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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 than the average firm. We test these predictions with a Tobit model based on a unique dataset and survey for the German manufacturing sector (the Mannheim Innovation Panel). In line with our predictions, endogenous entry threats perceived by the firms reduce R&D intensity for the average firm, but not for an incumbent leader. Moreover, the size of the firms and their patent stocks, proxy for the protection of IPRs, are positively related to R&D intensity. These results hold after a number of robustness tests with instrumental variables.

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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 adopt a Schumpeterian perspective and we challenge this view both from a theoretical and empirical perspective, showing under which conditions incumbent leaders do invest more than the other firms and providing empirical evidence in support of our thesis.

There are few competing explanations for innovation by incumbents in Schumpeterian growth models. The simplest one, due to Segerstrom (2007) relies on the fact that incumbents may have a technological advantage in the R&D activity. This assumption may be realistic in certain sectors and allows one to study monopoly persistence, but it is basically equivalent to assume the solution of the Arrow paradox rather than solving it. Moreover, taking this view literaly, we should conclude that whenever we observe monopoly persistence it is because the incumbent firm is more efficient than the other firms both at producing and innovating. There are many sectors in which incumbents do not appear to have any cost advantage in the development of innovations compared to the outsiders, and still both the incumbents and the entrants keep investing.

Acemoglu (2008, 2009, Ch. 14) has proposed a different rationale for innovation by leaders. This may be due to the fact that only the incumbents can invest in incremental innovations (because outsiders would infringe their patents through small improvements), while entrants can invest (alone because of the Arrow effect) in more radical innovations. In such a way, both the incumbents and the outsiders invest, and the growth rate depends on their rates of investment weighted by the respective productivity increases. This is a plausible mechanism, but it explains why incumbents may invest in small improvements of their own technologies, which is a trivial activity, and not why they may directly compete against outsiders to obtain radical innovations, which is the key issue.

Here, we propose an alternative explanation for innovation by incumbents which does not rely on technological advantages or exogenous market structures, but is based on a pure strategic advantage of the incumbents in patent races with endogenous entry of outsiders. We develop a simple contest for a drastic innovation with strategic interactions in the tradition of the recent works on endogenous market structures and market leadership,[2] and show the crucial role of entry pressure on the different behavior of leaders and followers. In markets where there are no incumbents, entry reduces the relative investment of each firm (though the aggregate investment increases). Therefore the endogenous entry threat tends to reduce R&D intensity of each firm. Moreover, in such a context, an incumbent would not invest at all because of the Arrow effect. However, things change under the assumption that the incumbent is also the leader in the contest for the innovation, as reasonable given its strategic advantage in the market. The incumbent that is also leader exploits its first mover advantage to invest more than the other firms. The intuition has to do with the impact of its investment on entry: a small investment attracts large entry and makes it likel that someone else will replace the incumbent, while a commitment to a large investment has the double advantage of reducing entry and increasing the chances of an innovation.[3] We

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

[3]Aghion and Howitt (2009, Ch. 14) have forcefully advanced an "escape competition" rationale for investment by incumbents under entry, but their models rely on the assumption that a single incumbent faces an exogenous probability of entry (or an endogenous probability that a single rival may replace its leadership). Under endogenous entry of

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).

We bring to the data the two basic predictions of our theoretical investigations: R&D intensity of the average firm is lower when there is an endogenous entry threat, and the R&D intensity of the incumbent leader is larger than the one of the average firm when there is an endogenous entry threat.[4] 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 Survey from 2005 conducted by the Centre for European Economic Research (ZEW), that includes a wide number of firm level data 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 survey results 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 employment level and the patent stock, which can be seen as a proxy for the degree of received protection of IPRs, are positively correlated with R&D intensity, while the other controls appear to be uncorrelated. The independence of

outsiders, their incumbent would not invest as usual as a consequence of the Arrow effect (and the escape competition effect would disappear as well).

[4] Aghion *et al.* (2009) provide additional empirical evidence on the impact of entry on incumbents' investments. For an alternative empirical investigation of the same result see Adams and Clemmons (2008).

the endogenous 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 there is the pressure of 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.

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.[5] 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:

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

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.

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

[5] 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 $\alpha + \beta = 1/2$.

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. Notice that the incentives of the incumbent to invest are lower than for the outsiders because of the Arrow effect. If the incumbent was choosing how much to invest at the same time with the outsiders, endogenous entry would lead the leader not to invest at all. However, here we are interested in the Stackelberg equilibrium where the incumbent leader decides how much to invest before the other firms and subsequently these other firms take their investment decision.

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.[6]

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 no outsiders enter. Since $N(z_I) = 1$ requires $\log\left[(1-z_I)V/dz\right] = 0$, 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.[7] Notice that the investment of the leader is

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

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

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.

2.3 Extension I: 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 Extension II: 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.[8] More generally, as shown in Etro (2006) and Maci

[8]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

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 there is an endogenous entry threat compared to when there is not.

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

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 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 only if they face a strong threat of entry pressure.

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:

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

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.

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. The ZEW conducts the survey since 1992 and it represents the German part of the EU–wide, harmonized Community Innovation Survey (CIS). It follows the Eurostat/OECD guidelines for collecting innovation data which are documented in the so–called Oslo Manual (see Eurostat and OECD, 1997). Readers not familiar with the survey are referred to the summary reports, e.g. Eurostat (2004, 2008). The MIP data constitute 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 arbitrary 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 leaders 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 our sample consists of 1,857 firm–level observations. 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.

Patent stocks, IPRs, and unobserved firm heterogeneity

A main determinant of the investment in R&D is the degree of protection of the intellectual property rights (IPRs) associated with the innovations that each firm can obtain. It is difficult to measure the degree of protection of the IPRs at the firm level, but we can proxy this with a measure of the stock of patents at the firm level. In particular, the differences between firms in the size of the patent portfolio can be associated with the differences in the degree of expected protection of the innovations of the firms, therefore we expect a positive correlation between R&D intensity and the patent stock. Moreover, the introduction of this important control variable allows us to obtain a robustness check that might account for unobserved heterogeneity even in the absence of panel data.

Our measure of the patent stock at the firm level accounts for all patent applications from 1978 onwards. 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.

Potential reverse causality between R&D and 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 possible concern of our approach relies in the independence of our entry variable from the dependent variable, R&D intensity. Reverse causality could affect our results: in principle, it is possible that current R&D leading to a future technological advantage makes firms perceive the entry threat as less severe, while, on the other side, if firms are not research active and neglect the development of new processes and products, entry may appear as a quite realistic threat. To test the possibility of a reverse relationship 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 key element determining entry pressure, the difference between the expected profits in the market and the fixed costs 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 sunk costs of entry determining scale economies or the importance of advertising in determining demand, and on the other side strategic barriers, for instance excess capacity, limit pricing, product differentiation and also innovative activity.

It is not simple to find a measure of the fixed costs of entry. Sutton (1998) uses the size of the median plant in an industry as a proxy for minimum efficient scale, and therefore for the size of the costs of entry. 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.[9] We have information on total industry sales and the number of firms active in an industry. This information is taken from official statistics and measured at a detailed industry level (NACE 3-digit level).[10] The ratio, industry sales per firm, is applied as a proxy for minimum efficient scale and enters the regressions as a lagged value (MES_{t-1}).

Another factor that can affect profitability and entry is the importance of advertising in determining demand. For our purpose, it is not relevant whether advertising is informative or has a direct impact on preferences. In a sector in which advertising is an important competitive factor entry could be easier because firms can gain market shares just by advertising their products. On the other side, when advertising investment in the industry is large, entry may be quite costly. In one way or the other, when advertising is perceives as important by the firms, it is likely to affect entry. Our survey collects 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. Consequently, we employ the variable $ADVERT$ which takes values between 1 and 6, where the largest value corresponds to the highest importance of advertising in the industry where the firm is active (and is not a measure of investment in advertising of the single firm).

Finally, the degree of substitutability between goods can heavily affect entry pressure, as Sutton (1998, 2006) has emphasized. 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

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

[10]NACE is the European standard industry classification, and the firms in our sample are active in 96 different NACE 3–digit industries.

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"(3) to "does not apply at all"(0).

Many empirical studies have also emphasized the role of net profitability for entry and market growth.[12] 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 experimented with 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, or industry turmoil. This turned out to have no correlation with the threat of entry, though. Consequently we omit this variable in the following.

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:

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

[11]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.

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

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				
MES_{t-1}	0.079	0.166	0.009	2.102
$ADVERT_{it}$	2.219	1.428	1	6
$SUBSTITUTE_{it}$	1.874	0.840	0	3

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

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

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 $EMP_{i,t-1}$, $EMP_{i,t-1}^2$, $KAPINT_{i,t-1}$, $LEADER_{it}$, $ENTRY_{it}$ as well as 12 industry dummies. In further models, we add the interaction term $LEADER_{it} \times ENTRY_{it}$, and $PSTOCK_{it}$ to control for further heterogeneity due to differences in IPRs protection.

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, confirming that firms receiving stronger protection of IPRs through patents tend to invest more - alternatively, firms that (successfully) conducted R&D in the past will also invest more in the current period. One could also read this result as contradicting the view for which firms with a lot of patents would be less innovative and use their patent portfolio to jeopardize further investments in R&D.

With respect to the other covariates, we find a positive and concave relation with employment, [13] while 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 emphasize a high correlation of R&D spending with firms of the Information &

[13] 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.

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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.

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 $\bar{X}_i$.[14] In contrast, the invest-

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

ment 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.

Results on reverse causality between R&D and entry

In this section we verify whether there is a problem of reverse causality for which high R&D intensity of a generic firm induces low entry threat and vice versa.

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 reverse causality 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.[15] 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:

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

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

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_{i2} is explained y_{i1}^*.

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

Staiger and Stock (1997) emphasized that the first–stage significance levels of the instrumental variables may be misleading, as it does not necessarily exclude a weak instrument problem, which would lead to considerable bias in IV regressions. Instead of interpreting the significance level, they argue — as rule of thumb — that the partial F–statistic should exceed the value of 10 in the case of a single endogenous regressor to confidently rule out weak instruments. As can be seen in Table 4, all F values exceed the value of 10, and consequently we can reject a weak instrument bias.[16]

Furthermore, we test whether the instrumental variables are uncorrelated with the error term in our structural equation. Only if we are confident of having no weak instrument problem, and the instruments are not correlated with the error term in the R&D equation, we can rely on our IV results. The validity of the IV candidates is usually assessed using the Sargan test or Hansen's J–test for a heteroscedasticity–robust version. Unfortunately,

[16]More recently Stock and Yogo (2005) derived new critical values for the weak instrument test on basis of the rank test (see e.g. Kleibergen and Paap, 2006), and it would be desirable to rely on these. However, the critical values are only available for a minimum of three instrumental variables. Although our model III employs three instruments, we will document below that these are not valid as this set–up does not pass the Hansen J–test. Therefore we cannot utilize the Stock and Yogo test statistics.

these test are based on standard 2SLS estimations, and not available for Tobit. Therefore, we employed regular 2SLS ignoring the censoring of our dependent variable for the test. The results are also shown in Table 4.[17] The set–up where we use MES and $ADVERT$ as instrumental variables pass Hansen's J–test, but when we include $SUBSTITUTE$, the test rejects the validity of this combination of instruments.

As final step, we test for endogeneity of $ENTRY$ using the Smith–Blundell test. As the results in Table 4 show, the exogeneity of ENTRY with respect to R&D investment is not rejected.

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.

In summary, we found relevant instrumental variables, but the potential reverse causality has 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.

In addition to feedback effect from R&D to entry, some readers may be concerned about feedback from R&D to our variable $LEADER$. There we simply checked if past R&D intensity (which we have for a subsample of about 1,000 companies) determines our leadership variable to a certain

[17]Note that the Hansen J–test is only applicable in case of overidentification. Thus, we cannot calculate the test for model I, where only one instrument is used.

extent. For this, we simply regressed $LEADER$ on past R&D intensity, past sales and industry dummies. It turn out that past sales, and thus past firm size, dominate the relationship. There is no additional effect of past R&D beyond firm size.

3.2.1 The determinants of endogenous entry

The first stage regressions for $ENTRY_i$ shown in Table 5 provide, as a side product, an interesting analysis of the determinants of the endogeneity of entry. They relate the perceived threat of entry to a number of control variables. In particular, we propose three models, all of which include the size of the firm, its capital intensity, the Herfindahl-Hirschman Index, the incumbent status variable and the minimum efficient size (as in Model I), with the addition of the importance of advertising (as in Model II) and also of the perceived substitutability between products (as in Model III). In this last case, we can emphasize a number of significant results.

First, larger firms, both in terms of employment and of their own perception of relative size, are less likely to be active in markets where entry is endogenous, while capital intensity and the index of concentration in the market do not appear to affect the extent of entry pressure in the market. More interesting, a large minimum efficient scale is negatively correlated with the perceived entry threat: in other words, natural entry barriers make it less likely that entry is endogenous. The perceived importance of advertising in the market is positively correlated with endogenous entry: this may suggest that entry is perceived as easy when investments in advertising are crucial to increase market shares. Also the perceived degree of substitutability between goods is associated with endogenous entry: when goods are highly substitutable, it is easy to enter and increase market share by offering the products at low enough prices, while differentiated goods reduce the relevance of entry pressure.

Of course, this is only a preliminary and incomplete investigation of the determinants of the endogeneity of market structures. Further work should uncover other explanatory variables and verify the possible links between them.

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 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	

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%).

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%).

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

Test	MES_{t-1}	MES_{t-1}, $ADVERT_t$	MES_{t-1}, $ADVERT_t$, $SUBSTITUTE_t$
F-Test on IV significance in 1st stage regression	$F = 14.33^{***}$	$F = 14.47^{***}$	$F = 21.41^{***}$
Blundell/Smith endogeneity test[a]	-0.53	-0.12	1.11
Hansen J–test[b]	—	0.028	7.704^{**}

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

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

[b] Based on 2SLS regressions as test is not available for Tobit.

Table 5: IV first stage regressions on entry (1,857 observations)

Variables	Model I	Model II	Model III
$EMP_{i,t-1}/1000$	-0.057^{*}	-0.051	-0.065^{**}
	(0.033)	(0.032)	(0.033)
$(EMP_{i,t-1}/1000)^2$	0.0014^{*}	0.0013	0.002^{*}
	(0.0009)	(0.0009)	(0.0009)
$KAPINT_{i,t-1}$	0.087	0.153	0.061
	(0.241)	(0.239)	(0.243)
$HHI_{i,t-1}$	-0.00001	0.0001	0.0002
	(0.0004)	(0.0004)	(0.0004)
$LEADER_{it}$	-0.242^{***}	-0.227^{***}	-0.223^{***}
	(0.068)	(0.068)	(0.068)
$MES_{i,t-1}$	-0.330^{***}	-0.319^{***}	-0.340^{***}
	(0.087)	(0.083)	(0.014)
$ADVERT_{it}$		0.050^{***}	0.054^{***}
		(0.014)	(0.014)
$SUBSTITUTE_{it}$			0.142^{***}
			(0.025)
Intercept	1.711^{***}	1.559^{***}	1.269^{***}
	(0.086)	(0.097)	(0.110)
F–test: industry dummies	2.44^{***}	2.07^{**}	1.88^{**}
F–test: IVs	14.33^{***}	14.47^{***}	21.41^{***}

Notes: Standard errors in parentheses. *** (**, *) indicate a significance level of 1% (5%, 10%). The 'F–test: IVs' refers to a joint significance test of our instrumental variables, which are MES in model I, MES and $ADVERT$ in model II and MES, $ADVERT$ and $SUBSTITUTE$ in model III.