Who Does Invest in R&D? Theory and Evidence

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Abstract

We develop a simple model of competition in the market that shows that, contrary to the Arrow view, when entry can be regarded as endogenous, average firms tend to invest less in R&D but incumbent leaders tend to invest more than the average firms. We test these predictions with a Tobit model based on a unique dataset and survey for the German manufacturing sector (the Mannheim Innovation Panel). We confirm the empirical validity of our predictions and perform a number of robustness test.

There is a lot of debate on the role of market leaders in investing in R&D and promoting technological progress. A commonly held view is that firms invest more in a more competitive market where the entry pressure is stronger, and incumbents tend to be less innovative than their followers, so that persistence of their dominance is typically the signal of market power and lack of entry pressure. This view is often associated with Arrow (1962), who has shown that incumbents have lower incentives to invest in R&D than the outsiders, and that in case of free entry in the competition for the market they do not invest at all, leaving the innovative activity to the outsiders.

In this paper we challenge this view both from a theoretical and empirical perspective. First, we develop the simplest theoretical model able to provide clear cut results on the incentives to invest in R&D for incumbents and outsiders. The model is in the tradition of the recent works on endogenous market structures and market leadership,[1] and shows the crucial role of the entry pressure on the different behavior of incumbents and outsiders. In markets where entry can be regarded as endogenous, in the sense that entry occurs if there are profitable opportunities and the existing firms are threatened by the entry pressure, each firm tends to invest less, but when the incumbents have a leadership in the competition for the market, they tend to invest more than the average firm. In other words, we obtain the exact opposite of the commonly held view associated with Arrow: entry pressure leads the average firm to invest less and the incumbent leader to invest more, which ultimately leads to a surprising association between entry pressure and persistence of dominance through innovations. We also show that these theoretical results are robust to substantially different model specifications, in particular they hold in general patent races with endogenous entry (as in Etro, 2004, 2008), and in models of preliminary investment in R&D as a strategic commitment for competition in the market with endogenous entry (as in Etro, 2006).

We bring to the data the two basic predictions of our model: endogenous entry threats induce the average firms to invest less in R&D and the incumbent leaders to invest more.[2] We test these hypothesis through OLS and Tobit models for R&D intensity. Our empirical investigation is based on a unique dataset on the German manufacturing sector, the Mannheim Innovation Panel from 2005, which includes a wide number of firm level data and answers to a survey conducted by the Centre for European Economic Research (ZEW) with a special focus on innovation. A novel aspect of our

[1]See Etro (2007) for a review of this literature.

[2]For an alternative empirical investigation of the same result see Adams and Clemmons (2008).

empirical approach is given by the fact that the same firms provide a subjective view on our key determinants of R&D intensity, the entry pressure and the leadership: rather than assigning a degree of entry intensity in a discretionary way or assigning a status of leadership on the basis of predetermined variables, we allow the firms to identify the existence of an endogenous threat of entry in the market and the identity of the leader in the market. Control variables include employment, capital intensity and sector dummies. The independence of the entry variable from the dependent variable R&D intensity is supported through an instrumental variable analysis and a number of exogeneity tests. Our main predictions are strongly supported by the empirical evidence: entry pressure reduces the average investment per firm, but incumbent leaders invest more than other firms when they are pressured by a strong threat of entry.

These results can be interpreted as a preliminary attempt to test the main predictions of the endogenous market structures approach, that analyzes the role of firms in markets where entry is endogenous. In this case, the behavior of incumbent leaders is radically different depending on the entry conditions, and the conclusions of the cited approach appear to be confirmed empirically. At a policy level, the results suggest also that we may have to change our way of looking at persistent dominance in technologically advanced markets: this may be the result of strong competitive pressures rather than of market power.

The paper is organized as follows: Section 1 describes the theoretical model and derives the empirical prediction, Section 2 provides the empirical evidence, and Section 3 concludes.

1 A Model of R&D Investment

Consider a simple contest between an incumbent monopolist and N other firms to obtain a drastic innovation which provides a flow of profits $V \in (0, 1)$

for the winner and generates no gains for the losers.

Each contestant i bears fixed costs F and invests variable resources $z_i \in [0,1)$ to try to innovate. The index I denotes the incumbent. We can think of the fixed cost as the investment necessary to be engaged in R&D activity (i.e.: a laboratory), and of the variable resources as the labor force employed in the R&D activity (as opposed to be employed in the production activity). The variable investment in R&D has a cost and, for simplicity, we will assume that this cost is quadratic, that is $dz_i^2/2$, where the constant d parameterizes the marginal cost of investing in R&D: we can imagine that the productivity of the workers, their wage level and the size of the labor force affect it.

R&D investment provides the contestant with the probability z_i to innovate. If multiple firms innovate at the same time, competition in the market drives their profits to zero, therefore only in case of a single innovator, the contest has a winner. Summing up, the expected profit function of a generic non-incumbent contestant i is:

$$E(P_i) = z_i(1 - z_I) \prod_{j=1, j\neq i}^{N} [1 - z_j] V - \frac{dz_i^2}{2} - F \qquad (1)$$

where the first term is the expected gain from innovating and the second term is the cost of the R&D investment. The probability of winning the contest for firm i is the probability of innovating z_i multiplied by the probability that no other firm (including the incumbent) innovates, $\prod_{j\neq i}(1 - z_j)$. With this probability, the contestant obtains the award V.

The incumbent is engaged in the same kind of investment, but it keeps the profits from the cutting edge technology until the next innovation takes place. In particular, we assume that the incumbent can exploit its technology to obtain profits $\pi > 0$ in a preliminary period. Moroever, if no one innovates, the incumbent retains its profits π again. Therefore, the expected profits of the incumbent are:

$$E(P_I) = \pi + z_I \prod_{j=1}^{N} [1 - z_j] V + (1 - z_I) \prod_{j=1}^{N} [1 - z_j] \pi - \frac{dz_I^2}{2} - F \tag{2}$$

in case of positive investment in the contest - otherwise expected profits are given only by the current profits plus the expected value of the current profits when no one innovates.

1.1 Entry and R&D investment

In this section we study the investment of the firms in an industry where there are not strategic advantages for the incumbent or any other firm, and we evaluate the impact of entry on the investment level of each firm.

First of all, let us consider a Nash equilibrium between the incumbent and an exogenous number of entrants N. The first order conditions for the incumbent monopolist and for the other firms in Nash equilibrium are:

$$z_I = \max\left\{ \frac{(1-z)^N (V - \pi)}{d}, 0 \right\}, \ z = \frac{(1-z)^{N-1}(1-z_I)V}{d} \tag{3}$$

which shows that the incumbent invests if and only if $V > \pi$, and that invests always less than each entrant because of the Arrow (1962) effect: its gains from innovation are the difference between future and current profits, while the gains for the outsiders are the entire future profits. In general, one can show that the investments of the outsiders, $z(N)$, is a decreasing function of the number of firms, because strategic substitutability characterizes the objective functions.[3] Of course, total investment is increasing in entry, but the individual impact is always negative. Notice that the investment of each

[3] In the special case in which $V \leq \pi$, the incumbent does not invest at all and only the entrants invest. In case of a single entrant, its investment is $z(1) = V/d$, while in case of $N = 2$, each outsider invests $z(2) = V/(d + V) < z(1)$, and so on. When $V > \pi$ the investment of the incumbent (without any other strategic advantage) decreases with entry as well.

firm is increasing in the value of the innovation V and decreasing in the marginal cost of the investment (in d), while it is independent from the fixed cost F.

Let us move to the analysis of the endogenous entry case. Since entry reduces the expected gross profits and at some point these become smaller than the fixed cost, we can characterize the endogenous market structure emerging when the number of potential entrants is high enough. Firms enter until the following zero profit condition holds:

$$z(1-z_I)(1-z)^{N-1}V = \frac{dz^2}{2} + F \tag{4}$$

This implies that, in the endogenous market structure each entrant invests:

$$z = \sqrt{\frac{2F}{d}} \tag{5}$$

and it is easy to verify that it is actually in the interest of the monopolist to give up to any chances of innovation ($z_I = 0$).

Our conclusions on the impact of entry on R&D spending per firm are unambiguous: this is reduced with entry and it is definitely lower when entry is endogenous compared to the case of an exogenous number of firms that does not exhaust the profit opportunities in the industry. Summing up, these results can be translated in the following prediction:

Hp. 1: The investment of the average firm is lower when entry is endogenous.

The equilibrium investment with endogenous entry does not depend anymore on the value of the innovation (which increases the number of individual investors), but it is now increasing in the fixed costs of entry, and remains decreasing in the parameter that measures the marginal cost of investment. We can think of the marginal cost of investment as an inverse function of human resources of the company: a larger pool of workers reduces the marginal cost of research and therefore it corresponds to a lower d. Accordingly, we obtain the collateral prediction that the equilibrium investment is positively affected by the size of the labor force. We are not emphasizing the positive impact of the fixed cost F, which could be interpreted as the capital requirement, and the zero impact of the value of innovation V on entry because, as we will see later on, these two effects are model specific.

1.2 Leadership and R&D investment

As we have seen in the symmetric model above, when entry in the competition for the market is endogenous, the incumbent should not invest at all. Such a strong theoretical result is of course too drastic to be realistic. In many sectors, technological leaders invest a lot in R&D, try to maintain their leadership, and they often manage: for this reason the theoretical finding of Arrow is considered a paradoxical outcome. We will now verify what happens in an industry where the same contest takes place, but the incumbent leader can commit to an investment level before the other firms, a realistic situation in many sectors where the technological leader plays a special role in the competition for the market.

First of all, notice that in the presence of an exogenous number of firms, there are two effects on the investment of the incumbent leader. On one side, the Arrow effect leads to a lower investment compared to the followers because the incumbent leader ha less to gain from innovating. On the other side we have a Stackelberg effect, which in this framework characterized by strategic substitutability works in the opposite direction. Nevertheless, as long as the current profits of the leader are high enough, the first effect prevails and the incumbent leader invest less than the average firm.[4]

[4] For instance, with $d = 1$ and $N = 2$ we have:

$$z_I = \frac{V\pi + (1-V)(V-\pi)}{1-2V(V-\pi)} \qquad z = \frac{V\pi + (1-V)V - V^3}{1-2V(V-\pi)}$$

and the Arrow effect prevails on the Stackelberg effect whenever $\pi > V^3/(1-V)$.

If we want to compare the differential impact on R&D spending of being a leader when entry is endogenous, we need to derive the Stackelberg equilibrium with endogenous entry for this contest. First of all, notice that, as long as the investment of the leader is small enough to allow entry of some followers, the endogenous entry condition delivers again the investment $z = \sqrt{2F/d}$ for each outsider firm, and the endogenous number of active followers is:

$$N(z_I) = 1 + \frac{\log\left[(1-z_I)V/\sqrt{2dF}\right]}{\log\left[1/(1-\sqrt{2F/d})\right]}$$

Putting together these two equilibrium conditions in the profit function of the leader, we would have the following expected profits of the incumbent leader:

$$E(P_I) = \pi + d\left[\left(\frac{z_I}{1-z_I} + \frac{\pi}{V}\right)\sqrt{\frac{2F}{d}}\left(1 - \sqrt{\frac{2F}{d}}\right) - \frac{z_I^2}{2}\right] - F \qquad (6)$$

which is always increasing in the investment of the leader. Because of this, profit maximization generates a corner solution such that no outsider enters. Since $N(z_I) = 1$ requires $\log\left[(1-z_I)V/dz\right] = 0$, we can conclude that the leader will invest:

$$z_I = 1 - \frac{\sqrt{2dF}}{V} > \sqrt{\frac{2F}{d}} \qquad (7)$$

When the monopolist is the leader in the competition for the innovation, the Arrow effect disappears, because the choice of the monopolist is independent from the current profits.[5] Notice that the investment of the leader is increasing in the expected flow of profits V (more expected profits require a larger investment to deter entry of the outsiders). Moreover, the investment is still decreasing in d, and is now decreasing in the fixed cost of entry of the other firms (which reduces the investment needed to deter entry).

[5]See De Bondt and Vandekerckhove (2007) for further extensions of this result to the case of R&D spillovers between firms.

The crucial result is that leadership in the competition for the market radically changes the behavior of an incumbent: from zero investment to maximum investment. Summing up, there are two sufficient conditions under which monopolists have incentives to invest in R&D and to invest more than other firms: 1) leadership for the incumbent monopolist and 2) endogenous entry for the outsiders in the race to innovate.[6] On this basis we can summarize our main empirical prediction as follows:

Hp. 2: The investment of the incumbent leader is larger than the investment of the average firm when entry is endogenous.

This result shows a clear contrast with what we expect for the average firms, and provides an empirical discriminant between the investment of the incumbent leaders and that of the average firms: the former should be larger than the latter if and only if there is a constant threat of entry in the market.

1.3 Robustness of the theoretical findings

The empirical prediction of our simple model are not model specific, and they can be found in much more general models of patent races (Etro, 2004) and of preliminary investment in R&D as a strategic commitment for the competition in the market. To convince the reader of this, we will briefly provide a couple of examples.

A patent race A wide literature on R&D investments (started by Dasgupta and Stiglitz, 1980) has studied patent races where the investment z_i generates innovations according to a Poisson process with arrival rate given by a general function $h(z_i)$ eventually exhibiting decreasing returns to scale, so that the expected value of innovating for an average firm is $h(z_i)/\left[r+\sum h(z_j)\right]$ with r interest rate. In such a case, entry reduces the investment of the average firm (confirming Hp. 1), and Etro (2004, 2008)

[6]See Czarnitzki and Kraft (2007) for a related discussion.

has shown that when entry is endogenous the incumbent leader invests always more than any other single firm (confirming Hp. 2), even if entry of followers is not deterred here. In case of linear variable costs of investment dz_i, the investment levels of the average firm z and of the incumbent leader z_I satisfy:

$$h'(z)\frac{V-F-z}{V}=h'(z_I)=\frac{dh(z)}{z+F}$$

which confirms that $z_I > z$ and that the investment of every firm is increasing in any factor that reduces the marginal cost of investment d, as the size of employment. This confirms the validity of the main empirical predictions of our basic model.[7][8]

Strategic investment in R&D Similar results have been developed in models of R&D spending as a strategic investment preliminary to the competition in the market. In these models, R&D spending per firm is typically decreasing with entry, which confirms our Hp. 1. Moreover, the investment of the incumbent leaders is radically different according to whether entry is endogenous or not. Etro (2006) has shown that investments in cost reductions aimed at reducing the price of a good give rise to neat predictions under

[7] However, the impact of the fixed cost is negative on the average firm, which shows that the comparative statics of the basic model with respect to F was not roboust.

[8] Notice that the same results hold in case of sequential innovations. Since incumbents invest more, their leadership is more likely to persist (it persists for sure in our model where incumbents deter entry). As noticed in Etro (2007), this suggests a way to discriminate between different degrees of persistence of leadership in innovative sectors. When entry of firms in the competition for the market is endogenous we should expect that technological leaders invest a lot and their persistence is more likely. Of course, when there is no competition for the market we should expect that the monopolistic leadership is also persistent. However, when the degree of competition for the market is intermediate (entry is not free but more than one firm invests), we should expect that the incumbent does not invest much in R&D and that its leadership is more likely to be replaced. This suggests that the degree of persistence of leadership should follow and inverted U relation with the degree of entry in the competition for the market.

competition in prices: in particular, market leaders should spend less than the other firms in R&D investments in cost reductions when the number of firms is exogenous, and they should spend more when entry is endogenous. One should keep in mind that this result holds under competition in prices, while under competition in quantities the leader would generally spend more than the followers in cost reductions under both entry conditions: nevertheless, also in such a case, entry would increase the investment of the leader. Again, this confirms our Hp. 2.

To verify the last result, let us briefly consider a model of Cournot competition with inverse demand $p = a - X$ between an incumbent leader with marginal cost $c(z_I) = c - \sqrt{z_I/d}$, with $d > 1$, affected by its investment z_I and N other firms with a constant marginal cost c. The Cournot equilibrium and the optimal (interior) investment of the incumbent leader can be easily derived in case of an exogenous number of firms and with endogenous entry. In the latter case, we have $x_I = d\sqrt{F}/(d-1)$ and $x = \sqrt{F}$ with the strategic investment of the leader: $z_I = \frac{dk}{(d-1)^2}$which implies the following rule for the optimal ratio between R&D spending z_I and sales of the leader px_I:

$$\frac{R\&D}{Sales} = \frac{\sqrt{F}}{(d-1)(c+\sqrt{F})} \tag{8}$$

This result is expressed in terms of a commonly used ratio in empirical work on innovation, and it supports again the comparative statics of our simple model. Moreover, as shown in Etro (2006) and Maci and Zigic (2008), the leadership generates always overinvestment for strategic reasons, which confirms our main theoretical prediction, for which leaders should invest more than the other firms, as a fraction of revenues, when they face endogenous entry.

2 Empirical Test

In this section, we perform a simple empirical test on whether actual firm-level investment data support our hypotheses derived from the theoretical framework.

2.1 Data sources

We use data from the Mannheim Innovation Panel (MIP) from the year 2005. This innovation survey has been conducted by the Centre for European Economic Research (ZEW), Mannheim, and covers a representative sample of the German manufacturing sector as well as business related services. For our study, we focus on the manufacturing sector. The 2005 spell of the MIP included some unique questions allowing to model entry threats and to identify leaders/incumbents.

The database has a cross-sectional structure, but the questionnaire collects information generally for the years 2002 to 2004. The quantitative variables, such as R&D investment, capital, employment, sales etc., are surveyed for a certain year. For instance, R&D investment is only collected for the year 2004. Other information that we use as controls are, however, collected for the two years 2003 and 2004, so that we can make use of lagged controls to avoid direct simultaneity bias in the regressions. Qualitative information, such as the competitive situation in a firm's main market, the firm's competitive position etc., are collected through one question each referring to the time period 2002–2004. We will use the qualitative information to construct variables on incumbency and entry threats during this period, and argue that the situation between 2002 and 2004 will have an impact on strategic investment behavior in 2004.

The dependent variable of our analysis is the R&D intensity in the year 2004 at the firm level. The intensity is defined as R&D divided by sales ($RDINT_i = R\&D_i/SALES_i \times 100$).

The most important right-hand side variables are aimed at identify the endogeneity of entry in the market where each firm is active and the leadership position. An innovative aspect of our empirical approach is given by the fact that the same firms provide a subjective view on these two factors: rather than assigning a degree of entry intensity in a discretionary way or assigning a status of leadership on the basis of predetermined variables, we allow the firms to identify the existence of an endogenous threat of entry in the market and the identity of the leader in the market.

The survey asked for several characteristics about the competitive situation in firms' main product markets in the time period 2002–2004. In particular, firms where asked to indicate if a list of six statements about the firms competitive environment apply to their situation or not. The response was based on a 4–point Likert scale, from "entirely applies" to "does not at all apply". Thus, our variable of entry threat, $ENTRY_i$, is an ordinal variable taking values from 0 to 3, where 3 indicates that the respondent firm strongly agreed to the statement that its market position is highly threatened by entry. When this is the case, we conjecture that entry in the industry where the firm is active can be regarded as endogenous; when the firm does not consider the threat of entry as present in its industry, this is regarded as one with an exogenous number of firms. As found in the theoretical framework (Hp. 1), we expect a negative sign of $ENTRY_i$ in the regressions for the average R&D intensity.

The theoretical definition of a market leader is associated with a strategic first mover advantage, but a more general definition can be based on the leading strategic position of the firm compared to its main competitors. Therefore, our incumbent variable is defined through a question on a firms' position compared to its main competitors. The respondents indicated if their competitors are larger, smaller, similar size, or larger and smaller than their firm. Consequently, an incumbent leader in our analysis is identified by an indicator variable, $LEADER_i$, describing a firm that is larger than the competitors in its main product market.

While we expect that entry has a negative impact on investment in general, the theoretical framework shows that incumbents choose to invest more than other contestants if their market is threatened by entry (Hp. 2). We capture this by an interaction term of leadership and entry ($LEADER_i \times ENTRY_i$).

As outlined in the theoretical model, it is desirable to control for employment and capital requirement. We include firms' employment in $t-1$ ($EMP_{i,t-1}$) as well as capital intensity ($KAPINT_{i,t-1}$) in the empirical model to account for such impacts on investment decision. For the size of the employment we expect a positive sign in the regression analysis on the basis of our theoretical work. Concerning the role of capital intensity, we noticed that theoretical results are model specific. For completeness, we estimate two separate slopes for capital intensity: one for the incumbents and one for the outsiders.

Finally, we used twelve industry dummies to control for unobserved heterogeneity in investment across industries. The industries are: Food, Textiles, Paper/Publishing, Chemicals, Rubber, Glass/Ceramics, Metal, Machinery, Electronics, Information & Communication Technology, Instruments/ Optics and Vehicles.

Table 1 shows the descriptive statistics of core variables used in the upcoming regression analysis. In total, we can use 1,908 observations for the empirical study. The average R&D intensity of firms is about 2.3% and average firms size amounts to 307 employees in the sample. 8% of all firms are classified as incumbents.

2.2 Econometric Analysis

As not all firms invest in R&D, we estimate both standard OLS models and Tobit models that take account for the left censoring of the dependent variable. The Tobit model to be estimated can be written as

Table 1: Descriptive statistics (1,908 observations)

Variable	Mean	Std. dev.	Min.	Max.
$RDINT_it$	2.271	5.112	0	38.914
$EMP_{i,t-1}/1000$	0.307	1.356	0.001	36.761
$KAPINT_{i,t-1}$	0.078	0.090	0.001	0.861
$LEADER_{it}$	0.080	0.271	0	1
$ENTRY_{it}$	1.531	0.851	0	3

$$RDINT_i^* = X_i'\beta + \varepsilon_i$$

where $RDINT_i^*$ is the unobserved latent variable. The observed dependent variable is equal to

$$RDINT_i = \begin{cases} RDINT_i^* \text{ if } X_i'\beta + \varepsilon_i > 0 \\ 0 \text{ otherwise} \end{cases}$$

X_i represents the matrix of regressors, β the parameters to be estimated, and ε_i the random error term. In the case of OLS, $RDINT_i = RDINT_i^*$. In our basic specification, X_i includes $EMP_{i,t-1}$, $EMP_{i,t-1}^2$, $KAPINT_{i,t-1}$, $LEADER_{it}$, $ENTRY_{it}$ as well as 12 industry dummies. In further models, we add the interaction term $LEADER_i \times ENTRY_i$. We estimate two separate slopes for the capital requirement as measured through capital intensity, one for the outsiders and a separate one for the incumbents.

For the OLS models, we compute robust standard errors. In the Tobit case, we first consider homoscedastic regressions, and subsequently test for heteroscedasticity as coefficient estimates may be inconsistent if the assumptions of homoscedasticity is violated in Tobit models. In order to estimate heteroscedastic Tobits, the homoscedastic variance σ is replaced with $\sigma_i = \sigma \exp(Z_i'\alpha)$ in the likelihood function (see Greene, 2003, pp. 768–9).

We consider groupwise multiplicative heteroscedasticity by using a set of five size dummies (based on employment) and the industry dummies in the heteroscedasticity term.

Table 2 shows the regression results for the different OLS and Tobit models. In the OLS I regression, we find weak evidence that the higher the threat of entry, the less firms invest in R&D, and incumbents' investment does not differ from that of the outsiders. When we add the interaction term of leadership and entry threat (See OLS II), however, interesting differences occur. While the incumbent dummy is still insignificant, we now find that incumbents who are faced by potential entry invest more than the outsiders. Also the entry threat variable is now negatively significant at the 5% level. The other covariates, except the industry dummies, are insignificant in both models. As the OLS models do not take the left censoring of the dependent variable into account, though, we continue with the Tobit estimations. The Tobit I and Tobit II models confirm the OLS results concerning entry threats and leadership. Stronger entry threats lead to lower investment in general. However, this effect is offset for the incumbent leaders: incumbents threatened by entry invest more then the outsiders, and also more than non-threatened incumbents, all else constant. As one can see in the heteroscedastic version of the Tobit II regression, the χ^2–test on heteroscedasticity shows that the assumption of homoscedasticity is rejected as the industry dummies and size dummies in the heteroscedasticity term are jointly significant. However, the main findings are robust across all Tobit models.

To sum up, our findings on entry are in line with our Hp. 1, that is, investment decreases with the strength of entry threats. Furthermore, we find that incumbents do not differ in their investment from other firms ($LEADER_i$ is insignificant), unless they are threatened by entry. Then the negative investment effect is offset (see the positive sign of the interaction term $LEADER_i \times ENTRY_i$). Thus, incumbents invest more than the outsiders under entry threat. In line with our Hp. 2, the competitive pressure

Table 2: Regressions on R&D intensity (1,908 observations).

$Variable$	$OLSI^a$	$OLSI^b$	Tobit I	Tobit II	Tobit II^b (*heter.*)
$EMP_{i,t-1}/1000$	0.143 (0.148)	0.158 (0.148)	0.825*** (0.267)	0.860*** (0.267)	0.618*** (0.108)
$(EMP_{i,t-1}/1000)^2$	−0.002 (0.004)	−0.003 (0.004)	−0.021** (0.010)	−0.022** (0.010)	−0.016*** (0.003)
$KAPINT_{i,t-1} * (1 - LEADER_{i,t})$	0.066 (0.995)	0.049 (0.995)	4.534** (2.158)	4.467** (2.157)	1.310 (0.987)
$KAPINT_{i,t-1} * LEADER_{i,t}$	0.523 (2.600)	0.498 (2.608)	0.868 (7.764)	0.595 (7.768)	−0.231 (2.405)
$LEADER_{i,t}$	−0.582 (0.404)	−0.608 (0.403)	0.089 (0.989)	0.039 (0.988)	0.327 (0.417)
$ENTRY_{i,t}$	−0.223* (0.117)	−0.326*** (0.125)	−0.578*** (0.224)	−0.854*** (0.248)	−0.317** (0.129)
$ENTRY_{i,t} * LEADER_{i,t}$	/	0.225** (0.115)	/	0.580*** (0.219)	−0.295*** (0.114)
Intercept	0.710*** (0.253)	0.691*** (0.255)	−4.953*** (0.946)	−5.006*** (0.946)	−0.902*** (0.325)
Joint signific. ind. dummies	19.60**	19.31***	344.99***	337.43***	161.90***
Wald Test on heter.	/	/	/	/	564.15***
R^2/ LogLikelihood	0.156	0.158	-3897.23	-3897.23	-3646.10

of the potential entry of other firms induces the market leaders to invest in R&D more than any other firm.

In contrast to the OLS models, we also find effects for the other covariates once we take the censoring of the dependent variable into account in the Tobit regressions. There we find weak support for the hypothesis that outsiders' investment is increasing with capital intensity. While the estimated coefficient for the outsiders is positive in all three Tobit models, it is only significant in the homoscedastic specifications. Finally, capital intensity does not seem to matter for the incumbents' investment.

We also experimented with separate employment effects for incumbents and outsiders, but these did never differ among the two groups in any specification. Thus, we just present estimates for employment that are common for both firm types. We allowed a non–linear effect with respect to employment and it indeed turned out that the estimated coefficients describe an inverse U shape. However, the extreme value of that curve is at about 19 thousand employees. As only 2 observations in the sample are larger than that, we basically find that investment is increasing with employment.

Instrumental variables

In our empirical investigation we have proxied the endogeneity of entry in the market where each firm is active with the existence of a threat of entry perceived by the same firm. This short cut avoids the need of investigating what are the determinants of the fact that a market is characterized or not by endogenous entry as opposed to being limited to an exogenous number of firms. While this does not affect our results, the determinants of entry are in itself interesting. More importantly, a main concern with respect to the results presented so far relies in the independence of our entry variable from the dependent variable. It is possible that successful innovative activity in the past leads to technological advantage of the firms, which are presently active in an industry: entry will then be difficult for outsiders. To the contrary, if the incumbents are not research active and neglect the development of new processes and products, entry will be relatively easy. Clearly this points to the relevance of past R&D on entry decisions, whereas our dependent variable is the ratio of current R&D to sales volume. However R&D expenditures are highly autocorrelated (probably because of high adjustment costs for research and development facilities and the hiring of highly specialized personnel) and then current R&D is related to past activities. Sutton (1998, 2006) characterizes R&D as a strategic factor, which is used by some companies to determine market structure. He also shows what factors determine the role of R&D as a strategic variable to deter entry. At least the possibility of a reverse relationship has to be investigated. We experimented with a number of candidates for instrumental variables as outlined in the following paragraphs.

To find instrumental variables that explain our entry variable but not the R&D intensity variable we need to look at the main factor that attracts entry, the difference between the expected profits in the market and the fixed costs of entry. Many empirical studies have emphasized role of profitability for entry and market growth.[9] One would expect that entry occurs more frequently in markets where profitability is expected to be high, and less frequently when profitability is expected to be low. However, expected profitability is hard to measure or to proxy, and the adoption of past profitability of the incumbent firms has often led to mixed results. For instance, Geroski (1995) points to empirical evidence from the UK that entry and exit rates are positively correlated, which is difficult to reconcile with the static profitability interpretation. Our dataset does not allow us to solve this problems. However, the business conditions of an industry matter and in order to take them into account, we use the number of defaults relative to the total number of firms in an industry. The number of defaults is obtained from Creditreform, the largest German credit rating agency. This serves as an indicator of an industry with turmoil ($Default_{t-1}$).

Let us move to the fixed costs of entry as a (negative) determinant of entry. There is a well developed theoretical and empirical literature on the so-called barriers to entry. The empirical studies on entry barriers address the question of natural barriers, like scale economies, and strategic barriers for instance excess capacity, limit pricing, product differentiation by means of advertising or also innovative activity. Economies of scale are frequently regarded as a cause of entry barriers. In practice it is not trivial to identify scale economies. Sutton (1998) uses the size of the median plant in an industry as a proxy for minimum efficient scale. In other studies variants of size

[9] A recent example is Berger *et al.* (2004).

measures are used, but most studies rely on observed size as it is very difficult to get information on the minimum efficient size required by the technology used.[10] We have no information on the median firm, but know total industry sales and the number of firms active therein. This information is taken from official statistics and measured at a detailed industry level (NACE 3-digit level). The ratio, industry sales per firm, is applied as a proxy for minimum efficient scale and enters the regressions as lagged value (MES_{t-1}).

Sutton (1998, 2006) also emphasizes the importance of substitutability among products. If products are homogenous (in the Sutton terminology a high α-industry), an entrant offering a product with a higher quality, captures a relatively large market share as many consumers are interested in a superior product. In contrast, if products are distant substitutes (low α-industry) a firm investing in improved product quality will only gain a small share of the industry sales as consumer preferences are very heterogenous. Hence product substitutability is a determinant of entry barriers, with higher substitutability supporting entry.[11]

The 2005 MIP questionnaire also collects information on the relation between products. The respective question is “Please indicate to what extent the following characteristics describe the competitive environment in your main market.” One characteristic is “Products of rivals are easily substitutable with ours.” The evaluations are rated by use of a four point Likert scale ranging from “applies entirely” to “does not apply at all”, which we transform into four dummy variables. Three of them are included in the first stage regression ($SUB2$ to $SUB4$).

Clearly, the demand for a product will affect entry, and demand for a

[10] Lyons *et al.* (2001) use engineering estimates based on the firms’ technologies employed in the production process.

[11] Shaked and Sutton (1982, 1983) analyse a game where firms choose whether to enter or not at the first stage of the game, choose quality at the second stage and prices at the third stage. Surprisingly they show in their model that only a few and in the limit only one firm will operate in the industry despite of endogenous entry.

product may in turn be affected by advertising intensity. For our purpose, it is not relevant whether advertising is informative or has a direct impact on preferences. In both cases demand reacts to advertising. The survey collected information on the importance of advertising. Firms were asked to rank the importance of several characteristics of their competitive environment (product quality, technological advance, service, product variety, advertising and price) where they are active. Thus we translate the variable into a series of six dummy variables indicating the importance of advertising for the firm's business strategy ($ADV1$ to $ADV6$).

We first test for endogeneity using the instrumental variables as described above. We apply a regression based test following Hausman (1978, 1983).[12] Suppose our R&D investment equation is given by:

$$y_{i1} = x_i'\beta + \alpha y_{i2} + u_i, \tag{9}$$

where the possibly endogenous regressor y_2 is the entry threat in our case, and the vector x_i denotes the other regressors. Then we write the reduced form equation for y_2 as:

$$y_{i2} = z_i'\pi + v_i, \tag{10}$$

where z_i' contains the vector x and the other instrumental variables described above. Once we estimate (10), we obtain $\hat{v}_i$, we can estimate our R&D equation including the generated residuals from the first stage regression as:

$$y_{i1} = x_i'\beta + \alpha y_{i2} + \rho\hat{v}_i + e_i, \tag{11}$$

The usual t–statistic of $\hat{\rho}$ is a valid test on the endogeneity of y_2. If it is not rejected that $\hat{\rho} = 0$, we do not find that y_2 is endogenous. In the Tobit framework, the test is equivalent and has been introduced by Smith and

[12]See also Wooldridge (2002, pp. 118–120).

Blundlell (1986). There, one simply estimates a standard Tobit instead of OLS to determine whether $\hat{\rho} = 0$.

Furthermore, we compute the Hansen J–Test (the heteroscedasticity robust version of the Sargan test) on overidentifying restrictions, that is, we test if our instrumental variables are valid candidates.

The following table reports several test statistics. First, we simply report the F–statistics of the instrumental variables (as given in the headline of the table). Second, we report the endogeneity test of Hausman based on OLS and Smith-Blundell based on Tobit models. Further, we report the overidentification tests. This, however, is only based on the OLS models, as such tests are not available for the Tobit framework. The logic of the result interpretation is as follows. First we find that the F-statistics on joint significance of our instruments indicate that they are highly significant in the first stage. They explain a significant share of the variation in the entry variable, and thus we can conclude that they fulfil a basic assumption of potentially valid instruments. Further, we find that the Hansen J-test rejects the validity of instruments in the version where we employ all possible instruments that we discussed in the text above (see right column of the Table). Further inspection has shown that the variables on product substitutability may not be considered as exogenous to R&D. However, if we use the reduced set of instruments, MES_{t-1}, $ADV2$ to $ADV4$, $Default_{t-1}$, the model passed the test. The null hypothesis that the instruments are valid is not rejected. Thus, we go ahead and check if the endogeneity tests indicate that the entry variable is in fact endogenous in our regressions for R&D intensity. While we find that the instruments have significant explanatory power in the first stage regressions, and that at least a subgroup of them turn out to be valid, we do not find evidence that the entry variable is endogenous in any of our regressions for R&D intensity shown in Table 2. Neither the Hausman test nor the Smith-Blundell test reject the exogeneity of this variable in our regression models. Therefore, we conclude that the regressions as shown in Table 2 are valid.

Table 3: Various tests on endogeneity of entry variable and instruments

Test	MES_{t-1}	MES_{t-1}, $ADV2$ to $ADV4$, $Default_{t-1}$	MES_{t-1}, $ADV2$ to $ADV6$, $Default_{t-1}$, $SUB2$ to $SUB4$
F-Test on (joint) significance in first stage regression	F(1,1887) = 15.52***	F(7,1877) = 5.30***	F(10,1874) = 8.55***
Hausman endogeneity test[a]	-0.60	-0.40	1.52
Blundell and Smith endogeneity test[b]	-0.08	0.39	0.18
Blundell and Smith endogeneity test (heteroscedastic model) [b]	-0.38	-0.38	-0.57
Hansen J-Test on overidentification[c]	—	0.400	0.052

Notes: *** (**,*) indicate significance level of 1% (5%, 10%).

[a] t-statistics of first stage residuals are displayed.

[b] t-statistics of first stage residuals are displayed.

[c] Based on OLS models. All estimations are robust against heteroscedasticity.

For completeness, it is noteworthy to mention that we actually estimated IV regressions for all models as shown in Table 2, and that all findings are robust. While already supported by the test statistics mentioned above, the IV results confirm our confidence in the instrumental variables. It does not seem that the regressions suffer from a significant weak instrument problem.

3 Conclusions

Who does invest in R&D? This article has provided theoretical and empirical motivations for a relatively surprising answer to this question: market leaders do invest in R&D more than other firms when they are under the competitive pressure of endogenous entrants. The immediate consequence is that under these conditions incumbents are more likely to innovate and therefore to persist in their leading position. This result suggests that we may have to change our way of looking at persistent dominance in a technologically advanced market: this may be the result of strong competitive pressures.

Our empirical analysis can be seen as a first attempt to test the predictions of the endogenous market structures approach. Further work could examine other predictions on the role of leaders in pricing strategies, preliminary investments, financial decisions and so on.

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