988	0.404	1.214	0.305	0.159	0.087
	(1.328)	(0.823)	(1.350)	(0.843)	(1.349)	(0.842)
$PASTINNO_{i,t-1}$	0.029	0.049	0.031	0.060*	0.027	0.038
	(0.042)	(0.041)	(0.037)	(0.036)	(0.038)	(0.036)
$PASTPCM_{i,t-1}$	0.705	0.525	0.873	0.487	-0.029	0.121
	(0.977)	(0.865)	(0.933)	(0.808)	(0.942)	(0.817)
$\ln(EMP_{i,t-1})$	1.178***	0.923***	1.216***	0.938***	0.839***	0.677***
	(0.145)	(0.144)	(0.132)	(0.127)	(0.156)	(0.148)
$PSTOCK_{i,t-1}/EMP_{i,t-1}$	5.639	4.519*	6.061**	4.490*	3.910	3.380
	(2.849)	(2.543)	(2.696)	(2.351)	(2.686)	(2.368)
$\ln(HHI_{i,t-1})$	-0.183	-0.059	-0.325**	-0.038	-0.242**	-0.087
	(0.114)	(0.101)	(0.160)	(0.127)	(0.114)	(0.101)
$\ln(RATING_{i,t-1})$	0.101	-0.077	0.098	-0.122	0.227	0.008
	(0.473)	(0.367)	(0.467)	(0.363)	(0.474)	(0.373)
Intercept	-8.400	-7.230**	-8.006**	-7.827***	-6.057*	-5.264*
	(3.514)	(2.912)	(3.357)	(2.720)	(3.435)	(2.852)

Table 3 continued

Joint significance of industry dummies ($\chi^2(10)$)	70.65***	39.56***	72.38***	40.30***	72.79***	39.71***
Joint significance of time dummies ($\chi^2(6)$)	70.54***	72.32***	75.33***	75.43***	64.31***	68.45***
Joint significance of regional dummies ($\chi^2(9)$)	13.51	7.93	15.05*	6.61	1618*	10.41
Joint test on difference of slope coefficients of UNC_NEW variables ($\chi^2(1)$)			2.44	0.07	18.95***	13.02***
Regular-R^2	-	0.500	-	0.503	-	0.491

Note: Standard errors in parentheses. *** (**.*) indicate a significance level of 1% (5%. 10%). 2929 firm-year observations covering 1995-2001.

Table 4: Alternative Rivalry Indicator for Model B

Variable	Model B Pooled Tobit[a)]	Model B RE Panel Tobit	Model B Pooled IV Tobit	Model B RE Panel IV Linear
$UNC\_NEW_{i,t-1}$ * D(RIVALROUS)	-2.702***	-1.694***	1.233	1.196
	(0.521)	(0.493)	(1.473)	(1.434)
$UNC\_NEW_{i,t-1}$ * D(NON-RIVALROUS)	-4.427***	-3.330***	-5.967***	-2.285**
	(0.347)	(0.333)	(1.129)	(1.096)
$UNC\_OLD_{i,t-1}$	-0.356	-0.312	-2.245	-3.908**
	(0.437)	(0.437)	(1.819)	(1.711)
$UNC\_IND_{i,t-1}$	0.132	0.503	0.356	0.158
	(1.518)	(1.175)	(1.344)	(0.813)
$PASTINNO_{i,t-1}$	0.015*	0.246***	0.051	0.062*
	(0.009)	(0.009)	(0.035)	(0.035)
$PASTPCM_{i,t-1}$	2.185**	1.513	1.876**	1.319**
	(0.960)	(0.966)	(0.917)	(0.814)
$\ln(EMP_{i,t-1})$	1.485***	1.559***	1.322***	1.061***
	(0.097)	(0.100)	(0.130)	(0.130)
$PSTOCK_{i,t-1}/EMP_{i,t-1}$	10.242***	10.428***	9.119***	7.019***
	(2.177)	(2.598)	(2.651)	(2.362)
$D(RIVALROUS_i)$	-0.508	-0.289	-4.960***	-2.402**
	(0.447)	(0.512)	(1.223)	(1.120)
$\ln(HHI_{i,t-1})$	-0.176	-0.057	-0.272**	-0.056
	(0.149)	(0.140)	(0.116)	(0.102)
$\ln(RATING_{i,t-1})$	0.164	-0.271	-0.041	-0.171
	(0.611)	(0.525)	(0.476)	(0.371)
Intercept	-12.755***	-12.782***	-8.775**	-8.445***
	(3.786)	(3.161)	(3.439)	(2.860)

Table 4 continued

Joint significance of industry dummies ($\chi^2(10)$)	70.66***	77.14***	64.64***	36.16***
Joint significance of time dummies ($\chi^2(6)$)	124.21***	137.50***	77.04***	83.86***
Joint significance of regional dummies ($\chi^2(9)$)	17.88**	15.43*	18.51**	8.99
Joint test on difference of slope coefficients of UNC_NEW variables ($\chi^2(1)$)	9.70***	11.62***	23.24***	6.80***
Log-Likelihood	-6068.33	-5872.12	-	-
McFadden-R^2 or Regular-R^2	0.157	0.184	-	0.482

Note: Standard errors in parentheses. *** (**.*) indicate a significance level of 1% (5%. 10%). 2929 firm-year observations covering 1995-2001. a) Standard errors are clustered at the firm-level (870 clusters).