Competition and Persistence of R&D

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Abstract:

This paper investigates the R&D persistence of R&D active firms in different markets with different intensities of competition, based on firm-level panel data for the period 1996-2008. In a dynamic setting of the empirical model it turns out that persistence is strongly related to market competition (measured by the number of principal competitors). Persistence of R&D expenditures is more likely to be observed in markets with few principal competitors (between 6 and 10) and is very unlikely to be observed in polypolistic type of markets (more than 50 competitors). These results call for a stronger coordination between competition policy and innovation promotion policy, since the former basically aims at larger markets with many competitors, while the latter aims at persistence of R&D efforts and thus markets with fewer competitors.

Key words: R&D expenditures; Persistence; Innovation; Competition; Panel data; Empirical investigation

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This paper investigates the R&D persistence of R&D active firms in different markets with different intensities of competition, based on firm-level panel data for the period 1996-2008. In a dynamic setting of the empirical model it turns out that persistence is strongly related to market competition (measured by the number of principal competitors). Persistence of R&D expenditures is more likely to be observed in markets with few principal competitors (between 6 and 10) and is very unlikely to be observed in polypolistic type of markets (more than 50 competitors). These results call for a stronger coordination between competition policy and innovation promotion policy, since the former basically aims at larger markets with many competitors, while the latter aims at persistence of R&D efforts and thus markets with fewer competitors.

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1. Introduction

This paper looks at the relationship between persistence of R&D expenditures and the number of principal competitors. The main issue of this paper is to identify whether past sales share of R&D expenditures are positively related to current sales share of R&D expenditures. Essentially two aspects are investigated. First, are relatively large sales share of R&D expenditures in the past positively, negatively or unrelated to the sales share of R&D expenditures in the present. Secondly, is the observed relationship between past and present R&D expenditures related to the competitive environment of a firm? These are important research questions for at least two reasons. Firstly, it is in the interest of the society that firms' engage persistently in risky R&D activities in order to provide consumers with new and useful products (e.g. environmental friendly products). Secondly, markets should be competitive in order to guarantee an efficient allocation of scarce resources among firms and to provide incentives for low market prices. Taking together these two important aspects, persistence of R&D investments and competition, it is useful to see if they work in the same direction, i.e. more competitive markets (greater number of competitors) promote the persistence of R&D expenditures, or if they go in different directions, i.e. a greater number of competitors is negatively related to the persistence of R&D expenditures. This should be clarified based on some theoretical notions and an empirical analysis using firm-level panel data. Following Schumpeter (1942) it could be assumed that a larger number of competitors do not necessarily provide the best platform for stable R&D investments. Aghion et al. (2005) found an inverted-U relationship between intensity of competition (measured by the Lerner Index) and citation weighted patents on an industry level. They also used R&D expenditures as an alternative innovation measure and again they find an inverted-U shape, although the coefficients are not statistically significant. However, Levin et al. (1985) found an inverted-U shape relationship between R&D intensity and competition measured through industry concentration. Also Schmidt (1997) identified two countervailing effects of competition on innovation. On the one hand competition increases the incentives of managers for innovative activities in order to avoid bankruptcy, on the other hand competition reduces the profitability of cost-reducing innovations, since firms' market share is expected to be low. Hence, also in Schmidts' (1997) findings one can identify an inverted-U relationship of competition on innovation (see Gilbert 2006). Persistence of R&D behavior is not investigated in this type of literature.

However, there are several reasons why persistence of innovation activities is likely. Gilbert and Newbery (1982) show that monopolists are likely to invest frequently in R&D in order to avoid new market entry. Already Schumpeter (1942) emphasized the importance of internal financial means for R&D activities. Since past innovation success increases the cash-flow of a firm, past innovation success is likely to provide sufficient financial means for future R&D expenditures. Hence, we would observe persistence in innovation activities. From an empirical point of view, investigations of persistence of innovation behavior essentially look at persistence in innovation outputs (new products or processes). Raymond et al. (2010) found persistence in the probability of innovating and they found persistence in innovation output intensity in the high-tech sector. Peters (2005) also found persistent innovation behavior at the firm level for both, manufacturing and service firms. However, these studies do not look at the innovation input side (R&D investments). Since we want to investigate the relationship between competition and persistence of innovation behavior, it seems more adequate to look whether competition provides incentives for persistent investment in R&D rather than persistence of innovation output. Hence, the paper at hand combines the notion of an inverted-U shaped relation between R&D expenditures and competition with the notions of persistence in R&D expenditures and tests this relationship empirically. That is new.

The investigation at hand shows that persistence of R&D expenditures is strongly related to the number of principal competitors. However, following the theoretical notions this relationship follows an inverted-U shaped form. Competition fosters persistence in R&D expenditures until 10 competitors. Between 11 and 15 competitors we still see a significant positive relationship, though with a lower coefficient. The effect of persistence gets insignificant in markets with 16 to 50 principal competitors and even turns into a significant negative effect in markets with more than 50 principal competitors. This way we see that competition and R&D persistence go hand in hand in markets with very few principal competitors and go separate ways in markets with more principal competitors. Here lies a great challenge for innovation promotion policy and competition policy.

The paper is organized as follows. Section two presents the theoretical notions that lead us to the hypothesis. Section three points at the empirical evidence of the relationship between R&D persistence and competition. Section four deals with empirical issues and section five presents the results. Section six concludes.

2. Theoretical notions

Aghion et al. (2005), Levin et al. (1985) and Schmidt (1997) presented theoretical models to understand the inverted-U shape relationship between competition and innovation performance from different angles. However, they do not refer explicitly to the persistence of R&D investments. Klepper (1996) stated that R&D expenditures remain the same over time, but he does not consider competition. To the best of our knowledge we still lack a theoretical concept about the relationship between competition and persistence of R&D behavior. Therefore the theoretical reasoning is built on a patchwork of different theories that help us to formulate a plausible hypothesis.

Gilbert and Newbery (1982) provided some evidence that monopolists have incentives for preemptive inventions in order to prevent market entry. The monopolist would invest in R&D in order to prevent entrance as long as the investments for R&D are lower than the potential losses from entrance. Furthermore the monopolist must be in a position to develop the potential product substitute at least as quickly as the potential entrant. The preemption threat would be credible if the monopolist is in a position to increase its R&D activities in response to the R&D activities of the potential entrant (see Gilbert and Newbery 1982). This means that actually the monopolist is developing the new innovative product and not the potential entrant, just like Schumpeter has stated already. In terms of persistence, it is important to consider that in this theoretical model the monopolist knows the entry date of the potential entrant and thus can delay its R&D investments in order to save R&D costs. Therefore we would expect that a monopolist would have a moderate level of persistence of R&D expenditures, since serious entry threat maybe frequently but does not appear ever day. In this setting the monopolist's expectations about entry date and the profit expectations of potential entrant are certain. In case of uncertainty it is likely that the monopolist and the potential entrants have different profit expectations from entering the monopolists market. In case the potential entrant is more optimistic, the incumbent's preemptive R&D investments would be insufficient to prevent entry.

Assuming that R&D expenditures in a monopolistic market are too low it is just a question of time until entry takes place. And as the number of R&D active principal competitor increases also uncertainty about the commercial success of the R&D result increases (see Reinganum 1984, Gilbert 2006), since several independent, concurrent research trials exist and time to market (or to win the patent race) can be decisive for commercial success of the product. The firms in such markets do not know for sure when competitors are likely to patent the new technology or commercialize the new product. Hence they are unlikely to reduce or delay R&D investments, since principal competitors cannot be expected to lag behind. Firms in such a research intensive competitive environment have great incentives to pursue several research paths simultaneously and cost consciousness is low, since what counts is to win the race and reap the rewards; to lose the race would leave the firm with great costs and no rewards. 'In general, the greater the number of competitors the greater are the incentives to act earlier rather than wait' (see Wernerfelt and Karnani 1987). Hence, it is the competitive pressure in a neck-to-neck competition (see Aghion et al. 2005) that provides incentives to firms to escape from competition through considerable investments in R&D and new product development. However, why R&D expenditures should be persistently high? Following Bloom (2007) we can assume that in such uncertain market circumstances firms may take a "wait and see" position in order to avoid too early steps that are likely to be revised afterwards. Thus, in uncertain market circumstances with few R&D active, principal competitors we would see persistent, great R&D expenditures.

If we further increase the number of competitors it is likely that R&D expenditures are decreasing and persistence is decreasing as well. Dasgubta and Stiglitz (1980) found already that greater demand elasticity comes along with lower R&D expenditures of firms or to express it differently that given a low degree of concentration, R&D effort per firm is positively correlated with concentration. These findings are in line with Martin (1993), who found that the greater is the number of firms in the market – the greater the degree of competition – the smaller are the payoff related with a marginal increase of firm efficiency (see Martin 1993). Since 'gain in efficiency' can be seen as an innovation output and the 'payoff' is the incentive for investments in R&D, it is clearly that markets with a greater degree in competition offer lower incentives for investments in R&D. But what does this mean in terms of persistence? Hall (1992) found already a positive relationship between R&D investments and cash-flow. Hall (1992) concludes that internal financial restraints prevent firms from R&D investments. Himmelberg and Petersen (1994) found that especially small firms are likely to suffer from internal financial constraints. Hence, smaller firms (with great number of competitors) are heavily exposed to external financial sources in order to invest in R&D projects. In order to attract external sources, firms have to overcome a typical principle-agent problem. The researcher may not always succeed to communicate its (tacit) knowledge about the R&D project to the potential investors or innovation promotion funds. Hence, external financial flows will be sporadic and as a consequence persistence of R&D investments in such a market environment is expected to be low.

Based on these theoretical notions we hypothesize the following non-monotonic relationship between market competitiveness and persistence of R&D effort.

H1: We state that the persistence of R&D investments increase with the number of principal competitors[1] until an oligopolistic market structure is reached. As the number of principal competitors further increases approaching a polypolistic market form, the persistence of R&D investment decreases. This way we observe an inverse-U shaped relationship between number of principal competitors and persistence of R&D investments (see figure 1).

Insert figure 1

3. Persistence and competition: previous evidence

The theoretical notions point at the effects of competition on firms' investment behavior and not on the results of R&D investments, e.g. innovative products. Since R&D projects are risky, it is difficult to identify R&D investments with R&D results (e.g. innovative product). R&D investments are a necessary but not a sufficient condition for the success of an R&D project. Furthermore market competition can be assumed to have an immediate affect on investments incentives and a more indirect (if any) effect on the R&D results. Therefore it makes more sense to look at R&D investments and not so much at R&D results (e.g. innovative products) when investigating the effects of market competition on persistence of behavior. However, existing literature on innovation persistence predominantly looks at innovation results and it is not conclusive about the existence of innovation persistence at all. Related to different methods, character of the dependent variable (e.g. patents, binary qualitative variable, quantitative measures of innovation), countries and time periods the results are fluctuating between no persistence (Raymond et al. 2010

[1] Following the investigations of Boone (2001, 2008) the intensity of competition is not necessarily related to the number of competitors, the price-cost margin of firms, or the Herfindahl index. However in our case we asked the firms for the number of principal competitors worldwide. Hence, we can assume that all firms within the respective markets have very similar marginal costs. In this case it is rather safe to assume that an increase in the number of principal competitors does indeed increase competition and lowers total industry profits. In case firms would have

(in the low-tech sector in terms of innovation intensity)), low persistence (Geroski et al. 1997, Malerba and Orsenigo 1999, Cefis and Orsenigo 2001, Cefis 2003, Raymond et al. 2010 (in the high-tech sector in terms of innovation intensity)), and high persistence (Crépon and Duguet 1997, Peters 2005). In contrast to the study at hand, these investigations do not look at the meaning of market competition for persistence.

Another strain of literature investigates the relationship between responsiveness of R&D investments and uncertainty. Bloom (2007) found that uncertainty decreases the responsiveness of R&D investments, based on a "caution" effect (see Bloom et al. 2007). Firms will refrain from actions if uncertainty characterizes the market environment, since early actions may cause great adaptation cost. Although 'uncertainty' and 'number of competitors' are related, there is at least one important difference. Referring to the 'theoretical notions' above, it is likely that we will observe increasing uncertainty with increasing number of competitors. However the effects on R&D responsiveness are expected to be different. While uncertainty is expected to be negative linearly related with R&D responsiveness, the 'number of competitors' is expected to be negative non-linearly related with R&D responsiveness (see hypothesis).

4. Empirical issues

4.1. Data

This investigation is based on a panel of Swiss firms observed across five periods (1996, 1999, 2002, 2005, and 2008). The data were collected by the Swiss Economic Institute (KOF) at the ETH Zurich, in the course of five postal surveys using a rather comprehensive questionnaire (available from www.kof.ethz.ch[2]), which includes questions on firm characteristics, innovation activities, and R&D activities, among other things. The surveys were based on a stratified random sample of firms having at least five employees covering all relevant industries in the manufacturing, construction, and service sectors. Stratifications is on 28 industries and, within each industry, three firm size classes (with full cover-

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very different marginal cost levels, the rise in competition is likely to reallocate output from low price-cost margin firms or inefficient firms to more efficient firms (see also Boone 2001, 2008).

[2] Questionnaires are available in German, Italian, and French language.

age of the upper class of firms). Responses were received from 1748 (32.5%), 2172 firms (33.8%), 2583 firms (39.6%), 2555 firms (38.7%), and 2141 (36.1%) for the years 1996, 1999, 2002, 2005 and 2008 respectively. Overall, we have a highly unbalanced firm-panel. We lose a number of observations, since we have to control for the initial endowment (R&D expenditures of a firm in 1996). Furthermore we have a lagged dependent variable in the models that also reduces the number of firms to those that answered in two consecutive surveys. In the end the estimations are based on 430 observations. Descriptive statistics show that the sales share of R&D expenditures (RDEXP; for the definition of dependent and independent variables see Table 1 and Table 2) lies between 3.7% (2008) and 4.8% (2002). On average RDEXP amounts to 4.2% (1999-2008), if we look at the firms that answered the survey in 1996 and the respective year 1999, 2002, 2005, or 2008. This figure is only slightly different from 4.3% (2002-2008*) if we exclusively look at the firms that we could use in the econometric estimations (see Table 3).[3] EDUC as well as SIZE are increasing across time. Quite interesting and typically for Switzerland, the share of firms that face fewer competitors (up to 10) is considerably greater than the number of firms that face 11 or more competitors. In Table 4 we see the average RDEXP for firms that find themselves in one of the "competitors' categories" respectively. It is obvious that firms in the category 'more than 50 competitors' (NCOMP50+) spend on average much less in R&D compared to firms facing fewer competitors. Looking at the firm average across years we see decreasing shares of RDEXP with increasing number of competitors (1999-2008). While R&D active firms with less than 5 principal competitors spend around 3.8% of their sales in R&D, firms with more than 50 competitors spend only 2.3% in R&D.

4.2. Empirical specification and estimation methods

Empirical specification

The following empirical base model is formulated:

[3] For the econometric estimations we could use only firms that answered in 1996 and in two consecutive surveys, i.e. 1999 and 2002 or 2002 and 2005 or 2005 and 2008, since we have also the lagged dependent variables in the estimations.

$$\begin{aligned} RDEXP_{it} &= \beta_0 + \beta_1 RDEXP_{it-1} + \beta_2 RDEXP_{it0} + \beta_3 NCOMP1-5_{it-1} + \beta_4 NCOMP6-10_{it-1} \\ &+ \beta_5 NCOMP11-15_{it-1} + \beta_6 NCOMP16-50_{it-1} + \beta_7 EDUC_{it} + \beta_8 SIZE_{it} + \beta_9 MILLS_{it} \\ &+ \beta_{10} DIND1 + ... + \beta_{37} DIND28_i + \beta_{38} TDUM05 + \beta_{39} TDUM08 + \beta_{40} M\_NCOMP1-5_i \\ &+ \beta_{41} M\_NCOMP6-10_i + \beta_{42} M\_NCOMP11-15_i + \beta_{43} M\_NCOMP16-50_i \\ &+ \beta_{44} M\_EDUC_i + \beta_{45} M\_SIZE_i + \beta_{46} M\_MILLS + \varepsilon_{it} \end{aligned} \quad \text{(a)}$$

The sales share of R&D expenditures in year (t) is explained through the lagged R&D expenditures ($RDEXP_{it-1}$) and the initial condition ($RDEXP_{it0}$) that controls for the R&D expenditures of a firm in 1996 (first year of observation). Furthermore it is expected that the number of competitors are significantly related with $RDEXP_{it}$. NCOMP1-5, NCOMP6-10, NCOMP11-15, and NCOMP16-50 are binary (dummy) variables that show whether the number of principal competitors lies between 1 and 5, 6 and 10, 11 and 15, or 16 and 50 competitors, respectively. The reference category is 'more than 50 competitors (NCOMP50+)'. Following the results of theoretical literature (see Reinganum 1983, or Wernerfelt and Karnani 1987) and taking into account the descriptive findings in Table 4, it is expected that fewer principal competitors provide greater incentives for R&D expenditures. Thus, NCOMPx ($x \in [1-5, 6-10, 11-16, 1-50, 50+]$) should show a positive sign by trend, since NCOMP50+ is the reference. EDUC and SIZE control for the education level of the firm and firm size, respectively. Since we are only looking at firms with R&D activities we have to control for a possible selection bias through the MILLS (Mills ratio derived from Heckman estimations for the cross sections 2002, 2005, and 2008 respectively, see Table A1 and Table A2 in the annex). We also control for 28 industries and three time periods. Moreover, following Wooldridge (2005) it is necessary to control for the time invariant unobserved firm heterogeneity. Like Peters (2009) and Wooldridge (2005) we estimate the unobserved time-invariant firm heterogeneity through the initial endowment and the time average of time varying variables in the model, i.e. $RDEXP_{it0}$, M_NCOMP1-5, M_NCOMP6-10, M_NCOMP11-15, M_NCOMP16-50, M_EDUC, M_SIZE, and M_MILLS.

In order to test the hypothesis of this paper, the base model has to be extended with interaction terms. The interaction model is split into 2 different equations. In (b) we test the persistence of R&D expenditures in markets with more than 5 principal competitors against markets with 5 or less principal competitors. In (c) we test NCOMP1-5 (between 1 and 5 competitors) against markets with more than 5 competitors.

$$\begin{aligned} RDEXP_{it} &= \beta_0 + \beta_1 RDEXP_{it-1} + \beta_2 RDEXP_{it0} + \beta_3 NCOMP6-10_{it-1} + \beta_4 RDEXP_{it-1} * NCOMP6-10_{it-1} \\ &+ \beta_5 NCOMP11-15_{it-1} + \beta_6 RDEXP_{it-1} * NCOMP11-15_{it-1} + \beta_7 NCOMP16-50_{it-1} \\ &+ \beta_8 RDEXP_{it-1} * NCOMP16-50_{it-1} + \beta_9 NCOMP50+_{it-1} + \beta_{10} RDEXP_{it-1} * NCOMP50+_{it-1} \\ &+ \beta_{11} EDUC_{it} + \beta_{12} SIZE_{it} + \beta_{13} MILLS_{it} + \beta_{14} TDUM05 + \beta_{15} TDUM08 + \beta_{16} DIND1 + ... + \beta_{43} DIND28_i \\ &+ \beta_{44} M\_NCOMP6-10_i + \beta_{45} M\_NCOMP11-15_i + \beta_{46} M\_NCOMP16-50_i + \beta_{47} M\_NCOMP50+_i \\ &+ \beta_{48} M\_EDUC_i + \beta_{49} M\_SIZE_i + \beta_{45} M\_MILLS + \varepsilon_{it} \end{aligned} \tag{b}$$

$$\begin{aligned} RDEXP_{it} &= \beta_0 + \beta_1 RDEXP_{it-1} + \beta_2 RDEXP_{it0} + \beta_3 NCOMP1-5_{it-1} \\ &+ \beta_4 RDEXP_{it-1} * NCOMP1-5_{it-1} + \beta_5 EDUC_{it} + \beta_6 SIZE_{it} \\ &+ \beta_7 MILLS_{it} + \beta_8 TDUM05 + \beta_9 TDUM08 + \beta_{10} DIND1 + ... + \beta_{27} DIND28_i \\ &+ \beta_{28} M\_NCOMP1-5_i + \beta_{29} M\_EDUC_i + \beta_{30} M\_SIZE_i + \beta_{31} M\_MILLS + \varepsilon_{it} \end{aligned} \tag{c}$$

In (b) we look at competitive markets comprising more than 5 competitors and separate them into the following categories: markets between 6 and 10 principal competitors (NCOMP6-10), markets between 11 and 15 principal competitors (NCOMP11-15), markets between 16 and 50 principle competitors (NCOMP16-50), and markets with more than 50 principal competitors (NCOMP50+).[4] Following the theoretical notions (see above) one can state that increasing the number of competitors starting from a low level, would also increase R&D competition, since firms cannot afford to fall behind in their R&D efforts and thus have to show persistence in their R&D expenditures. A strong positive marginal effect of lagged R&D expenditures across different types of competitive markets is expected. Moreover it is expected that the marginal effects of lagged R&D expenditures increases with the number of competitors until we are approaching polypolistic market circumstances. In polypolistic markets the persistence of R&D expenditures are expected to be insignificant or even negative significant.

In (c) the competitive effect of few competitors (less than five) on the persistence of R&D expenditures ($RDEXP_{it-1}$) is tested through the interaction term $RDEXP_{it-1}$*$NCOMP1\text{-}5_{it-1}$. In order to get the marginal

[4] The categories (number of principal competitors) are given in the questionnaires and can not be changed.

effect of RDEXP across different types of NCOMP (in (b) and in (c)) the first derivative has to be calculated (see 1).

$$RDEXP_{it} = \beta\ RDEXP_{it-1} + \gamma\ RDEXP_{it-1} * NCOMPx_{it-1} + ... + ...$$
$$E\left(\frac{\partial RDEXP_{it}}{\partial RDEXP_{it-1}}\right) = \beta + \gamma\left(NCOMPx_{it-1}\right) \qquad x \in \left[1-5, 6-10, 11-16, 1-50, 50+\right] \qquad (1)$$

The respective marginal effects are shown in Table 5. Since few R&D active competitors are expected to provide incentives for R&D expenditures, positive marginal effects are expected for markets with lower numbers of competitors and negative marginal effects are expected for firms in markets with a great number of principal competitors by trend.

Estimation method

In a dynamic empirical setting with the lagged dependent variable strict exogeneity of all regressors can no longer be assumed and following Hsiao (2003) the fixed effects estimator is no longer consistence (if T (time) is short and N (number of firms) is large), since the covariance estimation would be asymptotically biased. This bias is caused through the elimination of the individual effects through the fixed effects estimator, which in turn creates a correlation between coefficients of the explanatory variables and the residuals (Hsiao 2003, p. 72). Thus, endogeneity would be introduced into the model. Assuming that the initial endowment ($RDEXP_{it0}$) is independent of the individual effects (α_i) in a way that $Cov(\varepsilon_i, \alpha_i) = 0$, a GLS (Generalized Least Squares) estimator is an efficient, unbiased estimator. This assumption is valid, since estimations on single cross sections shows that the impact of the initial endowment on future sales share of R&D expenditures is diminishing in the course of the time. Furthermore it is assumed that the value of the initial endowment is a random draw from the population and not a fixed constant. Even if we would attenuate the assumption about the independence between initial endowment and individual effects, the GLS would remain a consistent estimator as long as T (time) is not fixed (see Hsiao 2003, p. 95). Following Wooldridge (2005) and Peters (2008) we control for the unobserved time invariant firm specific heterogeneity through the initial condition and the time average of time-varying variables (see Table 2 and equations (a), (b), and (c)).

There are many firms, especially smaller ones that do not have any R&D activities. This may cause a selection bias, since the decision of having R&D activities or not is not strictly exogenous. Therefore we have to estimate a 'Heckman' model in order to identify a selection bias. From the 'Heckman' model we isolated the 'Mills-ratio' and insert it as an additional control variable in the main estimations. The 'Heckman-models' are reported in the appendix. In the end we apply GLS random effects estimator with heteroscedasticity robust standard errors, including the mills ratio and the initial condition (see expression (a), (b), and (c) above).

5. Results

Focusing on the econometric results in Table 5 it is obvious that the responsiveness of R&D expenditures is low or in other words the persistence is great. All estimations in Table 5 show a significant positive sign for $RDEXP_{t-1}$ and marginal effects between 0.501 and 0.547. Also the initial endowment ($RDEXP_{it0}$) is significant positive in all equations, indicating the importance of controlling for unobserved individual heterogeneity. Furthermore it indicates the 'path dependency' of R&D expenditures. Also in line with the theoretical expectations, we see that R&D markets with fewer competitors are spending more in R&D compared to markets with many competitors. This is shown by the significant positive signs of NCOMP6-10 and NCOMP11-15. The control variables EDUC, SIZE, MILLS are not significant in Table 5. However, some of the industry dummies are significant.

In order to test the hypothesis we have to look at the marginal effects of $RDEXP_{it-1}$ across different types of $NCOMP_{it-1}$ (see Table 5 estimation (b) and (c)). The marginal effect of $RDEXP_{it-1}$*$NCOMP1\text{-}5_{it-1}$ is 0.504 and significant positive, indicating that firms in markets with 1 to 5 competitors are persistent in their R&D expenditures. However, like expected persistence increases with the number of competitors. If we consider markets with 6 to 10 principal competitors, we observe a marginal effect of $RDEXP_{it-1}$*$NCOMP6\text{-}10_{it-1}$ that amounts to 0.740 (see Table 5 estimation (b)). In markets with more principal competitors, we still see persistence in R&D expenditures, although to a lesser extent. The marginal effect of $RDEXP_{it-1}$*$NCOMP11\text{-}15_{it-1}$ amounts to 0.460 that is considerably smaller compared to markets with 6 to 10 competitors. Persistence in R&D expenditures disappears for firms in markets with 16 to 50 principal competitors. Although marginal effects of $RDEXP_{it-1}$*$NCOMP16\text{-}50_{it-1}$ are still positive (0.130), they are insignificant at a 10% level. This trend from significant positive marginal effects of the interaction term to insignificant effects continues and it turns into significantly negative at markets with 50 and more principal competitors (see Table 5 equation (b)); $RDEXP_{it-1}$*$NCOMP50+_{it-1}$ shows significant negative marginal effects (-0.215).

In sum we can confirm the hypothesis, that the relationship between the number of principal competitors and persistence of R&D investments shows an inverse U shape. Following the theoretical notions we see that persistence increases with the number of competitors. However, this is not a linear function. Persistence increases until 10 competitors then decreases and finally it becomes even significantly negative at markets with more than 50 competitors (see figure 2).

Insert figure 2

6. Conclusions

Based on firm-level panel data for the period 1996-2008, this paper investigates the R&D responsiveness (persistence) of firms in R&D markets with different intensities of competition. Intensity of competition is measured through the number of principal competitors. Persistence is measured through the lagged dependent variable and through interaction terms of the lagged dependent variable and the number of principal competitors in the markets. Furthermore we control for the initial endowment (unobserved individual heterogeneity) of R&D expenditures and the selection bias of the models, since we only look at R&D active firms. The dynamic setting of the empirical models causes some econometric challenges that are addressed following Hsiao (2003) and Wooldridge (2005). We apply a random effects model of GLS type with heteroscedasticity robust standard errors including the Mills-ratio in addition to a number of control variables. This way, we can test the hypothesis stating the non-monotonic relationship between the number of competitors and persistence of R&D expenditures. It becomes obvious that competitive conditions clearly have an effect on the persistence of firm behavior. Markets with very few competitors (up to 5) show persistence. However, information about the number of competitors does not essentially influence the base effect of the persistence observed through the lagged dependent variable if we only look at markets with 5 principal competitors. In contrast, market conditions gain in importance with an increasing number of competitors. We observe the greatest significant effect on the persistence of R&D expenditures at markets with 6 to 10 competitors. This effect decreases at markets with 11 to 15 competitors and diminishes at bigger markets (16-50 competitors) and even turns into a significant negative effect at polypolistic markets with more than 50 competitors. In sum we observe a type of inverse U-shaped relationship between R&D persistence and number of principal competitors.

These results have some policy implications. Innovation promotion policy and competition policy are perceived institutionally as two separated policy lines with few interactions. On the one hand competition policy aims to increase markets and increase the number of competitors in order to have intensive competition and lower prices. On the other hand we see that persistence of R&D expenditures is greater in markets with few R&D active competitors. Thus, it is clear that the innovation promotion policy does not share this interest for a greater number of competitors. In contrast, based on the results of this paper R&D persistence is greatest in markets with a lower number of R&D active firms and consequently innovation policies should provide incentives for niche-market activities with fewer competitors (at least for Switzerland). However, this might cause a situation where a greater coordination between competition policy and innovation promotion policy would be useful in order to avoid contradictions policy signals.

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Table 1: Dependent variable

Dependent variables	Description
$RDEXP_{it}$	Sales share of R&D expenditures
$RDYES_{it}$	R&D activities yes/no (1/0) (only for Heckman estimations)

Table 2: Independent variables

Independent variables	*Description*
$RDEXP_{it-1}$	Sales share of R&D expenditures in t-1 (lagged one period)
$RDEXP_{it0}$	Sales share of R&D expenditures in 1996 (initial endowment)
$EDUC_{it}$	Log of share of employees (in full-time equivalents) with tertiary-level education
$SIZE_{it}$	Log of number of employees (full-time equivalents)
$NCOMP1\text{-}5_{it-1}$	If a firm has between 1 and 5 principle competitors then the variable takes the value 1, 0 otherwise.
$NCOMP6\text{-}10_{it-1}$	If a firm has between 6 and 11 principle competitors then the variable takes the value 1, 0 otherwise.
$NCOMP11\text{-}15_{it-1}$	If a firm has between 11 and 15 principle competitors then the variable takes the value 1, 0 otherwise.
$NCOMP16\text{-}50_{it-1}$	If a firm has between 16 and 55 principle competitors then the variable takes the value 1, 0 otherwise.
$NCOMP50+_{it-1}$	If a firm has more than 50 principle competitors then the variable takes the value 1, 0 otherwise.
$RDEXP_{it-1}*NCOMPx_{it-1}$	Interaction term between R&D expenditures in t-1 and number of competitors (binary variable) in t-1. x stands for number of competitors is between 1-5, 6-10, 11-15, 16-50, or above 50 respectively; $x \in [1-5, 6-10, 11-16, 1-50, 50+]$
$MILLS_t$	Mills ratio from the Heckman estimations.
DIND1 … DIND28	28 industry dummies in a two-digit level (Construction (DIND19 is the reference)
TDUM02, TDUM05, TDUM08	Time dummies for the years 2002 (reference), 2005 and 2008 respectively
M_EDUC_i	Time average of EDUC for firm i.
M_SIZE_i	Time average of SIZE for firm i.
$M\_NCOMP1\text{-}5_i$	Time average of NCOMP1-5 for firm i.
$M\_NCOMP6\text{-}10_i$	Time average of NCOMP6-10 for firm i.
$M\_NCOMP11\text{-}15_i$	Time average of NCOMP11-15 for firm i.
$M\_NCOMP16\text{-}50_i$	Time average of NCOMP16-50 for firm i.
$M\_NCOMP50+_i$	Time average of NCOMP50+ for firm i.
M_MILLS	Time average of MILLS

Table 3: Means and number of observations of the dependent and independent variables

	1999	2002	2005	2008	1999-2008	2002-2008*
RDEXP	0.040	0.048	0.040	0.037	0.042	0.043
EDUC	1.759	1.607	2.135	2.526	1.943	2.026
SIZE	4.690	4.620	4.687	4.908	4.708	4.779
NCOMP1-5	0.201	0.260	0.379	0.340	0.286	0.244
NCOMP6-10	0.393	0.310	0.326	0.340	0.343	0.372
NCOMP11-15	0.135	0.135	0.096	0.142	0.127	0.114
NCOMP16-50	0.132	0.147	0.107	0.086	0.122	0.123
NCOMP50+	0.135	0.144	0.092	0.076	0.117	0.144
Obs.	318	319	261	197	1095	430

Note: * Means are based on the same number of observations as for the econometric estimations.

Table 4: Share of R&D expenditures and number of competitors

	1999	2002	2005	2008	1999-2008
RDEXP if					
NCOMP1-5	0.032	0.043	0.040	0.035	0.038
NCOMP6-10	0.034	0.035	0.032	0.038	0.035
NCOMP11-15	0.036	0.029	0.034	0.026	0.031
NCOMP16-50	0.021	0.039	0.022	0.034	0.030
NCOMP50+	0.019	0.025	0.027	0.022	0.023

Note: Based on full panel information

Table 5: Random Effects GLS regression results, dependent variable ($RDEXP_{it}$)

	(a)	(b)	(c)
$RDEXP_{it-1}$	0.501***	0.502***	0.547***
	(0.130)	(0.049)	(0.209)
$NCOMP1\text{-}5_{it-1}$	0.044		0.004
	(0.028)		(0.013)
$NCOMP6\text{-}10_{it-1}$	0.047**	-0.003	
	(0.022)	(0.010)	
$NCOMP11\text{-}15_{it-1}$	0.050**	0.012	
	(0.020)	(0.015)	
$NCOMP16\text{-}50_{it-1}$	0.023	-0.004	
	(0.017)	(0.017)	
$NCOMP50+_{it-1}$		-0.017	
		(0.023)	
$RDEXP_{it-1}$*$NCOMP1\text{-}5_{it-1}$			**0.504*** **
			(0.047)
$RDEXP_{it-1}$*$NCOMP6\text{-}10_{it-1}$		**0.740*** **	
		(0.158)	
$RDEXP_{it-1}$*$NCOMP11\text{-}15_{it-1}$		**0.460*** **	
		(0.124)	
$RDEXP_{it-1}$*$NCOMP16\text{-}50_{it-1}$		**0.130**	
		(0.179)	
$RDEXP_{it-1}$*$NCOMP50+_{it-1}$		**-0.215***	
		(0.160)	
$EDUC_{it}$	0.001	0.001	0.002
	(0.002)	(0.002)	(0.002)
$SIZE_{it}$	0.019	0.005	0.020
	(0.016)	(0.018)	(0.017)
$MILLS_t$	0.023	0.023	0.019
	(0.020)	(0.021)	(0.022)
CONS	0.020	0.001	-0.021
	(0.026)	(0.022)	(0.025)
Unobserved individual heterogeneity			
$RDEXP_{it0}$	0.188*	0.201**	0.153*
	(0.097)	(0.080)	(0.086)
$M\_NCOMP1\text{-}5_i$	-0.052		-0.017
	(0.036)		(0.016)
$M\_NCOMP6\text{-}10_i$	-0.027	0.019	
	(0.032)	(0.017)	
$M\_NCOMP11\text{-}15_i$	-0.055*	-0.003	
	(0.029)	(0.017)	
$M\_NCOMP16\text{-}50_i$	-0.024	0.023	
	(0.026)	(0.022)	
$M\_NCOMP50+_i$		0.045	
		(0.035)	
M_EDUC_i	0.002	0.001	0.002
	(0.003)	(0.003)	(0.003)
M_SIZE_i	-0.025	-0.010	-0.026
	(0.017)	(0.018)	(0.018)
M_MILLS	-0.019	-0.021	-0.019
	(0.020)	(0.022)	(0.023)
Wald Chi^2	240.37***	354.79***	239.28***
R^2 overall	0.461	0.539	0.531
N	430	430	430
No. of groups	271	271	271

Note: Marginal effects are presented. Heteroscedasticity robust standard errors in brackets. *, **, *** indicates a significant level of 90%, 95%, and 99% respectively. All estimations include 27 industry dummies and two time dummies. The marginal effects of interaction terms are calculated in the following way:

$$RDEXP_{it} = \beta\, RDEXP_{it-1} + \gamma\, RDEXP_{it-1} * NCOMPx_{it-1} + ... + ...$$

$$E\left(\frac{\partial RDEXP_{it}}{\partial RDEXP_{it-1}}\right) = \beta + \gamma\left(NCOMPx_{it-1}\right)$$

Figure 1: Number of competitors and R&D persistence – stylized graphic

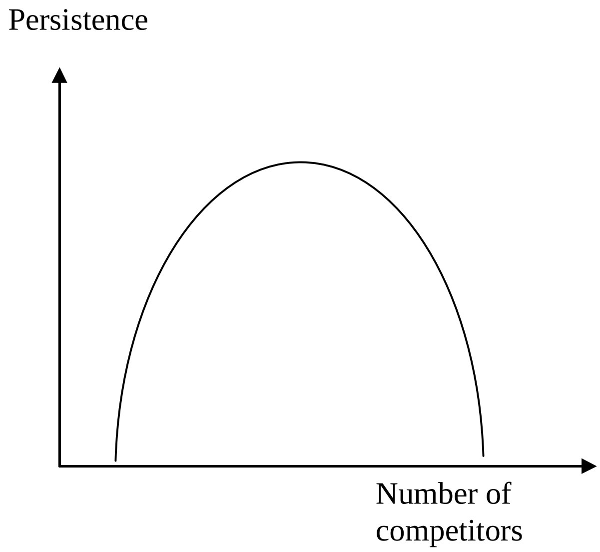
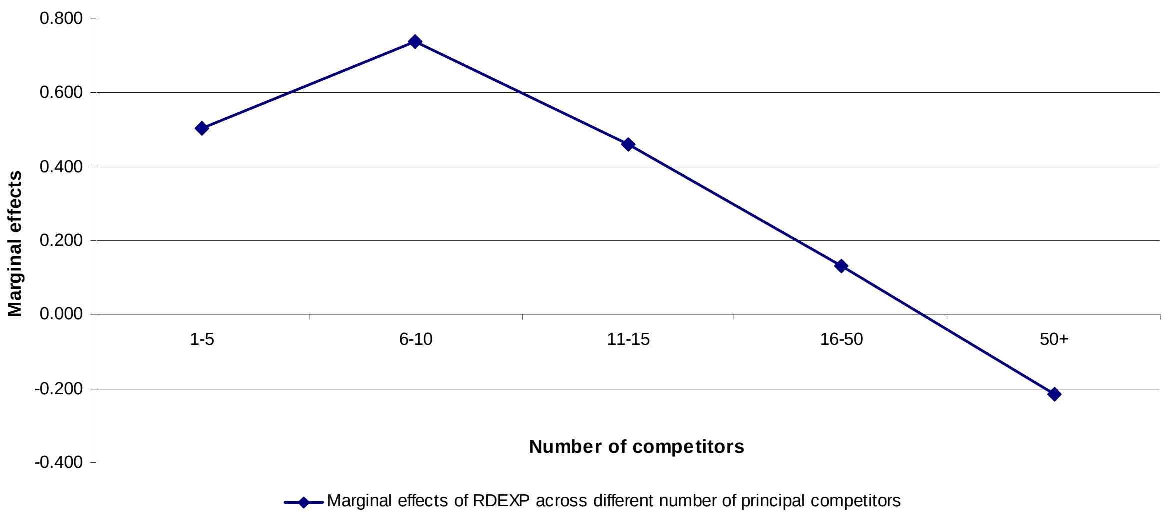


Figure 2: Marginal effects of R&D persistence across different number of principal competitors



Appendix

Table A1: Heckman-Estimations 2002, 2005, and 2008 without interaction terms

	2002	2005	2008
$RDEXP_{it}$ (intensity)			
$RDEXP_{it-1}$	0.891***	0.689***	0.580***
	(0.130)	(0.053)	(0.138)
$RDEXP_{it0}$	0.175	0.038	0.389***
	(0.109)	(0.080)	(0.091)
$NCOMP1\text{-}5_{it-1}$	-0.001	0.005	0.044***
	(0.014)	(0.012)	(0.014)
$NCOMP6\text{-}10_{it-1}$	0.028**	-0.001	0.040***
	(0.013)	(0.012)	(0.014)
$NCOMP11\text{-}15_{it-1}$	-0.003	0.009	0.045***
	(0.017)	(0.015)	(0.017)
$NCOMP16\text{-}50_{it-1}$	-0.005	-0.010	0.022
	(0.016)	(0.013)	(0.017)
$EDUC_{it}$	0.002	0.002	0.004**
	(0.002)	(0.001)	(0.002)
$SIZE_{it}$	-0.004	0.007	-0.003
	(0.005)	(0.005)	(0.003)
CONS	-0.043	-0.110	-0.054
	(0.063)	(0.077)	(0.037)
$RDYES_{it}$ (selection)			
$RDEXP_{it-1}$	15.044***	3.475*	65.730***
	(3.747)	(1.987)	(12.960)
$RDEXP_{it0}$	6.277*	9.685***	5.815
	(3.461)	(3.675)	(4.043)
$NCOMP1\text{-}5_{it-1}$	-0.065	0.024	0.610**
	(0.208)	(0.229)	(0.287)
$NCOMP6\text{-}10_{it-1}$	0.015	0.137	0.456*
	(0.188)	(0.216)	(0.272)
$NCOMP11\text{-}15_{it-1}$	-0.227	-0.009	0.461
	(0.238)	(0.252)	(0.333)
$NCOMP16\text{-}50_{it-1}$	-0.231	-0.010	-0.036
	(0.231)	(0.239)	(0.331)
$EDUC_{it}$	0.032*	0.035	0.087***
	(0.019)	(0.022)	(0.031)
$SIZE_{it}$	0.310***	0.312***	0.233***
	(0.055)	(0.058)	(0.068)
CONS	-2.345***	-2.667***	-2.315***
	(0.316)	(0.393)	(0.416)
MILLS			
lambda	0.035	0.046	0.023
	(0.029)	(0.031)	(0.015)
N	507	441	353
Wald chi2	104.50***	291.60***	103.21***

Note: *, **, *** indicates a significant level of 90%, 95%, and 99% respectively. Standard errors in brackets. All estimations include 27 industry dummies. NCOMP50+ (reference)

Table A2: Heckman-Estimations 2002, 2005, and 2008 with interaction terms

	2002	2005	2008
$RDEXP_{it}$ (intensity)			
$RDEXP_{it-1}$	-0.265	0.157	-0.127
	(0.219)	(0.402)	(0.242)
$RDEXP_{it0}$	0.240**	0.052	0.430***
	(0.095)	(0.071)	(0.088)
NCOMP1-5_{it-1}	-0.015	0.004	0.018
	(0.014)	(0.012)	(0.015)
$RDEXP_{it-1}$*NCOMP1-5_{it-1}	0.836***	0.378	0.905***
	(0.284)	(0.402)	(0.282)
NCOMP6-10_{it-1}	-0.011	-0.017	0.019
	(0.013)	(0.012)	(0.015)
$RDEXP_{it-1}$*NCOMP6-10_{it-1}	1.675***	0.716*	0.793***
	(0.236)	(0.402)	(0.299)
NCOMP11-15_{it-1}	-0.018	0.016	0.024
	(0.017)	(0.017)	(0.019)
$RDEXP_{it-1}$*NCOMP11-15_{it-1}	1.019***	0.302	0.728*
	(0.273)	(0.501)	(0.414)
NCOMP16-50_{it-1}	0.000	0.004	0.007
	(0.016)	(0.013)	(0.020)
$RDEXP_{it-1}$*NCOMP16-50_{it-1}	0.398	-0.154	0.686
	(0.283)	(0.435)	(0.491)
$EDUC_{it}$	-0.001	0.002*	0.004**
	(0.002)	(0.001)	(0.002)
$SIZE_{it}$	-0.009	0.007*	-0.004
	(0.004)	(0.004)	(0.003)
CONS	0.068	-0.125**	-0.015
	(0.048)	(0.053)	(0.030)
$RDYES_{it}$ (selection)			
$RDEXP_{it-1}$	51.759***	1.160	34.237
	(20.043)	(8.271)	(25.069)
$RDEXP_{it0}$	6.177*	6.896**	7.114*
	(3.602)	(3.619)	(4.083)
NCOMP1-5_{it-1}	-0.096	-0.085	0.370
	(0.230)	(0.258)	(0.316)
$RDEXP_{it-1}$*NCOMP1-5_{it-1}	-10.940	7.056	97.492
	(20.244)	(10.235)	(66.030)
NCOMP6-10_{it-1}	0.207	-0.154	0.022
	(0.202)	(0.245)	(0.311)
$RDEXP_{it-1}$*NCOMP6-10_{it-1}	-43.320**	25.474	136.055***
	(20.130)	(13.338)	(47.085)
NCOMP11-15_{it-1}	-0.108	-0.411	0.469
	(0.260)	(0.302)	(0.366)
$RDEXP_{it-1}$*NCOMP11-15_{it-1}	-37.200*	54.360	7.812
	(22.567)	(23.067)	(38.957)
NCOMP16-50_{it-1}	-0.215	0.083	0.038
	(0.253)	(0.248)	(0.351)
$RDEXP_{it-1}$*NCOMP16-50_{it-1}	-28.284	-2.824	-7.740
	(22.257)	(8.761)	(32.714)
$EDUC_{it}$	0.031	0.040**	0.108***
	(0.020)	(0.022)	(0.035)
$SIZE_{it}$	0.297***	0.286***	0.234***
	(0.056)	(0.060)	(0.070)
CONS	-2.379***	-2.461***	-2.352***
	(0.321)	(0.400)	(0.443)
MILLS (lambda)	-0.015	0.049 **	0.009
	(0.022)	(0.019)	(0.013)
N (cens./uncens.)	507 (269/238)	441 (233/208)	353 (186/167)
Wald chi2	199.53***	365.41***	126.86***

Note: *, **, *** indicates a significant level of 90%, 95%, and 99% respectively. Standard errors in brackets. All estimations include 27 industry dummies. NCOMP50+ (reference)