Non-technical Summary

One of the most discussed topics regarding innovation is the question, whether the current market leader invests more into R&D than a potential entrant who is not present at the market yet. Game theoretic models by Gilbert and Newbery (1982), Reinganum (1983, 1984, 1985) and others lead to opposing results. The so called auction model considers an incumbent firm which is faced with one or more potential entrants who also compete for process innovations. In this model, the incumbent offers more for a non-drastic innovation than a potential entrant. The second line of research are the so called stochastic patent racing models. Here, the incumbent invests more into R&D than a potential entrant: With increasing R&D investment the expected time period until innovation is shortened and therewith the current profits of the incumbent would disappear.

In this paper, we present the results of an empirical test on this issue. We use data from the Mannheim Innovation Panel of about 3500 German firms from 1992 to 1995. The main advantage of this survey is that the firms are asked about the exact purpose of their innovative activities. Thus, we are able to distinguish between the motivation to secure the current market share in contrast to the plan to enter a new market. Additionally, we use several control variables like market share, capital intensity, firm size, export intensity, import penetration and concentration. It turns out that the potential entrant invests more into R&D than other firms, but in contrast, the incumbent has no significant higher R&D intensity. Hence, the models on patent races by Reinganum and others are supported.

An Empirical Test of the Asymmetric Models on Innovative Activity: Who Invests More into R&D the Incumbent or the Challenger?

by

Dirk Czarnitzki* and Kornelius Kraft**

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Abstract:

The theoretical discussion concerning the question whether the incumbent or the (potential) entrant invests more into R&D has attracted considerable interest. This paper reports the results of an empirical study on this question using data of about 3500 German firms over the years 1992 to 1995. The survey explicitly asks the firms for their motives to undertake innovative activity. It is thus possible to take account of intended, not just completed, market entry. It turns out that the challenger invests more into R&D in order to enter a new market than the incumbent. Thus, the patent racing model by Reinganum and others seems to characterize innovative activity more accurately than the competing auction model of Gilbert and Newbery. We use a heteroscedastic tobit as well as a tobit model with selectivity in order to deal with the econometric problems of double censoring.

JEL Classifications: L12, O31, O32

Keywords: Innovative Activity, Patent Races, Uncertainty,
Incumbent versus Entrant, Tobit with Selectivity

* Centre for European Economic Research (ZEW), Mannheim
** University of Essen

1. Introduction[1]

One of the major discussions on innovation in recent years has been on the effect of current market power upon a firm's activity to engage in innovation projects (Schumpeter, 1934, 1942, Arrow, 1962). Nowadays, game-theoretic models are applied to investigate this topic. In short, there are two competing approaches which come to opposing results. This paper reports the results of an empirical test on this issue.

The effect of monopolistic market power versus the stimulus of an outside challenger on innovative activity has been analyzed by two competing models. Firstly, the so-called auction model by Gilbert and Newbery (1982) considers the question who offers more for a process innovation, a monopolist or a challenging firm. There is full information and no uncertainty on the effects of this innovation. The monopolist offers more than the challenger if the innovation is non-drastic and both bid the same amount if it is drastic.

Secondly, patent races (Lee and Wilde, 1980, Reinganum, 1983, 1984, 1985 among others) consider the path to innovation under uncertainty. Firms invest into R&D, but this can only influence the probability of successful innovation without certainty. In such a situation the challengers have an incentive to invest more than the incumbent and will most likely enter the market. This leads to a world of creative destruction (Reinganum, 1985), where the current leaders are likely to be substituted by entrants.

Until now – and to the best of our knowledge - not a single study exists that tries to perform an empirical test on the relevance of these theories for reality. This is surprising given the broad discussion about this issue but it is also not a trivial task since the models have quite restrictive assumptions and are

[1] We are grateful to the team of the Mannheim Innovation Panel (Thorsten Doherr, Günther Ebling, Sandra Gottschalk, Norbert Janz and Hiltrud Niggemann) for providing the data. Further, we have to thank Irene Bertschek, Norbert Janz, François Laisney and Georg Licht for helpful discussions.

highly stylized. The present paper tries to close this gap and reports results from an empirical study on this topic. It uses data of the Mannheim Innovation Panel (MIP) on about 3500 firms from 1992 to 1995 in Germany. Our panel is unbalanced, leading to 5862 observations. The main advantage of this survey is that firms are questioned about the exact purpose of the innovative activity. It is thus possible to distinguish between the motivation to secure the current market share from the plan to enter a new market. Hence, we can take into account the intention to enter a new market, and not only the actually realized entry. This is a major advantage over earlier studies, as the observed entry may only be due to luck, but not to systematic higher investment into innovative activity. In the empirical study it turns out that the potential entrant invests more into R&D than the incumbent.

The results are of considerable interest for both theory and economic policy. The literature on the role of the market leader versus the challenger in R&D processes is one of the most important contributions to the theory of innovation. The surveys by Reinganum (1989) and Tirole (1988, ch. 10) impressively demonstrate this. However, there is not a single explicit test on this issue. This is, however, in part due to the very restrictive set-up of the models which make a test rather difficult since the described world almost never exists. Furthermore, the data required for such a test is hardly available. As Reinganum (1984, p. 62) states: “In order to move into direction of empirical testing, we must both extend these models in more realistic directions to accommodate existing data, and attempt to gather the specific data required to test directly such models of firm behavior.” We intend to do this job.

It seems to be obvious that policy institutions need better information on the impact of competition. Theory might be helpful in this respect, but as the results are rather controversial, an empirical test seems to be an important contribution for policy recommendations. Subsidies by government agencies, as well as private credit from banks or other institutions tend to support established firms more than potential entrants to a market. This might be appropriate if the established firm provides a larger impact on technical progress than the challenger. A more detailed discussion is needed, however, if the potential entrant is the one that improves processes and products more significantly. The following section deals with theoretical considerations. Section 3 contains a data description and the econometric application.

2. Theoretical Considerations on Asymmetry in Market Power

The effect of market power on innovative activity is one of the questions, perhaps even the first question, that has been raised in the discussion on the determinants of technical progress. Schumpeter (1934, 1942) starts with an argumentation in favor of large firms and imperfect competition as supportive for innovation. Arrow (1962) shows that for both a drastic and a non-drastic process-innovation an incumbent monopolist has a lower incentive to invent compared to an inventor who currently has no market share. His result is due to the fact that the monopolist would sacrifice his current profits, which do not play a role for an entrant because the entrant has no current profits resulting from activities on this particular market. However, Arrow (1962) does not consider the case that the entrant could substitute the incumbent.

Further research on this topic has basically led to two opposing models on analyzing asymmetric situations. Gilbert and Newbery (1982) use the so-called auction model to examine this question. They consider the case of an incumbent firm which faces one or more potential entrants who also compete for a process-innovation. This model assumes that every firm enters a bid on the innovation and the maximal bid is regarded as the maximal amount spent for research and development. The firm with the highest bid will win this contest.

A sketch of this model is given in appendix A. At present, it is sufficient to compare the incentives of an incumbent and the challenger. The most important assumption in this tournament is that the monopolist would be substituted by the entrant in the case of a drastic innovation and has to share the oligopoly profits in the case of a non-drastic innovation. Thus, the monopolist has to take account of the possibility to be substituted. This is the major difference to the Arrow (1962) model.

In the case of a drastic innovation both the incumbent and the entrant bid the same amount. However, for a non-drastic innovation the monopolist has the incentive to offer more because when it wins the contest, then its position as a monopolist is secured. The challenger offers at most the amount equivalent to the duopoly profits of the duopolist with the lower costs. In general, this is less than the monopoly profits minus the duopoly profits of the incumbent if the challenger has innovated, which is the relevant comparison to make (see appendix A). This is due to the so-called efficiency effect which means the joint profits of the duopolists are equal or less than the profits of the monopolist.

The incentive for pre-emptive patenting and persistent monopoly arises from the dissipation of industry profits if the market becomes less concentrated. In a comment Salant (1984) discusses the possibility of licensing. If this is a possibility, then the most-efficient firm will win the patent. Afterwards, the winning firm may sell it to the other firm if this other one is a more effective producer. Optimal licensing will result in a monopolized market, but the innovator must not necessarily be the incumbent.

The second line of research analyses R&D processes by means of so-called stochastic racing models. Both the models and the results are in strong contrast to the auction model. A deeper analysis is relegated to appendix A, as our summary of the theory is not original.

The models usually consider the case of process innovation, but can under some assumptions be extended to product innovations (Reinganum, 1985). The basic model by Reinganum (1983) shows that when the successful innovator captures a sufficiently high market share, then the incumbent firm invests less in research and development than a potential entrant. The reason for this is uncertainty. The incumbent receives a flow of profits before another firm develops a successful innovation. The period until the discovery and introduction of the innovation is then of random length, but it will be shorter if all firms invest more into R&D as the probability of success increases. Now, the incumbent has relatively less incentives to shorten this period than the challenger, as it would substitute itself and the current profits would disappear. The challenger, by definition, has no current profits and has different, higher incentives to invest. Thus, the patent races have a clear connection to the original Arrow (1962) model, although the analysis differs considerably in detail.

A further problem is the distinction between drastic and non-drastic process innovations. Reinganum (1983) defines an open neighborhood of cost conditions such that if the technology is not drastic, the challenger still invests more into R&D than the incumbent.

The two models lead to opposing hypotheses on R&D intensity if a market leader is compared with a challenger. The main problem is that the models have a very restrictive structure, which severely limits the relevance and the possibility for an empirical test. The main emphasis of the models is on process innovation for an otherwise absolutely identical product. Product innovation is usually excluded. This procedure has the advantage that the market structure after innovation is easily described. Drastic versus non-drastic innovation is also clearly defined. It has the disadvantage for empirical research that in many cases process and product innovation are not independent events, but are related in one or the other way (Kraft, 1990). Furthermore, firms usually do not differ in practice between R&D for process and product innovation. Thus, an empirical test for R&D intensity limited to process innovation is hardly possible. Finally, Schumpeter and others had not only process, but perhaps even more product innovation in mind, when they discussed “creative destruction”, and the modern theory on the role of the incumbent versus the challenger should be able to say something about product innovation as well.

Reinganum (1985) shortly discusses the extension of the patent races models for product innovation. If the product innovation captures a “sufficiently large“ share of the new market, the analysis is similar to a drastic process innovation. The earlier developed products are of minor importance and could be disregarded. If, however, the new product is one among several, product differentiation has to be included and the models would become much more non-transparent. There would be the necessity to define the border case between a “sufficiently large“ market share and a smaller one. Hence, the models on patent racing apply to product innovation as well, if the new product is a close substitute to existing ones but has a significantly higher quality, like, for example, a color TV in contrast to black and white TV or a CD-player versus the conventional record-player (vertical product differentiation without significant price differences). In case of horizontal product differentiation the situation is much more complex and it is not clear whether the theories that have just been discussed are useful in such a case.

Dixit (1988), Bagwell and Staiger (1992) as well as, among others, Jensen and Thursby (1996) consider races between different countries for product innovation. Bagwell and Staiger (1992, p. 797) assume that "scale economies are sufficiently important, that the market can only support the entry of one firm”. Jensen and Thursby (1996) discuss the situation, where firms either develop the same product or develop closely related products. Dixit (1988) analyses the outcome of an R&D process that can apparently lead to a new process or an identical product, which cannot be imitated because of a patent. The assumption of an identical product is somewhat extreme, but that product innovations are close substitutes seems to be reasonable. The question remains whether close substitutes get independent patents, or if only the first product receives a patent. Only in the latter case do the models of patent races apply.

Most product innovations are licensed to other firms. However, this is less clear for process innovations. It is possible that licensing has an effect on the incentives to innovate. Salant (1984) has shown that this is the case for the auction model. The models on licensing based on the situation of patent racing show that a drastic (process-) innovation is never licensed, and thus licensing has no effect on the incentives to innovate (see Reinganum, 1989, section 4). The articles concerning licensing mainly consider the incentives to license during the different stages of R&D projects (see for example Grossman and Shapiro, 1987), but also on the incentives for R&D investment (see for example Katz and Shapiro, 1987). An incumbent who is ahead with respect to cost minimization may license its technology in order to protect itself against the risk of discovery of a lower cost technology by an entrant. However, it seems that this result is of minor importance for our empirical project.

3. Empirical Study

The purpose of this section is to report the results of an empirical study on the R&D investment of the market leader versus the challenger. Firstly, we discuss the data used and then the econometric models applied.

3. 1. Data

This study uses data from the Mannheim Innovation Panel (MIP) conducted by the Centre for European Economic Research (ZEW) on behalf of the German Federal Ministry for Education and Research (bmb+f). This survey was launched in 1992 and collects information from about 2000 firms of the manufacturing sector every year. It represents the German part of the Community Innovation Survey (CIS) of the European Commission. However, the response rate to some questions is limited and, overall, data concerning 3568 firms are used. We have information from the years 1992 to 1995 yielding an unbalanced panel of about 5862 observations. This sample can be divided in three main groups: 2419 observations are due to non-innovating firms and 765 observations to innovating firms that did not engage in any R&D activities. The third group are the innovating firms with R&D activities (2678 observations). Descriptive statistics of the variables used can be found in Appendix C.

The study analyses the activity of firms specified as the expenditures for R&D divided by sales (multiplied by 100). This is a standard variable and it is named R&D/SALES. On the one hand, the variable R&D expenditures has some shortcomings. For example, it is sometimes stated that in particular small firms do not record these expenditures correctly. However, we have no indication that this is true for the MIP. On the other hand, R&D is the appropriate variable to test for models on patent racing as only the intended but perhaps not successful innovation process is considered. We are thus in the position to follow the advice of Reinganum (1984) concerning empirical research on these models, to investigate the program of the unsuccessful firm, aside of that of the successful companies.

A major advantage of the data used is that the motives for R&D activities are recorded before the firm in question has succeeded in developing a new process or product and is actually present in a new market. Hence we are able to consider *potential* entry, which possibly never leads to actual entry. This is an important difference to studies like Geroski (1994, ch. 4 and 5) and others which analyze the effect of observed and successful entry, but not the attempts to enter that turned out to be unsuccessful.

The MIP asks the firms in detail for the motives to conduct R&D: "With product- and process innovation a number of different aims can be followed. We would like to know more about the most important motives for the innovation decision and the innovation strategy of your firm".[2] One question is about the entry into new markets, more precisely "the enlargement of the products out of the main markets you are operating in". The firms can rate this possibility as being of higher or lower importance on a five scale rating. Our variable ENTRY has unit value if firms say that this aim has a very high importance,

[2] We only have information on firms which are already existing and produce in one or more other markets. Otherwise a company cannot participate in the survey. It is possible that firms enter a market which have just been founded for this purpose and only start production after successful completion of the R&D process (with or without a new technology). These innovators cannot be considered here.

i.e. they rate its importance with 5. Otherwise, ENTRY is zero. Only 9% of our observations on innovative firms answer this question in the affirmative.

Another question is about the importance of securing and increasing the current market share. Again, the firms answer on a five scale basis. The dummy variable INCUMBENT has unit value if the firm in question puts a very high value, i.e. 5, on this aim. This aim is confirmed by a majority of the firms: about 65% of all innovators rate this aim with the scaling 5. The market share has a particular importance in this context. It is measured as

$$\text{SHARE}_i = \frac{\text{SALES}_i}{\sum_{i=1}^{n} \text{SALES}_i} * 100$$

for all i of each industry on a 3 digit level[3]. On the one hand, it may have an independent effect on R&D intensity[4]. On the other hand, it is of specific importance in the given context as the theoretical models deal with the market leader, in particular the monopolist. The question whether R&D is used in order to secure and to increase market share can be answered in the affirmative by large as well as by very small firms, as the market share is never zero. It is not asked whether the company has a large market share. However, the individual market share perhaps supplies additional information on firms' behavior. In order to identify the market leaders, we construct the interaction variable INCUMBENT*SHARE which has its largest value for firms that have a large market share, and perform R&D in order to secure this market share.

The main emphasis of this study is on the effect of the variables INCUMBENT, ENTRY and SHARE on R&D expenditures. However, in order

[3] As industry classification we use the European standard called NACE.

[4] One may argue that R&D has an effect on firms' market shares and thus endogeneity problems occur. However, R&D in period t will possibly induce innovations in period $t+s$. These innovations may have an impact on the market share in periods after $t+s$. Since we use the contemporary market share to explain R&D activities we do not consider the problem of possible endogeneity of SHARE.

to avoid an omitted variable bias as far as possible several control variables are included. Firm size is specified as the number of employees (EMP). This variable controls whether innovative activity varies with firm size. This variable takes account of another classical hypothesis by Schumpeter. The square of this variable $(EMP)^2$ is included as well in order to allow for a non-linear relationship.

The share of sales exported EXPORT is measured on the individual firm level and describes the participation to international competition. A related variable is the share of sales of foreign firms compared to total shares of both foreign and domestic firms in an industry, which is called IMPORT. This variable is expected to express the competitive pressure from other countries and is, of course, of high importance for an open economy like Germany. Unfortunately, for some industries IMPORT was only available on a two digit level. IMPORT is generated as *imports/(imports+production)**100 measured in the German currency unit DM.

The next variable is the concentration ratio CONC, which is defined as the Herfindahl-index on the three digit industry level. It is the sum of squared market shares of the firms operating in the three digit industry (and then multiplied by 1000). A major problem here is that in Germany the basic classification of industries has changed in the nineties from the SYPRO to the internationally more convenient NACE standard. The innovation panel classifies firms according to the NACE standard, but the German statistical office has published a Herfindahl index only for 1995. We transformed the data from SYPRO statistics to an index on the basis of the NACE standard for 1991 and 1993 (and calculated averages for the years in between), but this is not perfectly reliable. Hence, we instrument this variable in order to avoid an error-in-variable problem. The instruments used are the number of firms, the inverse of the number of firms, imports and total sales volume of the industry, as well as a deterministic trend. We have also experimented with the observed Herfindahl index from 1995 for the whole period, but the results did not differ, and thus we present just those which are based on the instrumented values. In addition we use the change of the index from period to period DCONC. We assume that the consideration of international trade, the concentration index, the change of this index, and the individual market share allow to identify the degree of competitive pressure a firm is faced with.

The panel covers firms which are active in West and East Germany (the former GDR). In the nineties, East German firms received many tax incentives and direct subsidies from the government in order to support their development, so that it is possible that East German firms behave different from Western German ones. Hence, we include a dummy variable EAST which has unit value for companies operating in the East German so-called new Bundesländer (federal states).

It is possible that the younger firms are also the more innovative ones, as the foundation of a firm usually goes hand in hand with the introduction of one or more innovations. The established firms are often reluctant to introduce “fundamental” innovations and these are launched by newly founded companies. The new firms are possibly also those which go into new markets. In order to take account of the effect of the age of a firm, we include the inverse of the age of a firm in question (1/AGE). We use the inverse in order to take account of a probable non-linear relationship between age and innovative activities. The variable capital intensity (KAPIN) is defined as tangible fixed assets per employee in millions DM and is included in order to control for differing technologies as well as for barriers to entry.

It is well known that the technical opportunities differ considerably between industries. We include 13 two-digit industry dummies in order to control for specific effects. The industry "food products and beverages" is the basis for the comparison. Furthermore, three time dummies indicate whether a observation is from 1993, 1994 or 1995. The year 1992 is the basis in this case.

3. 2. Econometric Methodology and Results

The survey is a sample of firms operating in the German manufacturing sector. As not all participating firms are innovative or conduct R&D activities, we have to take account of this problem of censored data. Firstly, we apply the standard tobit model only to the group of innovative firms because the objectives of innovations and the R&D activities are only observed for innovative firms. This yields 3443 observations where about 22% are zero, i.e. with innovative activities but no R&D.

In microeconomic data like ours heteroscedasticity is a common problem. This is a serious problem when the tobit estimation technique is applied as not only the estimated standard errors but also the coefficients would be inconsistent. Therefore, we also estimate a tobit model which accounts for heteroscedasticity. The technical details are relegated to appendix B. The firms in question have two decision possibilities: a) innovate or not and b) if it is decided in favor of innovative activity whether to perform R&D or not (in the latter case the firm buys external knowledge). This complicated structure of the econometric estimation is taken into account by the use of a tobit model with selectivity. The details are also discussed in appendix B.

For our specific question many observations on firms contain missing values or the firms did not respond every year. Especially, this is true to the innovation strategies. Hence, we do not estimate a panel model for tobit as we have not sufficient observations on firms over the four years. Many firms (more than 60%) are only observed once in our dataset. A panel model for the tobit case has been developed by Honoré (1992) in the first place for the special situation of two observations (years) per firm, but it can be extended to $t>2$ as well. However, we have very few observations per firm (and in many cases just one) and hence the “within” variation will necessarily be very limited. We use a specific tobit-model, which accounts for sample selection in an innovative way and it remains to be shown how this model is adapted to panel applications. Here we pool the data. Although the covariance matrix could be misspecified in that case this should not have a considerable effect on the estimated standard errors because the relative importance of repeated observations on same firms is marginal (see the pattern of the panel structure in appendix C).

Thirteen industry dummies were added in order to take account of differences in technological opportunities and reduce problems with individual effects as far as possible. These dummy-variables are usually highly significant.

The results of the standard tobit and the tobit with correction for heteroscedasticity are displayed in table 1. It turns out that the incumbent never has a significantly larger share of R&D expenditures in relation to sales. In contrast the challenger has significantly higher R&D expenditures. The results are very stable and do not depend on the choice between the normal tobit and that with consideration of heteroscedasticity. The tobit with endogenous correction for heteroscedasticity shows in addition the significant negative impact of the interaction variable INCUMBENT*SHARE. This is strong evidence in favor of the patent-race model.

We carry out two different kinds of heteroscedasticity tests. On one hand, we compute a Lagrange multiplier test (LM) based on the restricted homoscedastic model. Its advantage is that one needs neither to model the heteroscedasticity as a particular function nor to estimate any heteroscedastic model. See Greene (1997, p. 969) for the computation of the test statistics. If all regressors (except EMP^2) are suspected to cause heteroscedasticity, the Lagrange multiplier value for Model I [Model II] is LM = 2465.23 [2467.56]. Since this is asymptotically distributed χ^2 with 27 [28] degrees of freedom we can clearly reject the hypothesis of homoscedasticity. We also tested the regressors one by one but this lead to the same results, i.e. all regressors are considered to cause heteroscedasticity. On the other hand, we use a likelihood ratio statistic to test the hypothesis that all coefficients of the heteroscedasticity term are zero. Therefore, we have to compare the log likelihood values of both the restricted homoscedastic model and the unrestricted heteroscedastic one. The statistic is LR = 1793.36 [1799.54]. The hypothesis of homoscedasticity, i.e. all coefficients of the heteroscedasticity term being zero is, again, clearly rejected.

Table 1: Determinants of R&D/Sales – Tobit Estimates

	Model I		**Model II**	
Variable	Tobit	Tobit with Heteroscedasticity	Tobit	Tobit with Heteroscedasticity
Constant	-5.73 (-5.80)	-2.90 (-3.60)	-5.70 (-5.77)	-2.95 (-3.68)
EMP/100	.02 (2.90)	.01 (2.33)	.02 (1.88)	.01 (3.26)
$(EMP)^2/100$	$-1.64 \cdot 10^{-5}$ (-1.98)	$-7.21 \cdot 10^{-6}$ (-1.83)	$-1.59 \cdot 10^{-5}$ (-1.92)	$-7.35 \cdot 10^{-6}$ (-2.69)
EXPORT	.03 (4.78)	.02 (5.83)	.03 (4.80)	.02 (5.87)
IMPORT	.09 (3.26)	.03 (2.20)	.09 (3.28)	.03 (2.30)
KAPIN	1.24 (.94)	1.36 (1.11)	1.22 (.93)	1.36 (1.14)
INCUMBENT* SHARE	---	---	.04 (.76)	-.04 (-2.52)
SHARE	-.01 (-.33)	-.03 (-1.70)	-.03 (-.64)	-.02 (-1.51)
INCUMB	-.31 (-1.02)	-.02 (-0.15)	-.36 (-1.14)	.04 (0.25)
ENTRANT	1.33 (2.67)	.79 (2.51)	1.33 (2.66)	.81 (2.59)
CONC	.009 (1.39)	-.002 (-.45)	.009 (1.40)	-.002 (.71)
DCONC	.04 (1.17)	.03 (2.29)	.03 (1.15)	.04 (2.33)
EAST	2.46 (5.79)	.84 (2.87)	2.47 (5.80)	.78 (2.70)
1/AGE	.24 (1.15)	-.79 (-1.28)	.23 (.20)	-.73 (-1.18)
Log-Likelihood	-9971.18	-9074.50	-9970.90	-9071.13

Notes: All estimations include 13 industry dummies and three year dummies. The heteroscedasticity term as given in equation (B.3) of the Tobit with heteroscedasticity includes all explanatory variables except $(EMP)^2$. These results are not reported. The t-values are given in parentheses. The numbers of observations are n=3443 for each equation.

Additionally, we compare the two heteroscedastic models, i.e. we test if INCUMBENT*SHARE has significant explanatory power. Again, we use a likelihood ratio statistic to test whether the coefficients of this variable are zero. This statistic is distributed χ^2 with 2 degrees of freedom because INCUMBENT*SHARE is included in the model's equation, as well as in the heteroscedasticity term. This yields a critical value of 5.99 on a 5% significance level. Our test statistic is LR = 6.74. Thus, INCUMBENT*SHARE has significant explanatory power and the model including this variable is the relevant one.

The results in table 1 were obtained using innovative firms only. However, these results can be biased when the decision of untertaking general innovative activities and engaging in R&D are correlated. Therefore, we have to take account of this sample selection. Thus, we derive a regression model with double sample selection. In the first place, a firm has to decide in general on the question to innovate or not. If it wants to innovate, it can choose among several possibilities, e.g. buying new machines, buying licenses, introduce new services related to its products or, in our case, undertake R&D investment. Hence, we have to add the group of non-innovating firms to our former sample and apply a regression model with a double selection mechanism. Maddala (1983, sec. 9.6) discusses several models with multiple criteria for self selectivity (see the citations there). Additionally, e.g. Ham (1982) and Tunali (1986) consider multiple selection criteria in regression. Especially Tunali (1986) deals with the same selection problem as our model. However, both Tunali and Ham just expand Heckman's two-step approach to incorporate the second selection mechanism. As an alternative we use a full information maximum likelihood (FIML) estimation as this method is efficient. The likelihood function derived by us is given in Appendix B. For the first selection decision of being innovative we use the binary choice variable, whether the firm is an innovator or not. The second selection criterion of undertaking R&D is incorporated via the tobit model. Then, our likelihood function combines a tobit model and a binary choice "probit" model.

For identification we exclude 1/AGE in the tobit model since this was not significant in the first estimation (see table 1). However, the model has still considerable convergence problems with such a structure. Thus, for the probit equation we transform EXPORT to an export dummy and exclude SHARE and EMP^2 to reduce collinearity among regressors and ease identification. The results are shown in table 2. Again, all regressors of the tobit model are included in the heteroscedasticity term as given in equation (B.3).

As the coefficient of correlation between equations ρ is virtually zero the results are rather similar to those reported in table 1, and thus they seem to be quite robust. Again, these results are clearly in favor of the patent race model in contrast to the auction approach. As the auction model is based on certainty, while the racing approach explicitly includes time and uncertainty, the latter seems to be better suited for analyzing the innovation process. The empirical test supports this by the effect of ENTRANT and INCUMBENT. Further support comes from the significantly negative impact of the interaction variable INCUMBENT*SHARE[5]. As the theoretical models consider the incentive of a monopolist, this result is also of high importance for the test of the theory. The more innovative firms are the outsiders and not the current market leaders. The results for ENTRANT and INCUMBENT*SHARE may also contribute to the current discussion on the disproportionate share of major innovations introduced by small firms (Pavitt et. al., 1987, Acs and Audretsch, 1988, 1990).

[5] The use of an interaction variable possibly explains the difference to the finding of a positive significant market share by Blundell/Griffiths/van Reenen (1999). Another reason for this contradiction might be that we use R&D intensity while Blundell et al. use the number of innovations.

Table 2: Determinants of R&D/Sales – Tobit with Sample Selection

Variable	Selection Equation	Tobit Equation
Constant	-.52 (-4.00)	-2.93 (-3.28)
EMP/100	.006 (1.46)	.01 (3.01)
$(EMP)^2/100$	---	$-7.68*10^{-6}$ (-2.54)
EXPORT DUMMY	0.38 (6.64)	---
EXPORT	---	.02 (4.83)
IMPORT	-.02 (-3.19)	.03 (2.07)
KAPIN	.16 (.87)	1.77 (1.36)
INCUMBENT*SHARE	---	-.04 (-2.37)
SHARE	---	-.02 (-1.65)
INCUMBENT	---	-.01 (-.04)
ENTRANT	---	.87 (2.63)
CONC	.001 (0.64)	-.002 (-.61)
DCONC	.001 (0.09)	.04 (2.39)
EAST	.10 (1.47)	.78 (2.41)
1/AGE	.84 (4.74)	---
$\lambda^{§}$	-.06 (-.59)	
Log-Likelihood	-10663.83	

Notes: The estimation includes industry and year dummies. The heteroscedasticity term as given in equation (B.3) of the tobit with heteroscedasticity includes all explanatory variables except $(EMP)^2$. The results are not reported. The t-values are given in parentheses. The numbers of observations are n=5862 for every equation.

[§] λ is a transformation of the coefficient of correlation $\rho = 2/\pi * \arctan(\lambda)$. We impose this transformation to restrict the parameter ρ to the interval [-1;1]. Hence, $\rho = -.04$ which is not different from zero.

The other results are of interest as well. The control variables work quite well. A strong effect comes from the share of sales exported[6]. The import ratio also has a strong positive impact on innovative activity. Apparently, these firms are forced to be innovative in order to be successful in international competition. These results are in accordance with those for the leader and the entrant as in both cases more intensive competition increases innovative activity. In contrast, DCONC is sometimes significant and positive, which points to another conclusion. While the absolute level of concentration has no impact, the change in concentration has apparently a positive effect.

The time dummies 1993 and 1995 (which are not reported) are significant. Additionally, we find strong differences between the individual industries, which does not come as a surprise. Firm size has also an effect. Expenditures for R&D divided by sales increase with firm size, but with a diminishing rate. The maximal intensity is reached at a firm size of about 44000 employees. Four firms in our sample are larger, but for the majority we conclude that the bigger firms are the more research intensive ones. The concentration ratio is insignificant. The results concerning firm size and concentration and the other variables describing the competitive situation are somewhat different than in earlier research on German firms (Kraft 1989) and do only partly, if at all, support the theory of Schumpeter (1934, 1942). The impact executed by the potential entrants points to a creative destruction in the view of Reinganum (1985) on industry evolution and is perhaps in accordance with the general view of Schumpeter about technical progress. However, the creative destruction is driven by the challengers and competitive pressure supports innovative activity, which is not in the spirit of Schumpeter.

[6] One might question the assumed exogeneity of exports as internationally successful firms are possibly those with a high innovative potential. However, we have not tried to instrument the export variable, as we have no good instruments available and the methodology is already quite demanding.

3. Conclusion

The purpose of the presented study is to perform the first empirical study on the R&D activities of incumbent versus challenger firms. It is intended to carry out an empirical test on the conflicting hypotheses of the auction and the patent racing models.

The data used are 5862 observations from the Mannheim Innovation Panel (MIP) covering the years 1992 to 1995. The participating firms are, among other things, asked about the motives for innovative activities. With these variables it is possible to receive information on intended, but perhaps unsuccessful, entry into a new market. Thus, information concerning the unsuccessful firms can be used for an empirical test. This is important, as the successful introduction of an innovative process or product might be the result of a strategic decision to invest more than the competitors or the outcome of pure luck. Usually the researcher observes only the fact but not the reason for innovation. Given the large impact of risk and uncertainty in this connection, our data seem to be of considerable interest for an analysis of this question.

It turns out that the challenger invests more into R&D than other firms, but in contrast, the incumbent has no significantly higher R&D intensity. Thus, the predictions of the patent racing model are supported. Given the conflicting hypotheses and the somewhat restrictive assumptions of the two models, the results of the empirical test were by no means clear ahead of the estimation, and we regard the outcome of this first attempt as quite supportive for a combination of theory and empirical research.

The auction model may still have its relevance for innovation projects that are not as risky as R&D activities. If licenses are bought or a new technology (from outside) is introduced, the involved risk is presumably much smaller than that of an R&D process. It remains to be tested whether the Gilbert and Newbery (1982) model applies to such investments into innovation.

Of course, the question arises whether these results have any policy conclusions. At present, one has to be careful as this is the first empirical test on this issue but apparently the potential entrants into new markets play an important role for technical progress, especially if considerable uncertainty is involved. Traditionally, government subsidies go to a large extent to the established and large firms in industries. Perhaps this is counterproductive since these firms have a smaller incentive to create new processes and products, and thus the industrial structure is stabilized and creative destruction is hindered. Presumably, banks also tend to support the established firms in refining existing processes and products as this is less risky and demands less specific technical knowledge on the new technology and on new goods. However, an “industrial revolution” comes from the outsiders, who are most likely to have some problems with the access to financial sources.

The next step for empirical research on this issue is whether the larger R&D intensity really leads to more innovations. This is recorded by the MIP as well. Furthermore, it can be determined, how large the cost reduction due to process innovation is and how large the market share resulting from product innovation is. This research will presumably also be important in order to give clearer guidance for policy recommendations.

Appendix A

On the Auction and the Patent Racing Models

The auction model considers the situation, where either a monopolist or an entrant can introduce a process innovation. The process innovation can be drastic or non-drastic. The innovation leads to a cost reduction from c to c', with $c>c'$. The profits associated if the incumbent has introduced the innovation are $\pi^I(c')$. If not the incumbent, but the entrant has introduced the innovation, the profits of the incumbent are $\pi^d(c,c')$, which will be zero in the case of a drastic innovation and positive for a non-drastic innovation. If the entrant has introduced the innovation her or his profits are $\pi^d(c',c)$. The value of the innovation for $T=\infty$ and a discount rate r for the entrant is:

$$\text{(A1)} \quad V^c = \int_0^\infty \pi^d(c',c)e^{-rt}dt = \frac{\pi^d(c',c)}{r}.$$

The respective value for the incumbent is:

$$\text{(A2)} \quad V^I = \frac{\pi^I(c') - \pi^d(c,c')}{r},$$

with the possibility of $\pi^d(c,c')=0$ included. The so-called efficiency assumption states that two duopolists will realize less or equal profits than one monopolist:

$$\pi^I(c') \geq \pi^d(c,c') + \pi^d(c',c).$$

In the case of a drastic innovation $\pi^d(c,c')=0$ and the incentive to introduce or to bid for the innovation is the same for the incumbent and the entrant. However, in the case of a non-drastic innovation:

$$\text{(A3)} \quad V^I = \frac{\pi^I(c') - \pi^d(c,c')}{r} \geq \frac{\pi^d(c,c') + \pi^d(c',c) - \pi^d(c,c')}{r} = V^c$$

and, thus, the incumbent offers more for the innovation, if the inequality sign applies. In the Gilbert and Newbery model, there is no uncertainty concerning the effects of the innovation. However, if there is uncertainty about the cost reducing effect of the innovation, and therefore about the question drastic versus non-drastic innovation, the incumbent should bid more than the challenger.

In the case of patent racing following Dasgupta and Stiglitz (1980) or Lee and Wilde (1980) and in particular Reinganum (1983, 1985, 1989), the following assumptions are made: The expenditures for research and development x influence the probability to invent as the first, to receive a patent on the innovation and, thus, to terminate the race as the first. A hazard rate is considered, in which the probability of success by a firm i at a given time t is an exponential function. In order to derive this function recall that the definition of a hazard rate (named g in his case) is the probability that a firm will innovate in the next moment of time *P'(t)* given that it has not yet done so by time *t 1-P(t)*:

$$g(t) = \frac{P'(t)}{1 - P(t)},$$

with *P'(t)* being the derivative of the distribution function. This represents a differential equation, with the solution $P(t) = 1 - e^{-\int_0^t g(v)dv}$. The literature usually assumes $\int_0^\infty g(v)dv = h(x)t$.

That is if t_i represents firm i's (random) success date, then $\Pr(t_i < t) = 1 - e^{-h_i(x_i)t}$, where h_i is the hazard rate or conditional probability density of success, given no success at present[7]. The hazard rate $h(x_i)$ depends on investment into R&D. It is usually assumed that the hazard function is twice continuously differentiable, with $h'(x) > 0$ and $h''(x) < 0$. The choice variable of the firm in question is the flow expenditure x for R&D so that $\Pr(t_i < t) = 1 - e^{-h_i(x_{it})t}$.

For the exponential distribution the expected date of invention is simply $1\big/\sum h(x_j)$ with j=1,...,n denoting the firms (integrate $\int_0^\infty e^{-(\sum h(x_j))t}dt$). The expected success date for firm i is $1/h(x_i)$. Let $h_C = \sum_{j \neq i} h(x_j)$ be the aggregate rival hazard rate (with just one possible entrant this simplifies to $h_C = h(x_j)$).

The incumbent has to take into account the present profits R, as well as the probability that she/he or one of the challengers succeeds in innovating. One can define the derivative $P'(t) = h(x_i)e^{-h(x_i)t}$ as the probability that firm i innovates at time t. A similar probability can be calculated for the other firm. These probabilities are multiplied by the respective profit levels relevant in these situations. The expected profit of the incumbent as a function of its own investment rate and its rival's hazard rate is:

$$V^I = \int_0^\infty e^{-rt} e^{-(h(x_I)+h(x_C))t}\left[\frac{h(x_I)\pi^I(c')}{r} + \frac{h(x_C)\pi^I(c,c')}{r} + R - x_I\right]dt \tag{A4}$$
$$= \frac{\frac{h(x_I)\pi^I(c')}{r} + \frac{h(x_C)\pi^I(c,c')}{r} + R - x_I}{r + h(x_I) + h(x_C)}$$

---

[7] From the MacLaurin expansion of the exponential function follows $1 - e^{-h(x_i)} = 1 - 1 + h(x_i) - (2!)^{-1}(-h(x_i))^2 - (3!)^{-1}(-h(x_i))^3 - ... < 1 - 1 + h(x_i)$ but the difference becomes negligible for small $h(x_i)$ and then $1 - e^{-h(x_i)} \approx h(x_i)$.

Considering a simple situation with the incumbent (present monopolist) and just one challenger (potential entrant), the challenger calculates in a similar way:

(A5)
$$V^c = \int_0^\infty e^{-rt} e^{-(h(x_I)+h(x_C))t} \left[\frac{h(x_C)\pi^C(c',c)}{r} - x_C \right] dt$$
$$= \frac{\left(\frac{h(x_c)\pi^C(c',c)}{r} - x_c \right)}{r + h(x_I) + h(x_c)}$$

The term $e^{-(h(x_I)+h(x_C))}$ determines the probability density of innovation time. If neither firm has made a discovery, the incumbent's cash flow is $(R\text{-}x_I)$. The cash flow of the challenger in this case is $-x_C$. The difference between both payoffs are the flow profits of the incumbent, which she/he receives as long as nobody has succeeded. Secondly, the incumbent receives a (possibly positive) payoff $\pi^I(c,c')$ if the challenger wins.

The probability density that the incumbent discovers first at time t is $h(x_I)e^{-(h(x_I)+h(x_C))}$, and a related probability density can be calculated for the challenger. If the incumbent discovers an innovation first, its pay-offs are the present discounted value from time t of monopoly profit using the new technology $e^{-rt}\pi^I(c')/r$. In the case of the challenger, drastic and non-drastic innovations have to be distinguished. If the innovation is non-drastic, both firms produce positive output after the innovation. Then the firms' pay-offs are the present discounted value of the Cournot oligopoly profits: $e^{-rt}\pi^I(c,c')/r$ and $e^{-rt}\pi^C(c',c)/r$. If the innovation is drastic, the challenger's pay-off is the present discounted value of monopoly profits using the new technology, while the incumbent's pay-off is zero. (The double discounting is necessary as the investment expenditures arise today as well as in every period until discovery, while the expected returns from the investment are due (if at all) after the invention has actually taken place.)

Differentiation of (A4) leads to:

$$\frac{\partial V^I}{\partial x_I} =$$

(A6) $$\frac{\left(\frac{h'(x_I)\pi^I(c')}{r}-1\right)\left(r+h(x_I)+h(x_C)\right)-h'(x_I)\left(\frac{h(x_I)\pi^I(c')}{r}+\frac{h(x_C)\pi^I(c,c')}{r}+R-x_I\right)}{\left(r+h(x_I)+h(x_C)\right)^2}$$

$$=\left(\frac{h'(x_I)\pi^I(c')}{r}-1\right)-h'(x_I)\frac{\left(\frac{h(x_I)\pi^I(c')}{r}+\frac{h(x_C)\pi^I(c,c')}{r}+R-x_I\right)}{\left(r+h(x_I)+h(x_C)\right)}=0$$

This equation can be simplified to:

(A7) $$\frac{h'(x_I)\pi^I(c')}{r-1}-h'(x_I)V^I=0.$$

The effect of R on x_I is obtained by implicit differentiation and turns out to be for a drastic innovation

$$\frac{\partial x_I}{\partial R}=-\frac{\partial^2 V^I/\partial x_I \partial R}{\partial^2 V^I/\partial x_I^2}=-\frac{[-]}{[-]}<0.$$

The derivative of the first order condition with respect to R is negative, as the reader will easily verify. The second order condition requires that the denominator of the equation above is negative. Reinganum (1983) as a corollary states that if $R>0$, there exists an open neighborhood of cost conditions c such that if the technology is not drastic, $x_I < x_C$ follows.

The term V^I includes the possibility of (A3) and thus reflects the so-called efficiency effect of the Gilbert and Newbery (1982) model. The first term of (A7) stands for the replacement effect. $h'(x_I)$ is higher, x_I lower and $h(x_I)$ smaller because of the replacement effect, which dominates the efficiency effect in this model.

The direct relation to the auction model of Gilbert and Newbery (1982) is not easily established. One has to work with examples rather than with a general theory. First, consider the situation, where it is almost certain that a non-drastic innovation will be invented during the next period but it is unclear whether the incumbent or the challenger succeeds. With probability $h(x_I)$ the incumbent wins and with probability $h(x_C) \approx 1 - h(x_I)$ the challenger wins this race. The value function for the incumbent is in this case:

(A8) $$V^I = \frac{h(x_I)\pi^I(c')}{r} + \frac{(1-h(x_I))\pi^I(c,c')}{r} + R - x_I .$$

Differentiation with respect to R&D expenditures and rearranging yields:

(A9) $$h^{'}(x_I) = \frac{1}{\pi^I(c') - \pi^I(c,c')} .$$

A similar procedure for the challenger (who can only enter in the case of success) implies:

(A10) $$h^{'}(x_C) = \frac{1}{\pi^C(c',c)} .$$

In the case of a non-drastic innovation with the efficiency assumption $\pi^I(c') \geq \pi^d(c,c') + \pi^d(c',c)$ and because of $h^{'}(x) > 0$ and $h^{''}(x) < 0$ the incumbent invests more. In the case of a drastic innovation both players have the same incentives for R&D investment and thus the results of the Gilbert and Newbery (1982) model are repeated.

Secondly, consider the case of large efficiency advantages in innovation of the incumbent, say due to government subsidies to the R&D process. It is assumed as very probable that an innovation will take place in the near future and hence $h(x_I) \to \infty$. Because of the large advantage of the incumbent, the challenger does not invest into R&D and therefore $h(x_C) = 0$. Due to the subsidies, the incumbent is not automatically granted a patent on the innovation, but has to bid for it in a contest with the challenger. In this case V^I reduces to:

$$\text{(A11)}\quad \lim_{h(x_I)\to+\infty} V^I = \frac{\dfrac{h(x_I)\pi^I(c')}{r} + \dfrac{(1-h(x_I))\pi^I(c,c')}{r}}{r+h(x_I)} + \frac{R-x_I}{r+h(x_I)} = \frac{\pi^I(c')-\pi^d(c,c')}{r}$$

which is identical to (A2) and because of (A3) the incumbent bids more for the patent.

Appendix B

The tobit model with heteroscedasticity

The tobit model is used to account for the qualitative difference between limit observations (zero) and non-censored (continuous) observations. The tobit model can be expressed as (for more details see e.g. Greene 1997 or Maddala 1983)

$$
\text{(B.1)} \quad
\begin{aligned}
& y_i^* = x_i\beta + \varepsilon_i, \\
\text{with} \quad & y_i = 0 \ \text{ if } \ y_i^* \le 0, \\
& y_i = y_i^* \ \text{ if } \ y_i^* > 0.
\end{aligned}
$$

y_i^* is the latent variable, i.e. the propensity of undertaking R&D. However, y_i is the observed random variable transformed from y_i^*. β is the vector of parameters, x_i is the set of regressors and ε_i denotes the error term.

If $y_i^* \sim N(\mu, \sigma^2)$ the log-likelihood for the homoscedastic model is given as

$$
\text{(B.2)} \quad \ln L = \sum_{y_i > 0} -\frac{1}{2}\left[\ln(2\pi) + \ln\sigma^2 + \frac{(y_i - x_i\beta)^2}{\sigma^2}\right] + \sum_{y_i = 0} \ln\left[1 - \Phi\left(\frac{x_i\beta}{\sigma}\right)\right].
$$

Φ denotes the standard normal cdf. For the heteroscedastic model one has to replace σ^2 with

$$
\text{(B.3)} \quad \sigma_i^2 = \sigma^2 e^{\alpha' w_i}.
$$

Greene (1997, p. 968) reports that “this is a fairly general model that includes many familiar ones as special cases”. α denotes the vector of parameters and w_i the vector of regressors in the heteroscedasticity term.

The tobit model with sample selection

Our regression model is given as[8]

(B.4) $$\begin{aligned} y_1^* &= x_1\beta_1 + \varepsilon_1 \\ y_2^* &= x_2\beta_2 + \varepsilon_2 \end{aligned},$$

where the first equation concerns the selection whether the firm is an innovator or not. We observe $y_1 = 1$ if $y_1^* > 0$ and $y_1 = 0$ otherwise. The second equation is the, say, *tobit* equation, with $y_2 = y_2^*$ if $y_2^* > 0 \wedge y_1^* > 0$ and $y_2 = 0$ otherwise. We assume

$$\begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho \\ . & \sigma_2^2 \end{pmatrix} \right).$$

Thus, we can construct a likelihood function that consists of three parts taking account of the three different firm types:

1. Non-innovating firms: Let $\Phi_1(.)$ denote univariate standard normal cdf, then

   $$P(y_1 = 0) = 1 - \Phi_1(x_1 b_1).$$

2. Innovating firms without R&D activities: Let $\Phi_2(.)$ denote bivariate standard normal cdf and ρ the coefficient of correlation, then

   $$P(y_2 = 0 \wedge y_1 = 1) = \Phi_2\left(x_1\beta_1, \frac{-x_2\beta_2}{\sigma_2}, -\rho \right)$$

3. Innovating firms with R&D expenditures: To calculate $P(y_2 = y_2^* \wedge y_1 = 1)$ we have to apply a theorem on incidentally truncated distributions (see Greene 1997, p. 974-5). The truncated joint density is

   $$f(y_1, y_2 \mid y_1 > 0) = \frac{f(y_1, y_2)}{P(y_1 > 0)}.$$

   To obtain the incidentally truncated marginal density for y_2, we have to integrate y_1 out of the expression. For our model, this yields

$$\frac{f(y_2)}{P(y_1>0)}\int_0^{+\infty} f(y_1 \mid y_2 = y_2^*)\, dy_1 .$$

Thus, the contribution to the likelihood function is

$$P(y_2 = y_2^* \mid y_1 = 1) = \frac{1}{\sigma_2}\phi\left(\frac{y_2 - x_2\beta_2}{\sigma_2}\right)\frac{1}{\Phi_1(x_1\beta_1)}\int_0^{+\infty} f\left(y_1 \mid y_2 = y_2^*\right)dy_1 ,$$

where

$$\int_0^{+\infty} f\left(y_1 \mid y_2 = y_2^*\right)dy_1 = 1-\Phi_1\left(\frac{-E\left(y_1 \mid y_2 = y_2^*\right)}{\sqrt{Var(y_1 \mid y_2 = y_2^*)}}\right).$$

The moments $E(.)$ and $Var(.)$ are

$$E(y_1 \mid y_2 = y_2^*) = x_1\beta_1 + \frac{\sigma_{12}}{\sigma_2^2}(y_2 - x_2\beta_2),$$

$$Var(y_1 \mid y_2 = y_2^*) = \sigma_1^2(1-\rho^2) = (1-\rho^2).$$

Finally, the model's likelihood function is

$$L = \prod_{\substack{y_2>0,\\ y_1=1}} \frac{1}{\sigma_2}\phi\left(\frac{y_2 - x_2\beta_2}{\sigma_2}\right)\frac{1}{\Phi_1(x_1\beta_1)}\int_0^{+\infty} f\left(y_1 \mid y_2 = y_2^*\right)dy_1$$

(B.5)

$$\prod_{\substack{y_2=0,\\ y_1=1}} \Phi_2\left(x_1\beta_1, \frac{-x_2\beta_2}{\sigma_2}, -\rho\right)\prod_{\substack{y_2=0,\\ y_1=0}}\left[1-\Phi_1(x_1\beta_1)\right].$$

For our estimation we allow for heteroscedasticity in the tobit equation. Therefore, we replace σ_2 with σ_{2i} as in equation (B.3). We assume that the correlation among equations is constant. As a further step one could allow ρ to vary across observations. However, we restrict ρ being constant because the maximization of this likelihood function is already quite difficult.

---

[8] For convenience, we drop the index *i* indicating the *i*-th observation.

Appendix C

Descriptive Statistics

	Non-Innovating firms (2419 obs.)		Innovating firms (3443 obs.)	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
R&D/SALES	0	0	3.64	7.38
EMP/100	1.81	6.11	9.61	48.45
EXPORT	10.30	18.18	23.10	23.28
SHARE	.27	1.56	1.10	5.37
KAPIN	.09	.15	.09	.12
INCUMBENT	--	--	.65	.48
ENTRANT	--	--	.09	.29
EAST	.34	.47	.30	.46
IMPORT	19.41	10.13	20.17	8.74
CONC	43.07	31.14	48.27	34.78
DCONC	.41	5.03	.45	5.08
1/AGE	.15	.15	.16	.17

Panel structure

Observed Patterns						
1992	1993	1994	1995	Firms	Percent	Cum.
X				1243	34.84	34.84
			X	385	10.79	45.63
	X			284	7.96	53.59
		X		283	7.93	61.52
		X	X	248	6.95	68.47
X	X	X	X	246	6.89	75.36
	X	X	X	158	4.43	79.79
X	X			128	3.59	83.38
X	X	X		125	3.50	86.88
Other Patterns				468	13.12	100.00
				3568	100.00	

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