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Working Paper

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Non–technical Summary

There is a long debate on the role of market leaders in investing in R&D. Following Arrow (1962), a popular view regards competitive pressure as being supportive for innovative activity and that incumbents tend to be less innovative than outsiders. In this paper, we reconsider this view both from a theoretical and an empirical perspective. A theoretical model provides hypotheses on the incentives to invest in R&D for incumbent leaders and outsiders. It establishes the crucial role of entry pressure on the behavior of leaders and followers. In markets with free entry each firm tends to invest less, but when the incumbents have a leadership position in the competition for the market, they tend to invest more than the average firm. Hence, we obtain the exact opposite of the commonly held view associated with Arrow. We also show that these theoretical results are robust to different model specifications.

Our theoretically derived hypotheses are tested with a sample of German manufacturing firms. We study R&D intensity at the firm level, and the novel aspect of our empirical approach is given by the fact that the companies provided a subjective view on our key determinants: entry pressure and the identification of market leaders. Control variables include employment, capital intensity, a measure of the firms' patent stock, the Herfindahl index of concentration 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.

We find strong empirical evidence for our main predictions: 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. This implies that we may have to change our way of looking at persistent market dominance: this may be the result of strong competitive pressure rather than of market power.

Das Wichtigste in Kürze (Summary in German)

Seit langem wird über die Rolle von Marktführern bei Forschungs- und Entwicklungsausgaben diskutiert. In Anschluss an Arrow (1962) ist die Meinung weit verbreitet, dass sich Wettbewerbsdruck positiv auf Innovationsaktivitäten auswirkt, und Marktführer weniger innovativ sind als kleinere Konkurrenzunternehmen. In dieser Arbeit überdenken wir diese Sichtweise. Wir entwicklen ein theoretisches Modell zu den Anreizen, in Forschungs- und Entwicklungsaktivitäten zu investieren. Insbesondere unterstreicht dieses Modell die Bedeutung von Marktzutrittsmöglichkeiten. Bei freiem Marktzutritt investiert jede Firma weniger, aber die Marktführer investieren mehr als andere Firmen. Wir erhalten folglich genau das entgegengesetzte Ergebnis von Arrow. Wir zeigen, dass diese theoretischen Ergebnisse robust gegenüber Modellvariationen sind.

Die aus der Theorie hergeleiteten Hypothesen werden mit Daten deutscher Firmen empirisch überprüft. Wir analysieren die Forschungs- und Entwicklungsintensität auf der Unternehmensebene, wobei ein neuer Aspekt unserer Untersuchung die Art der Berücksichtigung von Marktzutrittsbarrieren und der Identifikation von Marktführern ist: beide Variablen basieren auf Selbsteinschätzung der jeweiligen Firmen für ihren relevanten Markt. Kontrollvariablen sind Beschäftigung, Kapitalintensität, der Patentbestand auf Unternehmensebene, Herfindahl–Konzentrationsindex sowie Branchendummies.

Exogenitätstests zeigen, dass die Marktzutrittsvariable von den FuE–Aufwendungen unabhängig ist. Unsere theoretischen Hypothesen werden durch die empirische Evidenz unterstützt: Bei freiem Marktzutritt investieren Unternehmen im Durchschnitt weniger in FuE. Marktführer investieren jedoch mehr als andere Unternehmen, wenn ihre Position stark duch Marktzutritt bedroht wird. Die Ergebnisse führen zu der Schlussfolgerung, dass die weitverbreitete Ansicht über dauerhafte Dominanz in Märkten überdacht werden sollte. Fortdauernde Marktführerschaft kann das Ergebnis von starkem potenziellen Wettbewerbsdruck sein und muss nicht von Marktmacht herrühren.

The Effect of Entry on R&D Investment of Leaders: Theory and Empirical Evidence[1]

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Abstract

We develop a simple model of competition for the market that shows that, contrary to the Arrow view, endogenous entry threat in a market induces the average firm to invest less in R&D and the incumbent leader to invest more. 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 with instrumental variables.

JEL–Classification: O31, O32
Keywords: R&D, Entry, Endogenous market structures, Leadership

[1]We are grateful to participants at the Intertic Conference on Endogenous Market Structures and Industrial Policy, at the ZEW Conference on the Economics of Innovation and Patenting and at the CRESSE Conference in Athens, inculding Christian Köhler, Jaanika Merikull, Frederic Scherer, and especially Richard Schmalensee, Frode Steen and Andrew Toole.

1 Introduction

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 the persistence of their dominance is typically the signal of market power and of the 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 incumbent leaders and outsiders. The model is in the tradition of the recent works on endogenous market structures and market leadership,[2] and shows the crucial role of entry pressure on the different behavior of leaders and followers. 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 leadership through innovations. We also show that these theoretical results are robust to different model specifications, in particular they hold in general patent races (as in Etro, 2004, 2008), and in models of preliminary investment in cost reducing R&D as a strategic commitment for the competition in the market (as in Etro, 2006).

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

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.[3] We test these hypothesis through a Tobit model 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 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 determining arbitrarily the size and composition of a market, assigning a degree of entry intensity in a discretionary way, and assigning a status of leadership on the basis of predetermined variables, using the questionnaire of the Mannheim Innovation Panel we allow the firms to identify the size of their main market, 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, a measure of the patent stock, the Herfindahl index of concentration 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

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

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.

2 A Model of R&D Investment

The aim of this section is to provide theoretical motivation for our testable predictions. With this purpose in mind, we first develop the simplest model that leads to our main results, and then we sketch other theoretical frameworks that support the same predictions.

Let us consider a simple contest between N 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 that lead to the probability of innovation $z_i \in [0,1]$. For simplicity we assume that the cost of the R&D activity is quadratic in z_i, that is $dz_i^2/2$, where the constant d parameterizes the marginal cost of investing in R&D.[4] 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 cost as the rate of investment in R&D spending.

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 contestant i is:

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

[4]This is what emerges in case of a Cobb-Douglas innovation function employing capital k_i and labor l_i, as $z_i = k_i^{\alpha} l_i^{\beta}$ with $\alpha + \beta = 1/2$.

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.

2.1 Entry and R&D investment

In this section we evaluate the impact of entry on the investment level of each firm in Nash equilibrium. The first order conditions for the investment choice of each firm can be written as follows in a symmetric equilibrium:

$$z = \frac{(1-z)^{N-1}V}{d} \tag{2}$$

Even if this is an implicit expression for the equilibrium investment, its total differentiation shows that R&D investments per firm is a decreasing function of the number of firms ($\partial z/\partial N < 0$). Of course, total investment is increasing in entry, but the individual impact of an increase in the number of firms is always negative. Moreover, the investment of each 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:

$$z(1-z)^{N-1}V = \frac{dz^2}{2} + F \tag{3}$$

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

$$z = \sqrt{\frac{2F}{d}} \tag{4}$$

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 as follows: the investment of the average firm is lower when the entry threat 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 the human resources of the firm: a larger pool of workers reduces the marginal cost of research and therefore it corresponds to a lower d. Accordingly, we could obtain the collateral prediction that the equilibrium investment is increasing in the size of the labor force ($\partial z/\partial d < 0$) and it is increasing in a less than proportional way ($\partial^2 z/\partial d^2 > 0$).

2.2 Leadership and R&D investment

Let us now introduce an incumbent leader in this model. Such a firm is defined as one that is perceived in the market as the larger incumbent firm and that is able to commit before the others to certain investment decisions.

In our model the market leader is engaged in the same kind of investment as the other firms, but can exploit its leadership to obtain extra profits $\pi > 0$ compared to the other firms in a preliminary period, and retain the same profits in case no one innovates. Therefore, the expected profits of the leader are:

$$E(P_I) = \pi + z_I \prod_{j=1}^{N} [1 - z_j] V + (1 - z_I) \prod_{j=1}^{N} [1 - z_j] \pi - \frac{dz_I^2}{2} - F \quad (5)$$

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. We are interested in Stackelberg equilibrium where the leader decides how much to invest and subsequently the other firms take the same decision independently.

First of all, notice that in the presence of an exogenous number of outsiders, 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 has 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 invests less than the average firm.[5]

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 z_I 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:

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

which is always increasing in the investment of the leader. Therefore, in this simple example, profit maximization generates a corner solution such that

[5] 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 $\pi > V^3/(1-V)$.

no outsiders enter. Since $N(z_I) = 1$ requires $\log[(1 - z_I)V/dz] = 0$, we can conclude that the leader invests:

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

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.[6] 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).

The interest of this extreme result emerges when we compare it to the case in which the incumbent has not a first mover advantage. In such a case, the standard Arrow effect leads to the opposite result: the incumbent does not invest at all and only the outsiders invest and possibly innovate. 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 leader and 2) endogenous entry for the outsiders in the race to innovate. 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.

The main empirical prediction of our simple model are not model specific, and they can be found in much more general models of patent races 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.

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

2.3 A general 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 an arrival rate given by a function $h(z_i)$ eventually exhibiting decreasing returns to scale, so that the expected value of innovating for an average firm is $h(z_i)V/\left[r+\sum h(z_j)\right]$ where r is the interest rate. In such a case, one can verify that entry reduces always the investment of the average firm, and Etro (2004, 2008) has shown that when entry is endogenous the incumbent leader invests always more than any other single firm. However, in this model entry of outsiders occurs and is not deterred by the leader. For instance, in case of linear variable costs of investment dz_i, the R&D investment of the average firm z and of the incumbent leader z_I satisfy:

$$h'(z)\frac{V-F-z}{V}=h'(z_I)=\frac{dh(z)}{z+F} \tag{8}$$

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 (typically the size of employment). This confirms the validity of the main empirical predictions of our basic model.

2.4 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 the number of firms, which confirms our earlier results. 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: 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.[7] More generally, as shown in Etro (2006) and Maci and Zigic (2008), the leadership generates always strategic overinvestment in R&D relative to sales when entry is endogenous.

2.5 Testable predictions

Our overview of simple and general theoretical models of the incentives to invest in R&D emphasizes two conclusions that appear robust to alternative modeling specifications. They can be summarized as follows:

Hp. 1: R&D intensity of the average firm is lower when entry is endogenous.

Hp. 2: R&D intensity of the incumbent leader is larger than the investment of the average firm when entry is endogenous.

The first hypothesis suggests a negative relation between the threat of entry perceived by the firms and their rate of investment in R&D, and it derives from the strengthening of competition for the market induced by entry. The second one is our main interest because it is in radical contrast

[7]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. 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:

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

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.

with the Arrowian view of the incumbent leaders as firms investing less than the other firms in R&D. According to our models, these leaders should invest more than the other firms if and only if they face a strong threat of entry pressure.

3 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.

3.1 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 the entry threat 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 were 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 "applies strongly" to "does not apply at all". 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 and concave relation on the basis of our theoretical work. Concerning the role of capital intensity, we noticed that theoretical results are model–specific. Thus, we do not have strong priors on the sign of the coefficient of capital intensity. We also control for the Herfindahl index of concentration of the industry where the firm is active.

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.

R&D and unobserved firm heterogeneity

While we believe that our unique survey data offer some interesting new insights about the empirical modeling of investment decision under entry threats, one may be concerned that we do not have panel data to control for unobserved heterogeneity.[8] However, we can offer one robustness check that might account for unobserved heterogeneity to a large extent. We are able to construct a patent stock at the firm level accounting for all patent application from 1978 onwards. While patents are certainly not a perfect measure (see e.g. Griliches, 1991), we believe that the patent stock proxies past R&D efforts of a firm to a large extent.

In particular, we compute the patent stock using the perpetual inventory method for each firm. The survey data has been merged with the database from the German Patent Office which covers all patents filed at both the German and the European Patent Office since 1978. We follow the common practice in the literature and impose a rate of obsolescence of 15% per year when computing the patent stock (see e.g. Griliches and Mairesse, 1984). Including such a rate of obsolescence implies, quite realistically that knowledge loses its relevance similarly as capital depreciates over time. The variable $PSTOCK$ is given by

$$PSTOCK_{it} = (1 - \delta)PSTOCK_{i,t-1} + PA_{it},$$

where $\delta = 0.15$, and PA_{it} denotes patent applications of firm i in year t. We set the initial patent stock in year 1978 to zero for all firms. Since we use data from 2002-2004 in our regressions, the bias arising from a zero starting value will have disappeared due to the included depreciation rate δ.

[8] While we certainly agree that it would add to the robustness of our results if we had panel data, the information we use is just not existing for multiple time periods in the survey (yet).

Potential feedback from R&D to entry threat

In our empirical investigation we proxy the threat of entry in the market where each firm is active with the perception of the firm as collected in our survey data. This shortcut 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. A main concern relies in the independence of our entry variable from the dependent variable. It is possible that current R&D leading to a future technological advantage makes firms perceive the entry threat as less severe. To the contrary, if firms are not research active and neglect the development of new processes and products, entry may appear as a quite realistic threat. Sutton (1998, 2006) characterizes R&D as a strategic factor, which is used by some companies to determine the 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 the 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. We use a proxy for the opposite of profitability, namely the percentage of defaults out of the total number of firms in an industry as a variable standing for risk 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 ($Default_{t-1}$).[10] We expect a negative impact of the default probability of

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

[10] This variable should be interpreted as an index only. The default data we have concern

the existing firms on entry rates.[11]

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 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.[12] 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.

all defaults in a given industry. However, the total number of firms stems from official statistics that only account for firms above 20 employees. Therefore the ratio should not be interpreted as the exact percentage of bankruptcies in an industry.

[11]However, 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.

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

Hence product substitutability is a determinant of entry barriers, with higher substitutability supporting entry.[13]

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 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 ($ADV2$ to $ADV6$). Descriptive statistics for the instrumental variables are reported in Table 1 as well.

[13] Shaked and Sutton (1982, 1983) analyze 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.

Table 1: Descriptive statistics (1,857 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
$HHI_{i,t-1}$	36.778	61.022	3.15	650.17
$PSTOCK_{i,t-1}/(EMP_{i,t-1}/1000)$	8.864	26.906	0	222.447
IV candidates				
$DEFAULT_{t-1}$	22.834	16.246	0	80.924
MES_{t-1}	0.079	0.166	0.009	2.102
$SUB2_{it}$	0.246	0.431	0	1
$SUB3_{it}$	0.450	0.498	0	1
$SUB4_{it}$	0.237	0.425	0	1
$ADV2_{it}$	0.061	0.239	0	1
$ADV3_{it}$	0.137	0.344	0	1
$ADV4_{it}$	0.129	0.336	0	1
$ADV5_{it}$	0.184	0.387	0	1
$ADV6_{it}$	0.464	0.499	0	1

3.2 Econometric Analysis

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

$$RDINT_i^* = X_i'\beta + \varepsilon_i \tag{9}$$

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

$$RDINT_i = \begin{cases} RDINT_i^* \text{ if } X_i'\beta + \varepsilon_i > 0 \\ 0 \text{ otherwise} \end{cases} \tag{10}$$

X_i represents the matrix of regressors, β the parameters to be estimated, and ε_i the random error term. In our basic specification, X_i includes $EMP_{i,t-1}$, $EMP^2_{i,t-1}$, $KAPINT_{i,t-1}$, $LEADER_{it}$, $ENTRY_{it}$ as well as 12 industry dummies. In further models, we add the interaction term $LEADER_i \times ENTRY_i$, and the patent stock to control for previous R&D.

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 homoscedastic models, and Table 3 for the heteroscedastic models. In the homoscedastic Tobit Model I, we find that R&D investment decreases as the threat of entry increases. The leaders' investment does not differ from that of the outsiders. When we add the interaction term of leadership and entry threat (See Model II), however, interesting differences occur. While the leader dummy is still insignificant, we now find that leaders who are faced by potential entry invest more than the outsiders. The results remain robust when we control for prior R&D using the patent stock. The patent stock is highly significant and positive, i.e. firms that (successfully) conducted R&D in the past will also invest more in the current period.

With respect to the other covariates, we find a positive and concave relation with employment.[14] Capital intensity is positively significant in all models, and the Herfindahl index is always insignificant. Furthermore there are differences in R&D investment across industries. The industry dummies are always jointly different from zero in the regressions, and our results em-

[14]The inverted U curve peaks at about 20 thsd. employees. As we have only a single observation that has more employees, we can basically conclude that R&D investment is increasing and concave in firm size.

phasize a high correlation of R&D spending with firms of the Information & Communication Technology.

Table 2: Homoscedastic Tobit models on R&D intensity (1,857 observations)

Variables	Model I	Model II	Model III
$EMP_{i,t-1}/1000$	0.840***	0.877***	0.803***
	(0.266)	(0.267)	(0.260)
$(EMP_{i,t-1}/1000)^2$	−0.021**	−0.022**	−0.019**
	(0.010)	(0.010)	(0.009)
$KAPINT_{i,t-1}$	4.126**	4.039**	3.621*
	(2.066)	(2.065)	(2.017)
$HHI_{i,t-1}$	0.001	0.001	0.001
	(0.004)	(0.004)	(0.004)
$PSTOCK_{i,t-1}$			0.050***
			(0.006)
$LEADER_{it}$	−0.099	−0.161	−0.298
	(0.676)	(0.676)	(0.660)
$ENTRY_{it}$	−0.598***	−0.853***	−0.727***
	(0.223)	(0.246)	(0.240)
$ENTRY_{it} * LEADER_{it}$		0.541***	0.488**
		(0.217)	(0.212)
Intercept	−4.788***	−4.844***	−4.816***
	(0.939)	(0.939)	(0.915)
Industry dummies $\chi^2(12)$	304.69***	298.33***	239.66***
Log–Likelihood	−3769.18	−3766.07	−3735.12

Notes: Standard errors in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%).

As Table 3 shows, the assumption of homoscedasticity is rejected for all models (see Wald tests on heteroscedasticity). The industry and firm size dummies are always jointly significant in the variance equation. However, our main results are robust to the model modification. Leaders, in general, are still not differently investing in R&D than the outsiders, and R&D investment is negatively affected by the entry variable. Leaders that suffer from entry threat also invest more than outsiders in the heteroscedastic version.

Table 3: Heteroscedastic Tobit models on R&D intensity (1,857 observations)

Variables	Model I	Model II	Model III
$EMP_{i,t-1}/1000$	0.625^{***}	0.640^{***}	0.610^{***}
	(0.112)	(0.111)	(0.112)
$(EMP_{i,t-1}/1000)^2$	-0.016^{***}	-0.017^{***}	-0.016^{***}
	(0.003)	(0.003)	(0.003)
$KAPINT_{i,t-1}$	1.047	1.037	1.031
	(0.919)	(0.927)	(0.924)
$HHI_{i,t-1}$	0.001	0.001	0.001
	(0.002)	(0.002)	(0.002)
$PSTOCK_{i,t-1}$			0.032^{***}
			(0.005)
$LEADER_{it}$	0.147	0.135	0.045
	(0.271)	(0.269)	(0.271)
$ENTRY_{it}$	-0.203^{*}	-0.322^{**}	-0.317^{**}
	(0.120)	(0.130)	(0.128)
$ENTRY_{it} * LEADER_{it}$		0.302^{***}	0.291^{**}
		(0.115)	(0.114)
Intercept	-0.802^{**}	-0.909^{***}	-0.949^{***}
	(0.331)	(0.334)	(0.338)
Industry dummies: $\chi^2(12)$	143.09^{***}	142.86^{***}	109.11^{***}
Log–Likelihood	−3533.40	−3529.90	−3511.60
Wald Test on			
heteroscedasticity: $\chi^2(17)$	534.22^{***}	530.71^{***}	514.14^{***}

Notes: Standard errors in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%).

There are no dramatic changes in the estimates of the other covariates. The patent stock is still highly positively significant, and the estimated employment effect remains stable. However, the positive relationship between

R&D and capital investment becomes statistically insignificant, once we correct for heteroscedasticity.

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 incumbent leaders do not differ in their investment from other firms ($LEADER$ is insignificant), unless they are threatened by endogenous 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 endogenous entry threat. In line with our Hp. 2, the competitive pressure of the potential entry of other firms induces the market leaders to invest in R&D more than any other firm.

In economic terms, the findings are also highly significant. Calculating the expected value of $RDINT_i$ for outsiders under no entry threat, yields (see Greene, 2003, pp. 768-9, for the computation of the expected value in Tobit models):

$$E(RDINT_i|LEADER_i = 0, ENTRY_i = 0, \bar{X}_i) = 0.98,$$

where the covariates are taken at the average $\bar{X}_i$.[15] In contrast, the investment intensity of outsiders under high entry threat only amounts to:

$$E(RDINT_i|LEADER_i = 0, ENTRY_i = 3, \bar{X}_i) = 0.49,$$

which means R&D intensity reduces by about 51%, all else constant. If a leader suffers from high entry threat, however, we get:

$$E(RDINT_i|LEADER_i = 1, ENTRY_i = 3, \bar{X}_i) = 0.93,$$

which corresponds only to a 5% decrease due to entry threat. Statistically, the leader's reduction due to entry is not even different from zero. With respect to our Hp. 2, we confirm the theoretical prediction that leaders invest more than the average firm under entry threat. Investment of leaders is about 89% higher (R&D intensity is 0.93% while outsiders only achieve 0.49%).

[15] Calculations are based on the heteroscedastic estimation of Model III.

Results on potential feedback from R&D to entry

First, we test if the above mentioned instrumental variables are relevant in the first stage regression of entry on all covariates and the excluded instruments. Table 4 shows the partial F-values for the instrumental variables in the first stage regression.

Then we test for endogeneity of entry in the second stage regression following Smith and Blundlell (1986). They introduced a regression based test which is basically equivalent to the procedure suggested by Hausman (1978, 1983) for the OLS case.[16] Suppose our R&D investment equation is given by:

$$y^*_{i1} = x'_i\beta + \alpha y_{i2} + u_i, \tag{11}$$

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:

$$y_{i2} = z'_i\pi + v_i, \tag{12}$$

where z'_i contains the vector x and the other instrumental variables described above. Once we estimate (12), we obtain $\hat{v}_i$, we can estimate our R&D equation including the generated residuals from the first stage regression using Tobit as:

$$y^*_{i1} = x'_i\beta + \alpha y_{i2} + \rho\hat{v}_i + e_i, \tag{13}$$

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.

Table 4 reports the IV relevance tests from the first stage regression (partial F–statistics), and the Blundell/Smith test on endogeneity of entry based on the heteroscedastic regressions of Model I (the homoscedastic version led to the same conclusions).

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

Test	MES_{t-1}	MES_{t-1}, $Default_{t-1}$	MES_{t-1}, $Default_{t-1}$, $ADV2$ to $ADV6$	MES_{t-1}, $Default_{t-1}$, $ADV2$ to $ADV6$, $SUB2$ to $SUB4$
F-Test on IV significance in 1st stage regression	F(1,1838) = 14.33***	F(2,1837) = 7.51***	F(7,1832) = 4.94***	F(10,1829) = 8.19***
Blundell/Smith endogeneity test[a]	−0.53	−1.01	−0.67	−0.69

Table 4: IV relevance tests and endogeneity test of entry variable

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

[a] Based on heteroscedastic model I. t–statistics of first stage residuals are displayed.

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 are relevant in explaining entry. Based on that, we then compute the Smith/Blundell test as described above. As can be seen in the table, the hypothesis of exogeneity of the entry variable in not rejected by any combination of instruments used. Note that we also tested more combinations of our IV candidates than shown in Table 4, but the results never changed. We also tested other IVs that are not mentioned in the text, e.g. the average profitability in the industry, and the ratio of capital depreciation and total assets at the industry level as a further proxy for sunk costs. None of these were significant in the first stage regression explaining entry nor did the Smith/Blundell test reject exogeneity.

As there is no statistical test on the validity of available instruments for the Tobit case, we additionally just computed he Hansen J–Test (the heteroscedasticity robust version of the Sargan test) on overidentifying restrictions based on standard 2–stage least squares regressions. The test confirmed the validity of the instruments as shown in Table 4 except in the last case where we added the substitutability variables to the list of IVs. The Hansen test rejects the null hypothesis at the 10% level in this case.

In summary, we found relevant instrumental variables, but the exogeneity of the entry variable has not been rejected by the tests. Furthermore, we can also confirm the validity of instruments based on 2SLS regressions using the Hansen J-Test for several IV combinations. Given these results, we conclude that the results as presented in Table 3 still hold, and that our two main hypothesis are thus confirmed: R&D investment decreases with larger entry threats in general, but leaders invest more into R&D when threatened by entry.

4 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.

A novel aspect of our 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 determining arbitrarily the size and composition of a market, assigning a degree of entry intensity in a discretionary way, and assigning a status of leadership on the basis of predetermined variables, using the questionnaire of the Mannheim Innovation Panel we allow the firms to identify the size of their main market, the existence of an endogenous threat of entry in the market and the identity of the leader in the market. Our empirical approach can be seen as a first attempt to test the predictions of the endogenous market structures approach and could be applied to other empirical implications, for instance, on the role of leaders in pricing strategies, preliminary investments, financial decisions and so on.

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Appendix

Table A1: Sample description by industry aggregates

Industry	# obs.	# leaders	Average R&D intensity (in %)
Food	121	13	0.33
Textiles/Leather	97	9	1.21
Paper/Publish	306	23	0.73
Chemicals	132	6	3.50
Rubber	138	9	1.16
Glass/Ceramics	82	11	0.93
Metal Production	61	5	0.63
Metal Fabrication	259	22	1.09
Machinery	222	23	2.68
Electronics	109	7	2.51
ICT	70	3	5.65
Instruments/Optics	172	14	7.10
Vehicles	88	4	2.37
Total	1857	149	