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The Interplay of Innovation and Market Structure in German Chemical Industry: Theoretical and Empirical Results on a Dynamic Schumpeter Loop

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Abstract

This paper investigates the relationship between innovation activities and market structure in the German chemical industry. We present a formal model that suggests the existence of a self-enforcing dynamic feedback between market concentration and innovation. This model is tested on the basis of empirical data on German firms from chemical industry taken from the Community Innovation Survey from 2005 (CIS 2005). The results indeed show that a decrease in the number of competitors results in higher innovation activities. The innovation activities in turn tend to reduce the number of competitors. We argue that this feedback can help to explain the industrial dynamics of the chemical industry, which is characterised by high degrees of market concentration and high and concentrated innovation expenditures.

Keywords: Innovation, market structure, competition, Schumpeter Hypothesis, chemical industry

1 Introduction

A long time ago Schumpeter (1934) observed that some markets become increasingly concentrated, both with respect to innovation activities and market competition. Based on this, he claimed that economic concentration will lead to a situation where innovation is predominantly performed by a few large entities. Later on he extended this notion to a normative understanding summarised in the so-called Schumpeter Hypothesis, which postulates that monopolists are more important engines of technological progress, because their size and market power enables them to profit more from successful innovation (Schumpeter, 1950, p. 101).

Schumpeter’s conclusions were certainly also inspired by the industrial evolution of the chemical industry, which indeed shows a distinct pattern of market concentration, on the one hand and significant innovation activities on the other.

This permits the more conceptual question, whether the industrial dynamics are shaped by the interplay of the innovation activities and market structure or whether they simply “co-evolve”. This question goes beyond the normative character of the Schumpeter Hypothesis (i.e. monopolists are more important for technological progress), because the latter implicitly treats the market structure as exogenous, while a potential (dynamic) feedback of innovation on the market structure is not considered.¹

In this paper, we intend to explicitly incorporate these dynamic aspects of the relationship between innovation activity and market structure. Specifically, we argue that it is possible that market concentration is associated with a higher degree of innovation effort as claimed by the Schumpeter Hypothesis. However, we also argue that innovation is itself one of the sources of the economic concentration process. Taken together, this can yield a self-enforcing loop where innovation triggers concentration, which in turn induces further innovation efforts. Eventually, this should result in high degrees of market concentration as well as increased innovation efforts. We tentatively call this mechanism the Schumpeter Loop.

As a promising matter of fact, this idea seems to explain the situation in the chemical industry quite well. However, the Schumpeter Loop, verbally as it is stated now, does not give guidance on the relevant micro-economic mechanisms through which it operates.

¹This is certainly not the case: even very simple models show that e.g. process innovations have profound effects on market structure, because they affect the minimum efficient scale (Kamien and Schwartz, 1982). While pure fix-cost reducing innovations will lower it and therefore lead to a deconcentration, marginal cost reducing innovations will increase it and result in larger firm-sizes (Swann, 2009, p. 39-40). In any case, the mechanics that will turn out to be important in this paper are fundamentally different from this line of argumentation and relate rather to risk than scale economies.

In order to work them out, we start our analysis with a derivation of stylised facts with respect to the chemical sector considering both the mode of innovation and the mode of competition. Based on this we devise a theoretical model that analyses the relationship between innovation and market structure. Indeed the model replicates the self-enforcing nature of the Schumpeter Loop. The model also sheds light on the relevant economic mechanisms that fuel this feedback loop, where we find that it is actually due to the interplay of the oligoplists' increased capability to reap the profits from innovation on the one hand and innovation-induced risk on the other hand. Based on the model we present two hypotheses, where the first captures the effects of market structure on innovation (essentially the Schumpeter Hypothesis) and the second captures the dynamic feedback effects from innovation on the market structure. We test these hypotheses using micro-data from the fourth Community Innovation Survey of 2005 (CIS 2005) for Germany. Our empirical results corroborate the theoretical model and suggest that the Schumpeter Loop provides a solid basis for the understanding of industrial and innovation dynamics in the chemical products sector.

The remainder of this paper is organised as follows: in Section 2 we present a short review of the relevant literature on both the static and dynamic relationship between innovation and market structure. In Section 3 we describe the main features of the innovation process as well as the type of competition in the market for chemical products. We also present five stylised facts, which are taken into account in the theoretical model presented in Section 4. Based on the model we derive hypotheses, which we will test empirically in Section 6. Section 7 concludes.

2 Literature Review

2.1 The Influence of Market Structure on Innovation Activities - The Static Perspective

Both the theoretical and the empirical literature about the effect of market structure on innovation are large. In any case, there are four broad categories of relationships between innovation behaviour and competition that are considered: first a negative (consistent with the Schumpeter Hypothesis), second a positive, third a u-shape, fourth an inverted u-shape.

Negative Relationship between Competition and Innovation

Many of the classical models of industrial organisation yield the result that innovation decreases with competition (e.g. Salop 1977). The same effect is claimed by Hoppe and Lee (2003) where technologically dominant monopolists seek to discourage laggard innovation

by own innovation. Comparable is Aghion et al. (2001) who stress the dominance of a 'competition escape' effect leading incumbents to innovate more. Also Acs and Audretsch (1988), Blundell et al. (1999), as well as Nielsen (2001) find evidence that larger firms are more innovative (in line with the Schumpeter Hypothesis (1950)).

Positive Relationship between Competition and Innovation

In this class of models falls Arrow's formulation (1959) which, using a model of Bertrand competition, puts forth the "replacement effect". He argues that monopolist markets provide lower incentives to innovate than fully competitive ones, because the monopolist gains less as a result of its own pre-innovation rents. This is confirmed also by Cellini and Lambertini (2005). A very extreme statement is given by Creane and Miyagiwa (2009) who state that under certain conditions a monopolist facing potential entry might not want to engage in the development of an efficient technology, because he fears that it will not pay off. The same is found by Miller (2008), who also presents proof from the computer industry. Boldrin and Levine (2008) link theory and empirical work and show that it is possible for competitive firms to earn positive rents due to innovation. Also Dolfsma and van der Panne (2008) argues that smaller firms drive technological progress.

Inverted U-shaped Relationship between Competition and Innovation

Among the first presenting a theoretical model leading to an inverted u-shape are Ahion et al. (2005) in a model of cost-reducing innovations. The latter article is particularly interesting, because it does not only present a theoretical model but also gives empirical proof for UK manufacturing firms. In fact, this inverted u-shape seems not to be a singular result at least for the aggregate economy. Based on data from CIS 2007, also Schubert (2010) was able to show that technological innovation activities in Germany are maximised for intermediate degrees of competition.

U-shaped Relationship between Competition and Innovation

A leading example of this class is Tishler and Milstein (2009), who use a two-stage model for optimal R&D investment to predict that innovation behaviour is u-shaped in the degree of competition. A model that can even recover positive, negative, and inverted u-shaped characteristics based on the appropriability of innovation efforts is developed by Lee (2005). Empirically the u-shape is corroborated by Roder et al. (2000). The u-shape emerges also in Schubert (2010) for non-technological innovations, while not - as argued above - for technological innovations.

2.2 The Dynamic Relationship between Innovation and Competition

The literature on the co-evolution of innovation and concentration is mainly based on evolutionary perspectives. Most prominently, Nelson and Winter (1982) show in a simulation model that high innovation rates cause industry concentration. A similar perspective is taken by Laincz (2009) and Kwasnicka and Kwasnicki (2006), who endogenise market structure as a function of R&D. On the contrary, in Malerba and Orsenigo (2002) no relation between innovation and concentration becomes apparent.

Abstracting from the question of the direction of the relationship, an important contribution of this literature has to be seen in the analysis of the microeconomic mechanisms through which this co-evolution is channeled.

Noting that concentration processes can be understood as stochastic growth cumulated over time (Nelson and Winter, 1978), the linkage to innovation is established by assuming that the growth process is (at least partly) determined by the innovation effort. Thus, an important issue in the dynamic interplay is randomness induced by innovation, which creates heterogeneity, even if it was absent before innovation activities were launched.

Furthermore, an important exogenous factor that is thought to fuel this mechanism is technological opportunities (Nelson and Winter, 1978). In the same line Malerba and Orsenigo (2002) devise an evolutionary simulation model for the pharmaceutical industry and show that technological opportunities do indeed increase the share of innovating firms.

In summary, the co-evolution of innovation and market structure can be related to technological opportunities, which cause firms to innovate more. The associated additional risk then triggers a process of market concentration, which operates through cumulated stochastic growth.

In fact, the model of Section 4 displays exactly this characteristic. But it even goes a step further, in that it shows that the concentration causes a positive feedback on innovation activities, which completes what we have coined the Schumpeter Loop. Focusing on the chemical industry, we will first, however, derive stylised facts for that industry that will guide the model set-up.

3 Innovation and Competition in the Chemical Sector - Stylised Facts

Although we focus on Germany in this paper, much of what follows (partly) extends to the chemical sector as such. Probably the oldest sub-field of modern chemical production

methods was the dyestuff industry, which emerged in Germany in the period between 1863 and 1872 (Landes 1969), where the firms Bayer, Hoechst, and BASF were among the first companies to organise in-house R&D facilities (Freeman and Sote 1997, p. 89). Only shortly afterwards, half of the world's dye production was of German origin (Schmauderer 1974). In the course of history of course many new applications of chemical processes have been developed, compilation of which can be found in Lacasa et al. (2003) or Arora (1998). This sized down Germany's position in the world. However, in 2007 it was still the largest exporter of chemical products with roughly €135 bn, followed by the US with about €112 bn Euro (GTAI 2009).

Leaving more details to Section 6, the chemical industry (code 24 of NACE 2003) is centred around the production of chemical base materials (24.1), pesticides (24.2), paint and ink (24.3), pharmaceutical (24.4), soap and cleansing products (24.5), and other chemical products (24.6).

3.1 The Mode of Innovation

The chemical industry is widely accepted as a science-based sector (Lacasa et al. 2003), which left considerable leeway for innovative activities. In any case, much of the innovation efforts are centred around new ways of production (Bower and Keogh, 1996). This becomes particularly obvious especially at the beginning of 20th century, where whole production processes become named after their inventors: e.g. the Fischer-Topsch Process (synthetic production of gasoline) or the Haber-Bosch Process (production of ammonia). Indeed, the naming of the processes conveys an important fact about the role of process innovations in chemistry. Process innovations here do not only induce incremental change, but sometimes are so radical that they cause the emergence of completely new markets. This somewhat explains the great importance of cost-reducing innovation behaviour.

This does not mean of course that product innovation is not important. Especially in the pharmaceutical sector (Kawaura and Lacroix 1995), new products can have considerable effects both on firms and on the market. An anecdotic example of important product innovations clearly is Viagra, which is among the top-selling products of Pfizer. Yet already this example conveys that once a product is invented it may have a very long product life cycle. Another well-known example of a very long-lived product is Aspirin, the world's top-selling analgesic for minor aches, which was already invented in 1853. Thus, unlike for example the automobile industry, chemical and pharmaceutical production will not necessarily require continuous change in the technical characteristics of a product.

3.2 Market Structure

The discussion above already laid the foundations for the characteristics of the market structure. Much of the innovation effort is about reducing costs rather than continuously changing the products. One of the most important reasons for that is the relative homogeneity of chemical products (Arora 1997, p. 395).

Typical for firms with homogenous products is not only a strong need for cost reductions due to intense price competition, but also incentives to produce on a large scale. Thus firms in the chemical sector tend to be large, to be able to reap the economies of scale in production (Malerba and Orsenigo 2002). To underline this: thermal cracking procedures had a capacity of 500 barrels per day in the 1920s. By 1956 facilities were operated with a capacity 200 times larger (Freeman and Soete 1997, p. 98).

Furthermore, since producing on large scale requires large market demand, firms are very international, with an export share of roughly three quarters in Germany (GTAI 2009). This increased firm size - often driven by mergers and acquisitions - however also created problems. Langowitz and Graves (1992) claim that large chemical firms are often less efficient in conducting innovation. They suggest that these entities should seek actively strategic research alliances. Indeed, after World War II also small engineering laboratories were founded, that provide the chemical producers with R&D services. In any case, due to their small size, they can hardly produce on their own, but rather license their results (Arora 1997, Zucker and Darby 1997).²

Another important point for the theoretical model are the protection mechanisms of innovation. Starting with a general conclusion, Arora (1997) claims that the chemical industry was always very efficient in protecting its technology knowledge using a combined strategy of patenting, secrecy, and know-how. Clearly, this is enabled partly by the nature of innovation: since in the case of process innovations (unlike product innovations) the technological knowledge remains within the firm, the room for unintended spillovers is comparably small. Reverse engineering for example is largely impossible. Any, in the long-run also in the chemical industry spill-overs exist. In the context of the theoretical model, we think that it is justifiable to assume proprietary innovation and neglect spillovers in the short run.

3.3 Important Characteristics of the Chemical Industry

In summary, the last two subsections have described a few dominant features of the chemical products sector. We will present them here in the form of stylised facts, which we will use

²Note that these labs are regularly not classified as firms from the chemical sector, but as providers of R&D services (NACE 73).

in the theoretical model (compare Section 4).

A1: A large part of the technical progress is driven by cost-reducing process innovations.

A2: The products in chemical industry are homogeneous.

A3: The results from innovation do not immediately spill over to competitors.

A4: The market in chemical industry is served by relatively large producing firms.

A5: R&D services can be often bought in externally from specialised small engineering laboratories.³

4 Modelling the Schumpeter Loop

To show the existence of a Schumpeter Loop, we need to prove two things. First, innovation activities increase when the number of competitors decreases. Second, increased innovation activities increase the hazard of market exit and therefore reduce the number of competitors.

We will proceed by devising a static model, which is able to show the first postulation. We will then extend the model to a dynamic perspective, in which we can show that the exit rate is increased by innovation. We stress here that by the assumptions to be made the static part may be interpreted as a representative period in multi-period model. This will become obvious in Section 4.2.

4.1 The Static Perspective

Using **A5** we assume the existence of two markets: a downstream market for the production of chemical goods populated by n comparably large firms and an upstream market with m comparably small firms providing the downstream firms with R&D services.

For the downstream market **A2** states that goods are homogeneous. In consequence purchasers of the final goods have no preferences. The inverse demand function is given as $P = A - b \cdot \sum_{i=1}^n q_i$.

Additionally, taking for granted that downstream firms are quantity-setting and price-taking, we assume that the product can be produced at baseline constant marginal costs c , if

³Of course we do not intend to belittle the prevailing importance of in-house R&D. Yet it seems interesting to model this feature explicitly. We remark, in any case, that it is of no importance for the model results whether R&D is performed in-house or externally bought in.

innovation activities are zero. Firms may conduct innovation externally by buying in R&D services from upstream firms. Following **A1**, successful innovation reduces marginal costs.

With respect to the upstream market of external R&D providers, we use a to denote innovation output. For the upstream firms we assume that they provide the downstream market with innovation goods that allows the latter to randomly reduce their marginal costs by $g\epsilon(a)$. We also assume that a downstream firm must choose one upstream firm. So, it cannot split its demand on many firms. Let $\epsilon(a)$ be distributed as $U(0, 2a)$ and g be some constant measuring the effectiveness of one unit of innovation. Thus g is a measure of technological opportunities.

Now assume that upstream firms face production costs of $\frac{a^2}{2} + F$, where F is a fixed cost component.⁴ Because the upstream market consists of comparably small R&D providers (**A4** and **A5**), it is reasonable to take for granted that the upstream market is fully competitive. Therefore the price p_a for one unit of innovation effort is given by the marginal costs a of providing it. For convenience, we assume that the downstream firms buy all R&D services at a single upstream firm; i.e. they do not split their demand on many R&D providers

Considering **A3** (i.e. the production costs only depend on own innovation expenses implying no spillovers at least in the short run), the profit of a downstream firm is given by the following expression, where it is silently assumed that marginal costs cannot become negative.⁵⁶

$$\begin{aligned}\pi_{j,down} &= Pq_j - (c - \epsilon(a)g)q_j - p_a a. \\ &= Pq_j - (c - \epsilon(a)g)q_j - a^2\end{aligned}\tag{1}$$

If firms are risk-neutral, they will maximise the expected pay-off, which is given by:

$$\mathbb{E}(\pi_{j,down}) = Pq_j - (c - ag)q_j - a^2.\tag{2}$$

Imposing *for simplicity* Cournot expectations, the corresponding first-order conditions with respect to a and q_j are given by:

⁴Such a quadratic cost function arises in a number of cases; e.g. when the innovation output is produced with two inputs according to $\mathbb{E}(a) = C^{1/4}L^{1/4}$ and the factor prices satisfy $\sqrt{rw} = \frac{1}{4}$.

⁵More formally $\mathbb{P}(c - g\epsilon(a) > 0) = 1$ implies that $a \leq c/2$. Using (9), this is guaranteed, if $c \geq \frac{g^2 \rho A}{1+g^2 \rho}$ irrespective of n . This essentially means that marginal costs should not be too low. If this inequality does not hold, we have a corner solution, where $a = c/2$. Optimal output, in this case, will follow from solving (3) with a replaced accordingly. All the following steps remain unchanged, so we will not describe them here explicitly. We could have avoided the possibility of corner solution for the innovation input by using a cost function that enforces non-negativity; e.g. an exponential function. However, in this case the model does not have an analytic solution, which would imply the need to evaluate the model numerically.

⁶Because we assume that the downstream firm will buy all R&D services at one upstream firms, the downstream firm will foresee the effect of its demand on the equilibrium price.

$$\frac{\partial \mathbb{E}(\pi_{j,down})}{\partial q_j} = A - 2bq_j - b \cdot \sum_{i=1, i \neq j}^n q_i - (c - ag) = 0 \quad (3)$$

and

$$\frac{\partial \mathbb{E}(\pi_{j,down})}{\partial a} = gq_j - 2a = 0. \quad (4)$$

Before proceeding, we derive the conditions under which (3) and (4) correspond to a maximum. For this to hold, the Hessian matrix of (2) must be negative definite. The latter can be calculated as:

$$\mathbf{H} = \begin{pmatrix} -2b & g \\ g & -2 \end{pmatrix} \quad (5)$$

Sufficient for negative definiteness is that all of its Eigen values are smaller than zero. The Eigen values λ are the solution to the characteristic polynomial defined by $\det(\mathbf{H} - \lambda \mathbf{I}_2) = 0$, where \mathbf{I}_2 denotes the 2×2 identity matrix. After some manipulation we obtain:

$$\begin{aligned} \lambda_{1,2} &= \pm \sqrt{(b+1)^2 - (4b - g^2)} - (b+1) \\ &= \pm \sqrt{(b-1)^2 + g^2} - (b+1) \end{aligned} \quad (6)$$

The second line of (6) shows that all roots are real, while the first is helpful to derive the central condition guaranteeing negative definiteness of the Hessian: i.e. $4b - g^2 > 0$. In terms of g this implies $g < 2\sqrt{b}$. Thus, if this condition is met, using (3) and (4) provides a decision rule corresponding to a maximum. Taking this for granted, we can go on and solve (3) by plugging in a defined in (4). This results in:

$$q_j = \frac{2}{4b - g^2} \cdot (A - b \cdot \sum_{i=1, i \neq j}^n q_i - c), \quad (7)$$

which gives firm j 's reaction function depending on the endogenous quantities produced by the other firms. For notational simplicity, define $\rho = \frac{2}{4b - g^2}$, which is assured to be greater than zero.

The equilibrium quantity produced by firm j can be found by summing the other $n - 1$ reaction functions as follows:

$$\sum_{i=1, i \neq j}^n q_i = (n-1)\rho(A - c) - \rho b \left((n-2) \cdot \sum_{i=1, i \neq j}^n q_i + (n-1)q_j \right) \quad (8)$$

Solving for the term on the left hand side and plugging this into (3) finally yields the equilibrium quantity q^* provided by each firm j :

$$\begin{aligned} q^* &= \frac{(1 - \rho b)\rho(A - c)}{1 + \rho b((n - 2) - \rho b(n - 1))} \\ &= \frac{\rho(A - c)}{1 + \rho b(n - 1)} \end{aligned} \quad (9)$$

Note that the downstream firms will always be willing to produce, since the expected profits will be greater or equal to zero. This follows immediately from simple reasoning. We know that in an n -player Cournot oligopoly without innovation, profits are always positive and tend to zero, when $n \rightarrow \infty$. Now, since in a model where innovation is possible, firms could always replicate these profits by choosing not to innovate, we also know that $\pi(n)^{*inn} \geq \pi(n)^{*noninn} \geq 0$ must be true.

Before, we derive our hypotheses, we will first close the model by looking at the upstream market. Since each downstream firm is served by exactly one upstream firm b , there cannot there cannot be more n upstream firms. Otherwise some firms would not serve any downstream producer and would incur losses equal to its fixed costs. They would leave the market. At the same time, there cannot be less than n upstream firms, because at least some firms would serve more than one downstream firm. Since marginal costs are increasing of R&D are increasing would open up new entry incentives, because they could provide R&D services at lower costs. So, in equilibrium we have $m = n$.

Of course this is only viable, if profits in the upstream market greater or equal to zero:

$$\begin{aligned} \pi_{k,up}^* &= p_a^* a^* - \frac{1}{2} a^{*2} - F \\ &= \frac{1}{2} a^{*2} - F \\ &= \frac{1}{2} \left(\frac{g\rho(A - c)}{2(1 + \rho b(n - 1))} \right)^2 - F \geq 0, \end{aligned} \quad (10)$$

which means that fixed costs should not be too large.

Again turning to the implications of the model: considering (4) and (9), after lengthy but straightforward calculations the relative innovation expenditures (innovation expenditures as a share of turnover) are given as:

$$\frac{a^{*2}}{P^* q^*} = \frac{g^2(A - c)}{2(A(2b - g^2) + 2bnc)} \quad (11)$$

First, this shows that firms tend to invest relatively more in innovation, if g is high and b is low. We already said that g can be interpreted as technological opportunities. It is easy to show that b , on the contrary, is associated with the elasticity of demand or, in an alternative interpretation, with the size of the market.

Second, from (11) it is directly obvious that relative innovation expenditures decrease in the number of competitors. Or in other words: when n is larger, the firms innovate less and have higher marginal costs compared to a situation with less competitors. This is absolutely intuitive: *ceteris paribus* the profit leverage of cost reductions is the larger, the larger the served market is. Thus, if the number of competitors goes up and the market becomes smaller and smaller, the incentives for innovation gradually erode.⁷ It is also easy to show that innovation output is increased by larger technological opportunities. Based on these observations we conclude with our first hypothesis, which basically corroborates the Schumpeter Hypothesis:

H1: Relative innovation expenditures are increased when the number of competitors decreases.⁸

H1 summarises the proofs on the first element necessary for establishing the Schumpeter Loop. What remains to be shown is that more investment in innovation causes higher exit-rates. That is, we need to show that the number of competitors n tends to be reduced when

⁷It is easy to show by using L'Hopital's rule that nq^* with increasing n converges to $(A - c)/b$, which is equal the usual Cournot result without innovation.

⁸Therefore, contrary to the Cournot oligopoly without innovation, there obviously is also a good side about a decrease in competition. However, whether we are better off with increased or decreased competition depends on the total market provision, which is given as:

$$Q_n = \frac{n\rho(A - c)}{1 + \rho b(n - 1)}$$

Thus efficiency of competition depends on how Q_n varies with n . For a case where a decrease in competitors is better, we must have that a negative derivative with respect to the number of competitors. Differentiating Q_n with respect to n , we obtain:

$$\text{sgn} \frac{\partial Q_n}{\partial n} = \text{sgn}(1 - \rho b)$$

This is negative only if $g > \sqrt{2b}$. Following the previously stated conditions on g , we find a non-empty set $\left] \sqrt{2b}, 2\sqrt{b} \right[$ of large g , where an decrease in competition will result in a more efficient market outcome. Again this is intuitive: the larger g is, the larger are the expected cost reductions from innovation. Since the incentive for innovation erodes when competition increases, the efficiency costs in terms of foregone innovation are larger the larger g (i.e, the more valuable innovation) is. Note that this is comparable to a finding of Greenstein and Ramey (1998) for the case of product innovations, because there is a welfare trade-off between static efficiency and innovation incentives.

the level of innovation goes up. Although the static model from above is not ideal to analyse this question, it has relevant implications for this question.

4.2 The Dynamic Perspective

The long term market structure depends on market exit and entries. In the following we will analyse only the first, neglecting market entry. This is probably a great simplification but still somewhat reasonable, because entry will become more difficult when earlier innovation of incumbent firms create barriers to market entry.

Although we looked at expected payoffs so far, we should make ourselves aware of the fact that innovation is actually assumed to be a random number. This implies that after its realisation the innovation investment induces cost heterogeneity. For expositional reasons we assume that this heterogeneity only holds for one period and is then equalised because of spillovers. I.e. each firm may use the best available technology freely after one period of selling. This implies that the static model from above actually may be interpreted as a description of a representative period in multi-period model. The reason is simple: the heterogeneity induced disappears after the production phase. Thus all that changes from one point in time to the next are marginal costs and (as we will see below) the number of competitors. This means that the formulae from above will also apply in any following period.⁹

Now, suppose that firms set quantities bindingly before they know the realisation of the innovation success variable and that a firm drops out, if it has to incur losses.¹⁰ After innovation success becomes known, firms do not adapt (e.g. because of limited flexibility, menu costs, or binding contracts). If firms earn non-negative profits, they decide to stay in the market. If they incur losses, they will drop out afterwards.

In any case, the probability of drop-out is equal to the probability of having made losses. But the latter is easy to calculate using (1). In equilibrium it turns out that:

$$\mathbb{P}(\pi_{j,down}^* > 0) = 1 - \mathbb{P}\left(\epsilon(a^*) < \frac{g^2 q^* - 4(A - bnq^* - c)}{4g}\right) \quad (12)$$

Using that $\epsilon(a)$ is distributed as $U(0, 2a)$ and plugging in the endogenous quantities q^* and

⁹Not assuming complete technology spillovers would have greatly increased the complexity of the model, because cost heterogeneity would persist making the symmetric Cournot oligopoly from above an unreasonable framework.

¹⁰It is clear that although we have seen that the expected profits are non-negative, the realised profits need not be.

a^* we obtain after some manipulation:¹¹

$$\mathbb{P}(\pi_{j,down}^* > 0) = \begin{cases} \text{undefined} & b \leq \frac{g^2}{4} \\ \frac{1}{4} + \frac{b}{g^2} & \frac{g^2}{4} < b \leq \frac{3g^2}{4} \\ 1 & b > \frac{3g^2}{4} \end{cases} \quad (13)$$

Calling n^{new} the number of competitors in the following period, we note that this variable is binomially distributed with length n and the probability calculated in (13). Its expected value is therefore given by:

$$\mathbb{E}(n^{new}) = \begin{cases} \text{undefined} & b \leq \frac{g^2}{4} \\ \frac{1}{4}n + \frac{b}{g^2}n & \frac{g^2}{4} < b \leq \frac{3g^2}{4} \\ n & b > \frac{3g^2}{4} \end{cases} \quad (14)$$

Thus b increases the expected number of competitors, while g has the opposite effect. To explain that, take for example g : we already know that firms spend more on innovation, if technological opportunities are high. However spending more on innovation increases the risk of losses, because innovative efforts may be unsuccessful.¹²

However, because of the way the Schumpeter Loop is stated the greater interest is in the (endogenous) relationship between innovation activities and market structure. Note that we can always write:

$$\frac{d\mathbb{E}(n^{new})}{dg} = \frac{d\mathbb{E}(n^{new})}{da^*} \frac{da^*}{dg}, \quad (15)$$

where the term on the left hand side is negative by (14) and the second on the right hand side is positive by (9) and (4). Thus the first term on the right hand side must be negative. This means that the number of competitors decreases with the level of innovation. The same holds true with respect to relative innovation expenditures. We note:

$$\frac{d\mathbb{E}(n^{new})}{da^*} = \frac{d\mathbb{E}(n^{new})}{d\frac{a^{*2}}{P^*q^*}} \frac{d\frac{a^{*2}}{P^*q^*}}{da^*}, \quad (16)$$

¹¹The boundaries are somewhat tedious to derive. To keep it short, they follow from two considerations. First, the probability is well defined only if it is between zero and one. Since the expression on the right hand side tells us that it is positive anyway, only the condition which ensures that the probability of not making losses is at most one remains. Second, we should still meet the condition for profit maximisation. I.e. $4b - g^2 > 0$. Otherwise the probability is undefined.

¹²Suppose for example, a firm decided not to innovate at all, it would earn non-negative profits with probability 1.

Since it is easy to show that relative innovation expenditures are positively related a^* , we conclude that also the first term on the right hand side (relating relative innovation expenditures and number of competitors) is negative, because the term on the left hand side is negative. We conclude this discussion with our second hypothesis:

H2: The larger the relative expenditures for innovation activities are, the lower the number of competitors is.

Combining H1 and H2 actually demonstrates the possibility of the Schumpeter Loop: firms with few competitors innovate more, which in turn results in higher exit-rates reducing the number of competitors, again increasing innovation activities.

Testing this relationship empirically is, however, complicated, because the number of competitors and the innovation level are simultaneously determined. Since by the set-up of the model the effects of b and g affect the number of competitors basically through their effect on innovation expenditures, we are already provided with two reasonable instruments for the latter. Following the discussion of (11), these are the degree of technological opportunities and a variable measuring the demand elasticity. Thus we will only need to determine instruments for the endogenous number of competitors, where the discussion about protection strategies (Arora, 1997) suggests that variables such as patenting activities or secrecy could be reasonable choices. In any case, we leave this discussion to the next section.

5 Econometric Methodology and Selection of Control Variables

5.1 Methodology

The empirical aim of the paper is to test the relevance of the previously established Schumpeter Loop. Since the hypotheses are stated in terms of causal relationships, it is natural to adopt regression-based approaches to test them.

Specifically, H1 relates relative innovation expenditures to the number of competitors. Since the innovation expenditures cannot be smaller than zero with mass-points at zero, this calls for a corner-solution model, such as Tobit. H2 - the other way round - relates the number of competitors to the relative innovation expenditures. Because the number of competitors is available only in classes, this suggests the use of a discrete response model or an interval regression.

However, simultaneous validity of H1 and H2 necessarily implies endogeneity and the inconsistency any specification based on exogeneity. The reason is that H1 and H2 mean that the number of competitors and innovation expenditures are simultaneously determined. Therefore, we decided to use IV-based methods, where the innovation expenditures were naturally modelled by IV-Tobit. In specific, we used a Full ML approach. With respect to the number of competitors, this variable is only available in classes. Therefore this regression should ideally be run as an endogenous ordered response model or an endogenous interval regression. However, such methods do not readily exist. So we ignored this fact and treated it as a count variable taking the smallest integer component of the class means as its observed value. Based on this variable, we ran an endogenous quasi-poisson-model following the method described in Wooldridge (2002, p. 663-664). Several alternative specifications were considered (compare Section 5.3).

5.2 Selection of Variables

The hypotheses derived from the theoretical model are stated basically in terms of bivariate relationships. However, it is reasonably clear that an empirical estimation strategy should take into account a sensible set of control variables. A concept that provides some guidance on how to choose the control variables follows from the notion of the innovation production function, which takes the analogy of a regular production and applies it to the situation where innovation (rather than products) are produced with the help of various inputs. This concept original dates back to Griliches (1995), who developed it for the case of the knowledge production function. Later on, it was extended to the case of innovation by Mairesse and Mohnen (2002). Thus an economically sound set of control variables should consist of variables that affect the innovation production in some way. They can work directly, for example in the case of an input, or indirectly when a certain characteristic of either the firm or its environment is important for innovation. In the following we discuss the rationale for our selection of the variables, where summary statistics and further details on definition can be found in Table 6.1.

- **Regression: Relative Innovation Expenditures**

With respect to the explained variable, we measure the relative innovation expenditures by the innovation-expenditures-to-turnover ratio. Furthermore, in an alternate specification we use also the R&D-expenditures-to-turnover ratio. The latter is less broad than the

first, because R&D only refers to innovation activities that are planned and organised in a continuous set-up. Furthermore, R&D refers to a more technologically oriented definition of innovation. It will not include marketing or organisational innovation.

With respect to the explaining variables, we collect them in thematic groups, which themselves are determined based on the ongoing discussion in the scientific literature. The basic categories are demand characteristics, mode of competition, size of the firm, internal firm resources, other characteristics, and additional subsector variables to capture otherwise unobservable sector-specific effects.

The *demand characteristics* and the *mode of competition* taken together shall reflect the market structure. The theoretical discussions in the literature have already highlighted the importance of the modes of competition for innovation behaviour. However, also the demand side should not be neglected. It is often argued that innovation activities may be triggered by the clients. In this context, the concepts of “user-centred innovation” and “lead users” have become very influential (e.g. Urban and von Hippel, 1988). To reflect this discussion we included variables that characterise the demand side. In specific, we use the export, the R&D, and the investment ratio in the main client sector. Concerning the modes of competition we choose a variable that measures turnover share accruing to the firm’s main product group. This somewhat captured diversification. Furthermore, we use subjective statements about the relative importance of the competition about price, the competition about quality, the importance of technological advantage, the importance of service quality, the importance of product variety, and the importance of advertising. This broad definition shall account for the fact that competition can emerge along many dimensions and is surely not always about price. The last variable in this category - also the variable of central concern for H1 - is the number of competitors. Because of equation (11) we also took into account the degree of product substitutability to account for the demand elasticity and the degree of technological opportunities measured by the perceived speed of technological change. Note that these two variables are also the instruments used in the regression for the number of competitors.

The *size* of the firm is clearly an important determinant of the innovation process. This fact was pointed out already by Schumpeter (1934), who postulated that primarily large firms will innovate. Indeed one of the economic mechanisms behind this is that innovation is more profitable the larger the market is (Schumpeter, 1950, Swann, 2009). This is immediately obvious for cost reductions, because their profit leverage will be greater the greater the market is. As a measure of size we included the turnover, the number of employees, and - to account for potential non-linearities - the squared number of employees.

The *resources* of a firm describe all assets that it can command. A resource can be tangible or intangible. It can be marketable or it may exist only implicitly, such as in the

case of non-codified knowledge. The notion of resources actually dates back to Penrose (1959), who made their importance for innovative behaviour very explicit. Probably the most important resources are knowledge and human capital. To account for them, the share of employees with tertiary education was included, which could function as a proxy for both.

Furthermore, we included some additional characteristics, which are not prominently discussed in innovation theory, but may still be of considerable importance. Specifically, we control for age of the company, the fact that it is located in East Germany, the investment for physical capital, and the fact that the company exports some of its goods. Additionally, dummies for the subsector based on the three-digit-NACE level included.

- **Regression: Number of Competitors**

This regression relates the number of competitors to the innovation expenditures. In principle, the model estimated here uses the same set of explanatory variables as the previous one. However, there are a few notable differences. Second, as already said, the number of competitors is clearly affected by the possibilities to enter the market, which in turn should depend on the protection mechanisms. Thus we included several variables describing a firm's innovation protection strategy. Among these are the use of patents to account for formal protection as well as informal ones (use of secrecy, use of lead time, complexity of product design). We also took into account the fact that a firm runs a niche market strategy and a variable measuring the market threat of competitors. These variables are also the instruments for the number of competitors in the innovation expenditures regression.

5.3 Analysis of Robustness

In fact there are several sources for estimation problems potentially plaguing the regressions presented above. Therefore, a large number of specification tests and alternative modeling strategies have been performed. The models in the subsequent section prove to be fairly robust with respect to the following issues.

First, there might be problems with *heteroscedasticity*. We considered that when running all models with robust standard error. The results shown in Tables 2 and 3, however, rely on the homoscedasticity assumption.

Second, we already said that the fact that the *number of competitors is available only in classes* was ignored when it was treated as a usual count variable. Since this is clearly not ideal, we investigated the robustness by running the model as a linear 2SLS regression and in an IV-Tobit set-up (which treats the number of competitors as continuous).

Third, in order to check the *quality of the instruments* we tested that they can be validly excluded in linear IV regressions based on Sargan's test. We did not observe problems

here, which indicates that the quality of the instruments is reasonable.

Fourth, the employed ML methods rely heavily on *distributional assumptions on the structural error terms*. To accommodate for biases here we have (not taken into account the potential endogeneity resulting from the simultaneity implied by H1 and H2) run semi-parametric distribution-free models. Specifically, we have replaced the Tobit specification by Powell's (1986) symmetrically censored least square estimator. Count data model was replaced by an ordered response model based on the general semi-nonparametric ML framework proposed by Gallant and Nychka (1987), who approximate the unknown error-distribution using Hermite polynomials. The results were in all cases stable and gave evidence both for H1 and H2.

Fifth, we have run rather complex models using relatively *small samples*. This may cause two kinds of problems. First, the normal approximation for the statistical inference may be misleading. Second, the IV-ML models may yield strongly biased estimates, especially the number of observations is small. Therefore, we have also run the models using bootstrapping techniques, which can account for departures from normality and/or for bias. Except for the case of the regression of number of competitors on relative innovation expenditures, where the significance is lost, no important changes can be observed (this result still holds using relative R&D expenditures).

In summary, we think that the results are quite robust to large number of alternative specifications. So we feel confident that the results do not simply collapse when the specification is changed.

6 Empirical Results

In the following, we will test H1 and H2 using empirical data on firms from German chemical industry. However, before we do so, we will shortly present the data source.

6.1 The Data Set and Descriptive Statistics

The data used in this paper comes from the German CIS 2007. The Community Innovation Survey is a large European survey conducted every two years in all Member States of the EU as well as some outside the EU. It is harmonised across the participating countries. Concerning the data structure, CIS is a moving cross-section, comprising a yearly sample size of about 5,500 firms (participation rate of about 20%) from all major sectors including, besides manufacturing firms, also provision of services. The main focus of the survey is on the innovative activities, including product and process innovations and lately also

marketing and organizational innovations, but contains many questions which are deemed to be relevant for the entrepreneurial innovation process, such as market conditions, public subsidies, hampering factors, and firm-specific features.

Without going into detailed analysis, a few things are worth noting. The average firm in our sample has a turnover of €405 m. This is almost three times more than the average firm in the CIS survey. Thus, as claimed, firms are much larger in this sector than in others. Furthermore, R&D makes up more than three quarters of all innovation expenditures. This is about 10 percentage points more than for an average German firm. This suggests that innovation in the chemical industry is probably a much more routine and organised task than elsewhere. It might also mean that technological innovation is more important than non-technological innovation such as marketing and organisational change (compare Schubert 2010).

With respect to the sector classification, we limit our sample to all firms that belong to NACE code 24 (“production of chemical goods”). It should be noted that this sample therefore does not include the petroleum sector (NACE 23) and rubbers and plastics (NACE 25). This was basically done to keep the sample as homogeneous as possible. In total the sample contains observations on 182 firms from the chemical industry, where of course due to item-non-response, the actual regressions will be based on fewer observations. Of these 182 firms 18% produced chemical base materials, 4% produce pesticides, 15% paint and ink, 26% pharmaceuticals, and 13% produced soap and cleansing materials. The remaining 24% are summarised in the residual NACE section 24.6 comprising firms producing other chemical products.

6.2 Market Structure and Innovation Incentives

Based on the theoretical model, H1 claims that innovation input relative to firm size is increased by a decline in the number of competitors. Likewise, H2 postulates that an increase in relative innovation activities will cause a positive feedback, because they tend to reduce the number of competitors. The methodology and the variables to test these relationships were described in Section 5. The results of the estimations can be found in Table 2 for the case of relative innovation expenditures and in Table 3 for relative R&D expenditures.

Both regression tables indeed show strong evidence for the phenomenon which we labeled the Schumpeter Loop. Irrespective of whether we take into account relative innovation or R&D expenditures, what we observe is that an decrease in the number of competitors increases the innovation, respectively the R&D expenditures. They in turn tend to reduce the number of competitors even further. All the coefficients are significant at least on the

Figure 1: Summary statistics

| | Details on definition | mean | std. err. | min | max |
|---|--|------------|--------------|------|---------------|
| <i>Regression: relative innovation R&D expenditures</i> | | | | | |
| Relative innovation expenditures | Total innovation expenditures in 2004 divided by turnover. | 0.19 | 0.42 | 0.00 | 3.39 |
| Relative R&D expenditures | Total R&D innovation expenditures in 2004 divided by turnover. | 0.13 | 0.35 | 0.00 | 2.71 |
| Export ratio of client sector | Export ratio of main customer sector. | 24.96 | 14.86 | 0.00 | 57.63 |
| R&D intensity of client sector | R&D intensity of main customer sector. | 3.07 | 4.10 | 0.00 | 22.28 |
| Investment ratio of client sector | Investment ratio of main customer sector. | 4.29 | 7.84 | 0.00 | 76.83 |
| Share turnover in main product group | Indicate your share of turnover accruing to main product group. % | 67.43 | 26.43 | 3.00 | 100.00 |
| Importance of price competition | Rate the importance of price competition. Likert scale: not important (1)-very important (6) | 2.03 | 1.17 | 1 | 6 |
| Importance of quality competition | Rate the importance of quality competition. Likert scale: not important (1)-very important (6). | 1.75 | 0.96 | 1 | 6 |
| Importance technological advantage | Rate the importance of technological lead. Likert scale: not important (1)-very important (6). | 3.44 | 1.44 | 1 | 6 |
| Importance of service quality | Rate the importance of price competition. Likert scale: not important (1)-very important (6). | 2.72 | 1.22 | 1 | 6 |
| Importance of product variety | Rate the importance of price competition. Likert scale: not important (1)-very important (6). | 4.11 | 1.32 | 1 | 6 |
| Importance of advertising | Rate the importance of price competition. Likert scale: not important (1)-very important (6). | 4.85 | 1.48 | 1 | 6 |
| Technologies change quickly | Indicate your agreement with the statement that technologies change quickly in your market. Likert scale: no agreement (0) to complete agreement (3). Classed: 0, 1-5, 6-15, >15. | 1.20 | 0.73 | 0 | 3 |
| Number of main competitors | Indicate your agreement with the statement that your products can be substituted easily. Likert scale: no agreement (0) to complete agreement (3). | 6.44 | 4.60 | 0 | 15 |
| Products can be substituted easily | Indicate your agreement with the statement that your products can be substituted easily. Likert scale: no agreement (0) to complete agreement (3). | 1.86 | 0.88 | 0 | 3 |
| Turnover | Turnover in 2004. 1,000€. | 407,506.20 | 1,763,638.00 | 2.00 | 15,200,000.00 |
| Employees | Number of employees. | 1,327.00 | 6,489.43 | 3.00 | 49,947.00 |
| Age of company | Years. | 20.64 | 19.62 | 0.50 | 139.50 |
| Eastern Germany | Located in Eastern Germany: Yes/no. | 0.24 | 0.43 | 0 | 1 |
| Share employ. tertiary educ. | % | 22.96 | 20.84 | 0.00 | 100.00 |
| Investment | Gross investment in 2004. 1,000€. | 18,163.04 | 95,088.55 | 0.00 | 736,216.60 |
| Export activities | Exporter in 2004. Yes/no. | 0.75 | 0.44 | 0 | 1 |
| Chemical base materials | NACE 24.1. Yes/no. | 0.18 | 0.38 | 0 | 1 |
| Pesticides | NACE 24.2. Yes/no. | 0.04 | 0.19 | 0 | 1 |
| Paint and ink | NACE 24.3. Yes/no. | 0.15 | 0.36 | 0 | 1 |
| Pharmaceutical | NACE 24.4. Yes/no. | 0.26 | 0.44 | 0 | 1 |
| Soap and cleansing | NACE 24.5. Yes/no. | 0.13 | 0.34 | 0 | 1 |
| <i>Regression: number of competitors</i> | | | | | |
| Niche market | Does your company follow a niche market strategy? Yes/no. | 0.21 | 0.41 | 0 | 1 |
| Patent applications | Use of patents highly important. Yes/no. | 0.39 | 0.48 | 0 | 1 |
| Lead time | Has your company relied on lead time to protect innovations? Yes/no. | 0.58 | 0.50 | 0 | 1 |
| Secrecy | Has your company used secrecy to protect innovations? Yes/no. | 0.68 | 0.47 | 0 | 1 |
| Complex product design | Has your company used product complexity to protect innovations? Yes/no. | 0.22 | 0.42 | 0 | 1 |
| Increase in market share | Have your innovation activities increased market share? Likert scale: no (0)-by much (3). | 1.75 | 1.10 | 0 | 3 |
| Market position endangered by competitors | Is your market position endangered by new competitors? Likert scale: no (0)-very much (3). | 1.52 | 0.83 | 0 | 3 |

Figure 2: The Long-term Relationship between Relative Innovation Expenditures and Market Structure

| Variable | Relative innovation expenditures (H1) | | Number of competitors (H2) | |
|--|---------------------------------------|---------|----------------------------|---------|
| | coef. | t-stat. | coef. | t-stat. |
| Constant | 0.2808 | 0.71 | 2.0165 *** | 5.61 |
| <i>Demand</i> | | | | |
| Export ratio of client sector | -0.0031 | -0.53 | -0.0112 | -1.57 |
| R&D intensity of client sector | 0.0139 | 0.57 | 0.0650 * | 1.84 |
| Investment ratio of client sector | -0.0111 | -1.51 | -0.0353 *** | -3.08 |
| <i>Competition</i> | | | | |
| Share turnover in main product group | -0.0011 | -0.55 | 0.0003 | 0.12 |
| Importance of price competition | 0.0661 | 1.44 | 0.2200 *** | 2.80 |
| Importance of quality competition | -0.0557 | -1.03 | -0.1486 *** | -2.67 |
| Importance technological advantage | -0.0939 * | -1.87 | -0.1561 *** | -3.66 |
| Importance of service quality | 0.0465 | 0.90 | 0.1193 ** | 2.49 |
| Importance of product variety | 0.0838 * | 1.83 | 0.1196 ** | 2.58 |
| Importance of advertising | 0.0010 | 0.03 | -0.0075 | -0.23 |
| <i>Schumpeter loop</i> | | | | |
| Relative innovation expenditures | | --- | -2.8430 *** | -3.80 |
| Number of main competitors | -0.1006 ** | -2.17 | | --- |
| <i>Size</i> | | | | |
| Turnover | 0.0000 | 1.21 | 0.0005 * ¹ | 1.65 |
| Employees | -0.0003 | -1.26 | -0.0006 ** | -2.46 |
| Employees ² | 0.0001 | 0.45 | 0.0004 * | 1.77 |
| <i>Resources</i> | | | | |
| Share employ. tertiary educ. | 0.0017 | 0.46 | 0.0152 *** | 2.66 |
| <i>Other characteristics</i> | | | | |
| Age of company | -0.0069 * | -1.83 | -0.0198 *** | -3.48 |
| East Germany | 0.3308 ** | 2.38 | 0.4115 *** | 3.20 |
| Investment | 0.0000 | 1.65 | 0.0000 *** | 3.01 |
| Export activities | 0.0668 | 0.55 | 0.1910 | 1.74 |
| <i>Subsector</i> | | | | |
| Chemical base materials | -0.1242 | -0.79 | -0.2854 | -1.70 |
| Pesticides | 0.7193 | 1.57 | 1.2931 *** | 4.41 |
| Paint and ink | -0.0242 | -0.16 | -0.1702 | -1.07 |
| Pharmaceuticals | 0.4368 | 1.59 | 0.4227 ** | 2.31 |
| Soap and cleansing | 0.0831 | 0.44 | -0.0259 | -0.14 |
| <i>Exclusion restrictions</i> | | | | |
| Technologies change quickly | -0.0141 | -0.16 | | --- |
| Products can be substituted easily | 0.1938 ** | 2.13 | | --- |
| Niche market strategy | | --- | -0.8130 *** | -3.88 |
| Patent applications | | --- | -0.1929 | -1.4 |
| Lead time | | --- | 0.2227 | 1.27 |
| Secrecy | | --- | -0.2482 | -1.7 |
| Complexity of product design | | --- | -0.2476 * | -1.68 |
| Increase in market share | | --- | 0.0409 | 0.65 |
| Market position endangered by competitors | | --- | 0.1116 * | 1.93 |
| N | 103 | | 103 | |
| Chi-sq/ model sign. (26 df/ 31 df) | 60.39 *** | | 157.23 *** | |
| Chi-sq / exogeneity (1 df) & t-stat./ exogeneity | 3.98 ** | | -3.42 *** | |
| Ci-sq/ Exclusion Restriction based on LIV (6 df/ 1 df) | 8.83 | | 0.93 | |

¹ coefficient and standard error times 1,000 to make non-zero digits visible

Figure 3: The Long-term Relationship between relative R&D Expenditures and Market Structure

| Variable | Relative R&D expenditures (H1) | | Number of competitors (H2) | |
|--|--------------------------------|---------|----------------------------|---------|
| | coef. | t-stat. | coef. | t-stat. |
| Constant | 0.0878 | 0.3 | 1.9534 *** | 5.22 |
| <i>Demand</i> | | | | |
| Export ratio of client sector | -0.0053 | -1.33 | -0.0055 | -0.89 |
| R&D intensity of client sector | 0.0195 | 1.15 | 0.0067 | 0.26 |
| Investment ratio of client sector | -0.0098 * | -1.86 | -0.0209 ** | -2.05 |
| <i>Competition</i> | | | | |
| Share turnover in main product group | 0.0008 | 0.59 | 0.0014 | 0.65 |
| Importance of price competition | 0.0213 | 0.64 | 0.0202 | 0.40 |
| Importance of quality competition | -0.0086 | -0.23 | -0.0937 * | -1.75 |
| Importance technological advantage | -0.0406 | -1.19 | -0.0934 ** | -2.11 |
| Importance of service quality | -0.0038 | -0.11 | 0.0720 | 1.42 |
| Importance of product variety | 0.0925 *** | 2.77 | 0.1367 *** | 2.85 |
| Importance of advertising | -0.0386 | -1.45 | -0.0571 | -1.53 |
| <i>Schumpeter loop</i> | | | | |
| Relative R&D expenditures | --- | --- | -2.1753 *** | -3.53 |
| Number of main competitors | -0.0656 ** | -2.48 | --- | --- |
| <i>Size</i> | | | | |
| Turnover | 0.0000 | -0.87 | 0.0000 | -1.13 |
| Employees | 0.0002 | 1.45 | 0.0004 | 1.53 |
| Employees ² | -0.0003 | -1.62 | -0.0005 ** | -1.98 |
| <i>Resources</i> | | | | |
| Share employ. tertiary educ. | 0.0069 *** | 2.77 | 0.0147 *** | 2.64 |
| <i>Other characteristics</i> | | | | |
| Age of company | -0.0046 * | -1.81 | -0.0076 * | -1.71 |
| East Germany | 0.2022 ** | 2.17 | 0.2342 ** | 2.00 |
| Investment | 0.0000 | 0.09 | 0.0000 | 0.56 |
| Export activities | 0.0050 | 0.06 | 0.0647 | 0.55 |
| <i>Subsector</i> | | | | |
| Chemical base materials | -0.0431 | -0.37 | -0.2219 | -1.27 |
| Pesticides | 0.0675 | 0.24 | 0.8258 *** | 2.89 |
| Paint and ink | -0.0868 | -0.78 | -0.2335 | -1.42 |
| Pharmaceuticals | 0.0706 | 0.41 | 0.2343 | 1.13 |
| Soap and cleansing | -0.0570 | -0.43 | -0.0822 | -0.41 |
| <i>Exclusion restrictions</i> | | | | |
| Technologies change quickly | 0.0596 | 1.02 | --- | --- |
| Products can be substituted easily | 0.0992 * | 1.76 | --- | --- |
| Niche market strategy | --- | --- | -0.3168 | -1.9 |
| Patent applications | --- | --- | 0.0303 | 0.2 |
| Lead time | --- | --- | -0.2384 * | -1.75 |
| Secrecy | --- | --- | 0.1240 | 1.04 |
| Complexity of product design | --- | --- | 0.0404 | 0.26 |
| Increase in market share | --- | --- | -0.1178 ** | -2.23 |
| Market position endangered by competitors | --- | --- | 0.0960 | 1.55 |
| N | 97 | | 97 | |
| Chi-sq/ model sign. (26 df/ 31 df) | 74.84 *** | | 142.90 *** | |
| Chi-sq / exogeneity (1 df) & t-stat./ exogeneity | 4.25 ** | | -2.65 *** | |
| Ci-sq/ Exclusion Restriction based on LIV (6 df/ 1 df) | 5.07 | | 2.64 | |

5% level.

This result is reflected in the finding of the exogeneity tests, which indicate that the innovation, respectively the R&D expenditures, on the one hand, and the number of competitors on the other hand are simultaneously determined.

With respect to robustness of the results, we have run the regressions also with heteroscedasticity-robust standard errors without observing important changes. The mechanism of the Schumpeter Loop remained unaffected. We have also tested the quality of the instruments by inspecting the excludability. Based on the Sargan test run for linear 2SLS specifications, we find no evidence of a lack of excludability. Therefore, the instruments seem trustworthy.

Considering the size of the effects by calculating the marginal effects reveals that one additional competitor reduces innovation expenditures by 4.6% and reduces R&D expenditures by 2.7%. On the contrary, one additional percentage of turnover spent on innovation reduces the number of competitors by 0.17. An additional percentage spent on R&D reduces the number of competitors by 0.13%. At this stage it seems tempting to use these estimates to model the dynamic evolution of the market and analyse the speed of the concentration process. This could underpin the argument of Schumpeter Loop, because it would allow us to test whether the speed of concentration actually fits the observed industrial evolution in this sector. Unfortunately, because both the theoretical and the empirical are essentially static in nature, none provides sufficient information on the dynamics of the concentration process. To evaluate this question convincingly, we should ideally use a combination of a more complex multi-stage model, which could then be tested using panel data.

Sticking to a more static view, the marginal effects in any case imply that a firm that spends an average amount on innovation has 2.9 competitors less than a firm which does not devote resources to innovation. Likewise, a firm with average R&D expenditures has roughly 1.7 competitors less than a firm that does not perform R&D. Compared with a mean number of 6.6 competitors, we think that this is quite a strong decline. Thus, already this static perspective seems to suggest that the Schumpeter Loop could be a powerful explanation for the ongoing concentration processes in the chemical industry.

7 Conclusion

In this paper we investigated the interplay of innovation activities and market structure. Based on stylised facts in the chemical industry, we set up a theoretical model which was able to show that innovation and market structure affect each other in a dynamic self-enforcing relationship: fewer competitors tend to increase innovation activities. Furthermore,

innovation activities reduce the number of competitors. The first effect is due to the increased ability of large firms to profit from successful innovation - an effect already foreseen by Schumpeter (1950). The decline in competitors, on the contrary, results from the additional risk induced by innovation, which also increases the probability of market exit. We labeled this feedback relationship the Schumpeter Loop.

Using data from CIS 2005 for the German chemical industry, we were able to collect empirical evidence on predictions of the Schumpeter Loop, where we explicitly took into account that market structure and innovation are simultaneously determined. Although we are not able to recover the complete dynamics of the sector's industrial evolution based on the cross-section data at hand, we argue that the empirical evidence on the positive feedback loop provides a promising explanation for the ongoing concentration processes in the chemical industry.

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