What made southwest German firms innovative around 1900?

Assessing the importance of intra- and inter-industry externalities

By Jörg Baten *, Anna Spadavecchia †, Jochen Streb ‡, and Shuxi Yin §

* ; Department of Economics, University of Tübingen and CESifo, Mohlstrasse 36, D-72074 Tübingen, Germany; e-mail: Joerg.baten@uni-tuebingen.de

† University of Reading

‡ University of Hohenheim

§ University of Tübingen and Hohenheim

This is the last working paper version before this study was submitted and accepted. Please cite as Baten, Joerg and Spadavecchia, Anna and Streb, Jochen and Yin, Shuxi. "What made southwest German firms innovative around 1900? Assessing the importance of intra- and inter-industry externalities", O*xford Economic Papers*, Volume 59, Issue suppl_1, October 2007, Pages i105–i126.
Online: https://doi.org/10.1093/oep/gpm032

Abstract:

This paper investigates the impact of clustering on the innovative activity of firms. The study, one of the few using firm-level data, is based on a newly constructed dataset, including information on patents and 2407 manufacturing firms located in the state of Baden at the turn of the 20th century. The analysis assesses the importance of intra- and inter-industry externalities among other determinants, for the innovative activity of firms in the sample. The results show that both types of externalities were important, with the former being more important for the whole sample and the latter for small firms. Moreover, consistent with Winter's theory of 'technological regimes', our results show that firms differ in the type of knowledge base they utilize in their innovative activity, a result rich in policy implications.

JEL: O31; O33; N63; N93; R11.

1. Introduction

Innovation is a broad concept, embracing products, production processes and organizational set-ups (Dosi, 1988).[1] This paper focuses on firms' innovative activity concerning the first two areas, and follows the approach to innovation as research, development, imitation and adoption of both new products and new production processes (*Ibid*).[2] This is consistent with an important stream of historical and theoretical works regarding innovation, in the form of technological progress, as a fundamental determinant of economic growth.

A long standing tradition, beginning with Marshall (1890), has stressed that external economies arise from concentrations of similar industries. Industry-specific regional concentrations, or clusters, lead to thick labour and intermediate input markets, and to the exchange of innovative ideas, both voluntary and involuntary. This stream of work poses interesting questions concerning the importance of clustering for firms' innovative activity, an issue on which the novel dataset used in this paper can shed new light. The analysis uses an original dataset including information on patents granted, and firms located, in the state of Baden between 1895 and 1913, years of sustained industrial growth. At that time, Baden occupied a middling economic position in Germany. As explained in greater detail in section 4, the dataset was constructed using two main sources: an unpublished 1906 census of Baden firms with

---

[1] The similarity between the various types of innovation identified by Dosi and those previously identified by Schumpeter is clear; see Schumpeter (1942), p.65-6; on this point see also Nelson and Winter (1982), p.276-8.

[2] This choice is dictated also by the usage of patents as a proxy for innovation. New organizational set-ups would not be patented and therefore their determinants cannot be analysed in this paper. However, it is acknowledged that new organizations are important in promoting knowledge transfer across firms' boundaries, as shown in previous studies (see Streb, 2003).

10 or more employees, including 2407 manufacturing firms and excluding branches and subsidiaries (Verzeichnis der einer besonderen Aufsicht unterliegenden Fabriken und diesen gleichgestellten Gewerbebetrieben), and the *Annual Patent Directory* (*Verzeichnis der im Vorjahre erteilten Patente*) published by the German Patent Office (Kaiserliches Patentamt) in Berlin. From the latter, the patents registered in Baden which are considered as having a high economic value, that is renewed for a minimum of 10 years, were singled out. These, 329 in total, were matched with the patenting company. Therefore, our dataset includes 2407 firms, of which 82 had patents of high economic value.[3]

This paper is organized into six sections. The following section introduces the theories behind the main questions addressed in the empirical analysis. Section 3 presents the data used in the analysis and the methodology adopted to overcome the shortcomings of using patents as a proxy for innovation. Section 4 discusses the model used in the econometric analysis, whereas section 5 presents and interprets the results. Section 6 concludes, and discusses the implications of the findings.

2. Theoretical background and testable questions

The concept of innovation adopted in this paper stresses the implementation of 'new knowledge' either in the production process or in the form of new products, which, in turn, is very likely to imply changes in the production process. If new knowledge is the single most important input in the production of innovations (Winter, 1984), factors facilitating the generation and diffusion of such knowledge should have a positive effect on the rate of innovation. Following this approach, externalities and knowledge spillovers in particular play an important role in fostering innovative activities, as maintained by a stream of research in the economics of technology, new growth

[3] Moreover, 49 patents were granted to those firms earlier, on which we base the "previous patenting"

economics and economic geography (Audretsch and Feldman, 1996; Krugman, 1991; Porter, 1998).

Marshall (1890) explained the advantages enjoyed by similar firms concentrating in the same neighbourhood, and called these external economies. External economies arise mainly from the development of subsidiary industries and the concentration of a specialized labour force, which, among other advantages, brings about a rapid diffusion of ‘inventions and improvements’ as new ideas are discussed promptly (*Ibid*. p.270).

Contemporary studies have taken the concept of Marshallian external economies further. In economic geography, Krugman pointed out that economic activities and production tend to concentrate within clusters. This is because the three types of externalities, specialized labour market, intermediate inputs and technological spillovers, typically developed within clusters, yield increasing returns to scale and are geographically bounded (Krugman, 1991). In the specific case of technological knowledge, diffusion is particularly rapid within clusters as new technological knowledge is at least partly informal, uncodified and tacit, and thus can flow more easily over short, rather than long, distances (Pavitt, 1984). Other authors have pointed out that the rapid diffusion of new technology within clusters is also due to fierce competition between firms and frequent contacts with customers, which provide an ever more sophisticated demand (Porter, 1998).

While it is widely agreed that clusters foster knowledge externalities, a more controversial point is how such knowledge diffuses. Marshall (1890), Arrow (1962) and Romer (1986) (henceforth M-A-R) suggest that knowledge spillovers arise among firms in the same industry, thus fostering the growth of that industry and region. On

---

variable.

the contrary, Jacobs (1970) believes that the most important knowledge spillovers develop across various industries. Therefore, according to the M-A-R approach, knowledge externalities should be more pronounced in specialized industrial areas, whereas, according to Jacobs, such dynamic externalities will take place particularly in highly diversified industrial regions (Glaeser *et al*., 1992). Jacobs' argument has received support from studies confirming the significance of inter-industry technology flows (Bairoch, 1988; Scherer, 1984; Streb *et al.*, 2007), and Glaeser *et al*. found that Jacobs' externalities were more important to the growth of mature industries than M-A-R externalities. However, Glaeser *et al.* suggest that the latter might be more significant at the early stages of an industry, although they could not test the point. As our dataset includes firms trading in the period of the German industrial take-off, it will help to assess whether M-A-R externalities are more important in periods of rapid industrial growth. Our dataset enables us to contribute to the debate concerning M-A-R and Jacobs' externalities by addressing the following question:

Question 1 Is the innovative activity of firms within a cluster associated with intra-industry or across-industry knowledge spillovers?

Recent studies have tried to test empirically whether firms within clusters are more innovative than firms located elsewhere. Baptista and Swann (1998) indicate, using a dataset of 248 firms, that cluster specialization has a moderate positive effect on the innovative activity of firms within the same sector. On the contrary, employment in other industries has a negative effect, although this is not significant. Such results suggest externalities of the M-A-R type, whereas Baptista and Swann (1998) infer that employment in other industries could be a source of weak congestion effects. However, they admit that the use of aggregated two-digit industries might conceal important results, as inter-industry externalities might take place among technologically close industries that would be combined in the two-digit industries.

This line of investigation is taken further by Beaudry and Breschi (2003), using a very large dataset for 1990-8 from the UK and Italy. They find that the concentration of particularly innovative firms in the same industry fosters firms' innovative activity, rather than the cluster itself. On the contrary, the presence in the region of innovative firms in other industries has a negative and significant coefficient in the case of the UK. Therefore, both studies not only suggest the existence of M-A-R externalities among innovative firms, but also indicate that innovative firms in other industries generate congestion costs. On the basis of our dataset, we will investigate the following issues:

Question 2 Do innovative firms have a positive impact on the innovative activity of firms in the same industry?

Question 3 Do non-innovative firms have a negative impact on the innovative activity of firms in the same industry?

While the stream of literature following from Marshall, Arrow, Romer and Jacobs concentrates on positive externalities, other works point out the limits to the positive feedback process generated within clusters. Such limits are related to congestion and competition effects that might overcome the benefits as clusters grow (Brezis and Krugman, 1993). Costs of labour, land and facilities, together with pressure on infrastructure, might discourage employers and employees from concentrating within crowded clusters, as exemplified by contemporary developments in Silicon Valley (Morck and Yeung, 2001). Moreover, knowledge externalities might be perceived as a leakage of information, which would erode the appropriability of the innovation. Patent licensing contracts can ensure the patenting firm a significant share of competitors' profit. However, due to imperfect contracts and reverse engineering, this solution can be impractical (Caves, 1982). Therefore, the most innovative and best performing firms might be the most likely to move out of the cluster (Shaver and Flyer, 2000). Our contribution to this debate consists in testing the following question:

Question 4 Is the innovative activity of firms within a cluster affected negatively by congestion costs?

Firms within clusters might benefit to various degrees of knowledge spillovers. Winter (1984) argues that innovation in new entrants or established firms emanates from different economic and technological conditions or 'technological regimes'. The concept of 'technological regimes' summarizes the main economic characteristics of technology, such as its comprehensiveness and appropriability, and of the learning processes involved in the innovative activity. An 'entrepreneurial regime', with technological ease of entry and comprehensiveness of innovations, among other characteristics, is favourable to innovative entry and unfavourable to innovative activity by established firms; a 'routinized regime' characterised by the inverse conditions, is favourable to established firms (*Ibid*, p.297; Breschi *et al*., 2000). This approach has its foundation in Schumpeter's theory of innovation. In particular an entrepreneurial regime encapsulates Schumpeter's 1911 initial approach (Schumpeter, 1936) where innovation was associated with entrepreneurship and new firms. A routinized regime reflects the 1942 Schumpeterian hypothesis, according to which oligopolistic firms are in a better position to innovate, due to financial resources that could be invested in R&D and the appropriability of returns (Breschi *et al.*, 2000).

Especially important for our study is the difference between the sources of technological knowledge in the two regimes. Winter (1984, p.292-3) differentiates between two major types of technological knowledge: R&D, a type of knowledge available only to the firm that produces it, and the firm's external environment, including other firms involved in similar activities and the education and experience of firms' personnel. Small-firm innovative advantage is roughly correlated to the wide base of the external knowledge environment, from which innovative ideas might diffuse. This understanding is confirmed by studies showing that university R&D plays a more decisive role in innovation for small firms, whereas corporate R&D plays a relatively more important role in large firms' innovations (Acs *et al*., 1994). Our dataset enables us to contribute to the technological regimes approach and we will address the following question:

Question 5 Is the innovative activity of firms in our sample associated with sources of technological knowledge typical of an entrepreneurial or routinized technological regime?

3. Data

This article revisits theoretical issues concerning clusters and innovation on the basis of a compounded dataset, including information on patents and firms trading in the German state of Baden between 1895 and 1913. Baden was at the time a separate arch-dukedom within the German Empire and, because of its accurate statistics, the state has often served as a sample region for Germany. The roots of Baden's industrial success were already clear around 1900, when the state included some dynamic regions with high wages, many patents and many new firms, while other regions lagged behind.

In the period under consideration, Baden occupied a position between the states that were industrializing rapidly (such as Saxony, Berlin or Rhineland-Westphalia), and the agricultural states in the South East and East. Tax-based regional estimates of GDP *per capita* in 1913 suggest that Baden occupied a middle position within Germany: the *Bezirke* (or counties: Baden had 4 *Bezirke*) of Mannheim and Karlsruhe were respectively 10% and 13% above the German average, while Freiburg and Konstanz were 13% and 18% below the average (Handbuch, 1992; Frank, 1994). Nominal wages in the state were relatively high, which, combined with relatively high estimated prices, resulted in real wages ranging from the 47th to the 65th percentile of German regions (see Baten, 2003).

Inventive activity in Baden was, around 1900, already far above the German average (Fischer, 1989). Important (ten-year-prolonged) patents per capita in the *Bezirke* of Konstanz reached only the 32nd percentile of German regions. However, the remaining three *Bezirke* were far above the median (Freiburg 62nd, Karlsruhe 74th and Mannheim 83rd) of German patenting activity (Borscheid, 1976; Abelshauser, 2002). The dataset thus gives us the unique opportunity to study a region which was fairly representative of Germany in terms of real wages, but less representative in terms of important patents, as three of the four regions were above the median German region.

Today, Baden is one of Europe's richest regions with an economy biased towards capital goods. Yet, in the period of our analysis, its industrial structure was similar to a random sample of German firms (table 1). The main difference is that Baden had many more firms in metal processing (especially jewellery, concentrated in the city of Pforzheim), and in the food and tobacco sector (an especially large number of cigar-makers in Baden). Conversely**,** there were fewer firms in textiles, clothing, and stone (especially brick) processing.

[Table 1 around here]

Our dataset has been constructed using two sources. The first is an unpublished census of firms with 10 or more employees, conducted in Baden in 1906 (Verzeichnis der einer besonderen Aufsicht unterliegenden Fabriken und diesen gleichgestellten Gewerbebetrieben). The source is one of the few that lists all individual firms, excluding only the smallest artisan firms. Our 'industrial size' segment of firms employing 10 or more workers contains 2407 manufacturing firms, excluding branches and subsidiaries. A second dataset, including all important patents granted in Germany between 1895 and 1913, was constructed using the *Annual Patent Directory* (*Verzeichnis der im Vorjahre erteilten Patente*) published by the German Patent Office (Kaiserliches Patentamt) in Berlin.[4] From this second dataset, patents registered in Baden and renewed for a minimum of 10 years were matched with the patenting company or entrepreneur. Table 2 presents some summary statistics concerning the final compounded dataset. As expected, after matching firms and patents, some companies held a large number of important patents, whereas most of the firms had no long-lived patents at all. Since we take into consideration only important patents, it is not surprising that our percentage of non-innovative firms is slightly higher than the samples of contemporary British and Italian firms analysed by Beaudry and Breschi (2003), who counted every patent.

[Table 2 around here]

Patents are used widely as an indicator of innovative output, but this proxy has its limitations. Previous work has pointed out that not all inventions are patented, and that the propensity to patent varies across industries. Moser (2005) offers useful indications of industries' propensity to patent in mid-19th century England. She assumes that the number of exhibits at the 1851 Great Exhibition reflected the true number of innovations, and interprets the share of patented exhibits as the industry-specific propensity to patent. Her findings show that industries such as food processing and chemicals had a low propensity to patent, whereas engineering had the highest by far. The relative ranking of engineering and the chemical industry is reversed when looking at the late 20th century, when petroleum and chemical industries display the

[4] In addition, to construct a variable on "previous patenting", we also included those patents back to

highest propensity to patent (Scherer, 1983; Arundel and Kabla, 1998). A plausible explanation of the dramatically different position of the chemical industries in the rankings in the two periods lies in the fact that Moser's data refer to a period immediately preceding the wave of innovations in these industries, which culminated in Germany in the 1880s and 1890s with a new generation of synthetic dyes (Streb *et al.*, 2007). This would help explain why in our sample chemical industries display a high value of patents per worker, second only to engineering (see table 4). The implications of the above for our analysis are that we cannot reject the hypothesis that the propensity to patent was not only different between industries, but also changed between the 19th and the late 20th century. In order to control for the unobserved degree of differences of patent numbers by industry, industry dummy variables have been included in our analysis (see section 4).

A frequent criticism of patents as an inter-firm proxy for innovation is the difficulty of accounting for the varying economic and technological importance of patented inventions. This paper addresses this shortcoming by taking into account only patents renewed for at least 10 years. Patentees who were willing to renew their patents faced increasing renewal costs. In 1877 a patent protection law was passed in Germany. For the first time, patent protection was granted throughout the German Empire, rather than in a specific state. According to this law, patents could be renewed for up to 15 years, but the cost increased over time, in order to discourage renewal of patents with low private economic value. In the period under consideration the patent fee increased from 50 Marks in the first two years to 700 Marks in the fifteenth year (Streb *et al.*, 2006). Therefore, the patent renewal period can be interpreted as an indicator of its private economic value (Schankerman and Pakes, 1986) as, assuming

---

1878 from the same source.

economically rational behaviour, the patentee would renew the patent only if the costs of doing so were lower than the expected future returns. As a result, we interpret patents with a high economic value as those that had been renewed for 10 years or more. Selecting a 10-year renewal period led to the discarding of 90% of the patents, leaving 329 important patents that could be matched with the population of 2407 relevant firms.

Table 3 displays the top 25 firms in terms of numbers of important patents. Among the firms with many important patents, engineering and chemical firms are clearly well represented. These industries were historically, and still are, the so-called 'net donors' of innovations that are often applied in other industries. Moreover, table 3 clearly shows that small firms could be highly innovative. Slightly less than one third of all firms with important patents had less than 50 employees (24 out of 82). We shall assess more systematically below whether this is also the case among the remaining 2382 firms.

[Table 3 around here]

The distribution of important patents by industry suggested in table 3 is confirmed when considering the number of important patents per worker. In particular, the machinery and equipment sector displays one important patent per 106 workers, followed by chemicals and metals, with one patent per 188 workers and 232 workers, respectively.

[Table 4 around here]

Only 82 firms had important patents. The distribution of important patents per worker, and the large number of non-innovative firms, mean that any regression model that attempts to explain patent numbers per firm should take into account that there are many zeroes in this variable, hence we employ a Tobit regression model.

The innovative behaviour of our Baden firms is discussed in the light of the study by Beaudry and Breschi (2003) focusing on the 20th century. The comparison is made on the grounds that differences between the two systems of innovation, separated by roughly one century, are not as large as they may seem. R&D and patenting activities had nearly the same meaning for the innovating firms in the late 19th century, as they did for their counterparts a century later. This is proved by developments in industry following the approval of the first German patent law in 1877. German firms not only invented industrial R&D departments, in which, for the first time in economic history, scientists tried to discover profitable inventions systematically, based on the division of labour between researchers, but also deployed patents consciously as a means to appropriate the profits from their product and process innovations (Meyer-Thurow, 1982; Liebenau, 1988; Homburg, 1992). The industrial leaders already understood that they could use patents also to pre-empt competitors' innovations, as demonstrated by Bayer's extensive patenting in 1885 to prevent AGFA from filing patents in the same field (Murmann, 2003, p. 134), and Siemens' use of its patent stock to prevent General Electric from entering the German market in 1911 (Erker, 1990).

Furthermore, we studied how the size of firms in the Baden sample compares with that of contemporary Britain and Italy, used in Beaudry and Breschi (2003), in order to establish whether our results can be biased by a smaller weighting of large firms. The comparison showed Baden's firms around 1900 were actually not smaller than today's firms in Italy and Britain. The smallest size segment of 10-19 workers has, frequently, a lower share in Baden, compared with the large firm size segments of 20-49, 50-199, and above (see table 1 in the on-line Appendix). This is the case in 10 of

11 comparable industries. Thus, we conclude that in the size segment we consider here, Baden's firms were certainly not smaller.

4. Towards a testable model

Baptista and Swann (1998) found that employment in the same industry and cluster had a positive effect on firms' propensity to patent. However, Beaudry and Breschi (2003) rejected this result, finding that the total number of workers in the same industry and cluster did not increase patent numbers. Only the number of workers in innovative firms within the same industry and cluster had a positive effect, while employment in non-innovative firms led to negative congestion externalities. In the empirical analysis, we focus on the number of patents per worker in 1907-13 as the dependent variable. The Beaudry and Breschi (2003) variables are included as explanatory variables: employment in innovative firms, same industry, and employment in non-innovative firms, same industry. For each individual firm, we subtracted the number of workers employed in the firm from the respective region/industry-specific variable.

We list those M-A-R-type externalities in the upper quarter of Fig. 1. The plus and minus signs indicate the influence we expect on patenting propensity. A third M-A-R variable, Herfindahl, is the Herfindahl index of industry employment within a region. Our Herfindahl variable measures to what extent employment within each of the 52 districts is concentrated in manufacturing, as compared to the Baden average. Consistent with the M-A-R theory we expect this variable to be positively associated with firms' innovative activity. The rounded corners in Fig. 1 indicate that this variable is measured at the regional level.

[Fig. 1 around here]

The lower quarter of Fig. 1 lists Jacobs-type external effects tested in the econometric analysis. Jacobs' inter-industry externalities are expressed through the variable employment in other industries, same region. This variable, introduced by Baptista and Swann (1998), was broken down by Beaudry and Breschi (2003) into employment within innovative and non-innovative firms in order to test whether the former had a positive impact, and whether the latter had a negative one. In our case it was not possible to distinguish between workers in the two types of firms in other industries, as there was multicollinearity between the two variables.

The degree of urbanization of the regions, variable urbanization, might have a positive as well as negative influence. It could be positive because urbanized areas can transmit cross-industry technological spillovers more easily, as expected by the Jacobs approach. On the other hand, urbanization might capture the residual urbanization effects after industrialization has already been controlled, to some extent, with the variable employment in other industries (in the same region). Urban environments were in some cases also characterized by administrative functions, and Freiburg and Heidelberg were clearly dominated by university education in the humanities, which might not have translated directly into technical patents. Hence our expectation that urbanization might also be negative, if it captures this non-industrial urban residual effect.

Another variable taken into account is labour cost, variable wage, which represented a high percentage of total costs for firms in this period. This is used as an indicator of congestion costs that might be generated within clusters, and that might affect firms' innovative activity in an ambivalent way. On the one hand, high wages might represent a disincentive to innovate, as they would reduce firms' profit margins, *ceteris paribus*. On the other hand, high wages might promote innovation conducive to production processes that were less labour-intensive, as well as to innovative products as these command premium prices, which would rebuild firms' profit margins. We decided not to model the other direction of causality, for example, the influence of patenting of individual firms on regional labour costs, because the influence of one individual firm is reasonably small. We assessed, however, the potential endogeneity of the variable firm size, as this variable is given at the individual firm level.

Other regional variables are listed in the right quarter of Fig. 1: infrastructure; human capital formation; and taxation. Infrastructure is proxied with the dummy variable Rhine in table 5 - assuming the value of 1 for those districts with access to the Rhine, a major route for transportation.[5] Regional human capital formation is expressed through the variable pupils in technical education, in table 5, defined as the number of pupils in technical and commercial schools, of secondary and tertiary level, per 1000 population. Technological and commercial knowledge taught in specialized schools should increase the propensity to innovate. Moreover, a wide diffusion of such knowledge would represent a wide knowledge base from which innovations develop in entrepreneurial technological regimes. Therefore, a positive and significant result of this variable would indicate that our firms display some features typical of that regime. Taxes reduce the expected returns of successful patents, and hence decrease a firm's propensity to apply for, and to renew, a patent, given the costs of patenting. Regional taxation has been proxied with the dummy variable taxes, in table 5, assuming the value of one, if the average regional taxation was above the Baden average.

[5] On the influence of means of transportation on patenting in the United States see Sokoloff (1988). Sokoloff focused on navigable waterways. Another important means of transport was the railway, but in Baden this followed mainly the Rhine valley, with the main railway lines running parallel to, and close to, the river.

Finally, on the left side of Fig. 1: we list firm-specific variables through which we are trying to capture internal economies; these should also indicate whether our firms display some of the distinctive features of a routinized or entrepreneurial regime. Firstly, the dummy variable, previous patents, indicates whether a firm had a patent already in the period 1878-1906, i.e. before 1907-13 (see also Baptista and Swann, 1998; Beaudry and Breschi, 2003). If the impact is significant and positive, this can be interpreted as a suggestion that our sample displays features of a routinized technological regime characterized by a high degree of cumulativeness of innovation. If the variable turns out to be not significant this would indicate features of an entrepreneurial regime in our sample. The variable age, expresses the age of the firms, in logarithms. This variable might proxy the experience of the firms, or established routines that might even act as a disincentive for new patents. We also test the effect of firm size, in terms of employment, on patenting, as with this we might capture economies of scale internal to the firm. A positive impact of the firm size variable indicates that our firms display characteristics of a routinized technological regime. Moreover, a positive result would point in the direction of the Schumpeterian hypothesis.

We now sum up the differences between our analysis and previous studies. Firstly, and most importantly, we focus on regional human capital formation built up in technical and commercial schools, as an important source of innovative knowledge. Secondly, applying for a patent and renewing it for ten years normally means that the actor has a substantial profit expectation, after deducting all costs of the production process and the economic environment. Therefore, we expect that high regional taxation, for example, would discourage an entrepreneur or a firm from applying for a patent.

Infrastructure might also play an important role, as the easy shipment of raw materials and final goods increases profit expectations. However, after urbanization and all the other related variables are controlled for, it might be that firms close to the Rhine have comparative advantage in bulky, perhaps simple products, whereas remote firms, such as those in the Black Forest, are specialized in light and technology-intensive products.

5. Econometric analysis

Table 5 displays the results of an IV regression (Regression 1 and 2), chosen in order to deal with potential endogeneity problems.[6] Regression 3 is an OLS version of Regression 2, and demonstrates that the results are not statistical artifacts of the IV estimation. We also employed a Tobit model in regressions 4, 5 and 6 to make sure that the many zero patent values do not represent latent, very small propensities to patent due, for instance, to high patenting fees; obviously, 'fractions of a patent' were not observable. Even if we now divided by workforce, the zero values could still be considered as very small propensity to patent. Finally, we included industry dummies (Regression 1) to control for differences in the propensity to patent between various industries, and possibly for other unobservable industry characteristics. All industry dummies turned out to be insignificant, with the sole exception of the dummy for industrial machinery and equipment (SIC 35), the industry with the highest ratio of patents per worker.

[Table 5 around here]

The econometric analysis shows that larger firms in our sample were granted more patents, particularly when considering regressions 1, 2, and 3 in table 5, a result

[6] We studied also bivariate relationships between patents per worker and the main explanatory variables; see Graphs 1-5 in the on-line Appendix.

consistent with Italian and British firms during the 1990s. One important difference here is that we calculated the number of important patents on a per-worker basis, whereas Beaudry and Breschi (2003) took the total number of all patents per firm, and then controlled for firm size. As large firms have more employees who can produce innovations, the positively significant coefficient in their analysis might be expected.[7] In our regressions, the positive coefficient is quite remarkable, as we would have expected that firms employing many workers would be found in such industries as textiles, which did not produce a high number of patents in the period of the Second Industrial Revolution. Moreover, we find a positive effect of the firm size variable, even after controlling for possible endogeneity.

Firm size is a potentially endogenous variable as, in principle, it might be possible that firms grew large because they had a high number of important patents per worker, rather than the other way round. To avoid contemporaneous correlation in the OLS and the Tobit regressions, we based our explanatory variables on the period up to 1906, whereas the innovative activity we measure took place during the period 1907-13. Moreover, we perform an IV regression (1 and 2), where we use the number of workers in an earlier period (1895 instead of 1906) as an instrument. This instrumental variable is clearly correlated with the potential endogenous variable (correlation coefficient is 0.80), but is not correlated with the error term. As a result, the coefficient is reduced in size, but remains statistically significant. This robust influence of firm size on patents per worker is certainly one of our most important results.

---

[7] We also performed NEGBIN regressions and the results were largely consistent with the other regressions normalized by the number of workers (available from the authors). We are very thankful to the referees for suggesting the normalization of the dependent variable, to put the size hypothesis to a harder test.

Endogeneity is certainly less of a problem for the regional and industry-specific variables, as our work is based on firm data, unlike similar studies based on national or regional aggregates, and the impact of individual firms on the external environment is, in most cases, quite limited. Moreover, our sample included only a very limited number of firms that would have been able to have such impacts (such as Siemens or AEG in other regions of Germany).

If we include only those 84 firms with important patents, firm size in terms of employment is not significant at conventional levels (regression 5 in table 5); rather, the p-value is 0.27. Within this core of innovative firms, some were quite innovative with a small number of workers, and others were giants. This was also visible in table 3 above, although we should note that this table was created under the criterion 'most important patents', and thus excluded all firms without such patents (which were mostly small).

The higher propensity of large firms to innovate supports the Schumpeterian argument that large firms with market dominance are in a better position to innovate. This requires high fixed costs, and can therefore be undertaken by firms holding comparable financial resources. Moreover, increasing returns to scale associated with innovation, particularly innovation yielding cost reductions of a given percentage, result in higher profit margins for larger firms (Acs and Audretsch, 1990, p.39-40).

With the exception of small firms, our sample displays a positive effect of workers in innovative firms within the same industry and cluster, and a negative effect of employment in non-innovative firms in the same industry and cluster, as pointed out by Beaudry and Breschi (2003). It should be noted that our definition of those variables differs from the Beaudry and Breschi study, as we excluded the number of workers of one's own firm from this explanatory variable. If we consider endogeneity of the firm size variable (regressions 1 and 2), the result is also statistically significant, although the coefficient is now very small. This stresses the importance of M-A-R intra-industry externalities for our region and period, which is very close to that of Marshall, whereas the negative coefficient of employment in non-innovative firms in the same industry, suggests that such firms are a source of congestion costs.

We found that our indicator of clustering within each of the 52 regions (Herfindahl) did not yield significant results, which is consistent with Beaudry and Breschi (2003). Therefore, our sample confirms their finding that the cluster itself does not have a positive impact on innovation. Rather, the key factor is the extent to which such clusters contain innovative firms.

Previous patents are clearly another crucial factor promoting further innovation. Here we confirm earlier studies (e.g. Baptista and Swann, 1998; Beaudry and Breschi, 2003). Our firms display features typical of a routinized regime, characterized by a continuous flow of innovations based on, and reinforcing, technical knowledge and innovative capabilities internal to the firm (Breschi *et al*., 2000). Beaudry and Breschi distinguished further between the rapidly discounted stock of patents (discount rate 0.3) and the previous patenting dummy variable. Thus, the difference is whether a firm patented at all and the number of discounted earlier patents that proxies its propensity toward repeated patenting. They interpreted the positive coefficient of the discounted stock of patents and the negative one for the previous patenting dummy, as evidence that it is not previous patenting *per se*, but recent and repeated previous patenting that plays a major role in promoting further innovation. In fact, controlling for the stock of patents one previous patent only could have an adverse effect. We cannot test this, because we had extreme multicollinearity between the previous patenting dummy and the stock of patents variable.

A different and interesting story emerges when isolating small firms (fewer than 50 workers). For these firms, variables such as size, previous innovations and the presence in the region of other innovative firms in the same industry do not yield significant results, although displaying the expected sign. The two factors displaying the highest levels of association with innovation within small firms are a large number of workers in other sectors (employment in other industries, in table 5) and innovation-specific human capital (pupils in technical education, in table 5), one of the variables which was not taken into account in some previous studies.

The high and significant coefficient of employment in other industries, clearly suggests that the innovative activity of small firms benefits from the presence of firms in other sectors. This suggests that inter-industry knowledge spillovers, and therefore Jacobs-type externalities, are more important for this group of firms. This seems particularly important, and confirms that small firms were often able to make useful discoveries using knowledge spillovers from R&D-intensive firms in upstream industries (see Beer, 1959). However, small firms also seem to be negatively affected by congestion costs within clusters, expressed by the degree of urbanization.

Among the regional variables, pupils in technical education has a strong and significantly positive effect only when isolating small firms. This finding, together with the lack of significance of previous patenting, clearly points towards an entrepreneurial technological regime, where innovative activity is not associated with cumulative knowledge internal to the firm, but rather with a diffused knowledge base. This finding also indicates the importance of government investment in technical and commercial schools, which have a positive impact on patents, and via positive knowledge externalities, on economic growth in the better-equipped regions.

Taxes, the dummy variable for regional taxation, displays a constant negative sign in all regressions, but is significant when we isolate small firms. Central government taxation was generally moderate in Germany around 1900, although there were also municipal taxes, which represented half the total tax burden for firms and account for the variations of this variable in our regressions. This finding suggests strongly that small firms might be particularly penalized by a policy of high business taxation.

Wages in Baden were higher than in other states of the German Empire, as mentioned in section 3. However, the variable wage does not turn out to be significant. Yet another non-significant variable is the dummy Rhine, and therefore we do not confirm a positive association between innovative activity and proximity to a means of transport, as suggested by Sokoloff (1988).

6. Conclusions

This work offers several contributions. One of its major merits lies in its original dataset, which helps overcome what Kuznets (1962) considered one of the greatest obstacles to understanding the role of innovation in economic processes, i.e. the lack of measures of inputs and outputs of inventive activity (*Ibid*, pp. 31-41; Acs and Audretsch, 1990, p. 37). This dataset is even more important as it allows us to study a state like Baden, which, in the period under analysis, presented an industrial structure similar to the German average, and therefore offers insights into a fundamental determinant of economic growth in one of the world's largest economies.

Whereas most work on patents uses regional units, this article is one of the few based on firm-level data and it offers a contribution to various controversial issues, as well as pointing out factors overlooked by previous empirical studies.

Our sample indicates that both M-A-R and Jacobs' externalities had a positive impact on firms' innovative activity, with the former affecting the whole sample, and the latter small firms only. These results suggest that the strong presence of innovative firms in the same industry and region stimulated the innovative activity among large firms, probably also through competition. It seems particularly important that M-A-R externalities are the only factor showing a positive impact when we isolated firms with important patents. For this 'innovative firm elite', the strong presence of innovative firms in the same industry and region allowed the creation of patenting cores that stimulated each other. Those might also have spilled over to small firms in other industries, rather than in the same industry where, instead, the presence of the 'innovative elite' might have increased barriers to entry for small firms.

The innovative activity of our firms seems to respond to different characteristics of knowledge conditions. When considering the whole sample, we found that innovative activity is related to accumulated knowledge and internal economies, thus supporting the Schumpeterian hypothesis and displaying key features of a 'routinized' technological regime. However, the importance of internal knowledge does not deny the positive impact of knowledge spillovers from other innovative firms in the same industry and region.

The innovative activity of small Baden firms displays features of an entrepreneurial technological regime, as it is not associated with internally accumulated knowledge, but rather with a wide knowledge base as indicated by the significance of the human capital variable. This finding is important, as it indicates that the excellent state of technical and commercial schools of 19th-century Baden significantly increased firms' successful patenting activities, and supports the established view that state intervention in the educational sphere was the single most important contribution to the development of an industrial system (Kocka and Siegrist, 1979). This suggests that the overdue upgrading of the current German higher education system would improve the overall productivity of the economy, and more specifically would increase the output of investment in research and development. Secondly, the greater importance of knowledge spillovers from technical and commercial schools, or universities, for small firms and the negative impact of taxes, point out two areas of public intervention which could be effective economic policy tools that would help small business to stand up to their larger counterparts in the Schumpeterian competition.

References

Abelshauser, W. (ed.) (2002), *Die BASF. Eine Unternehmensgeschichte*, C.H. Beck, München.

Acs, Z.J. and Audretsch, D.B. (1990) *Innovation and Small Firms*, MIT Press, Cambridge, MA.

Acs, Z.J., Audretsch D.B., and Feldman, M.P. (1994) R&D spillovers and recipient firm size, *The Review of Economics and Statistics*, **76,** 336-40.

Arrow, K.J. (1962) The economic implications of learning by doing, *The Review of Economic Studies*, **29,** 155-73.

Arundel, A. and Kabla, I. (1998) What percentage of innovations are patented? Empirical estimates for European firms, *Research Policy*, **27,** 127-41.

Audretsch D.B. and Feldman, M.P. (1996) R&D spillovers and the geography of innovation and production, *The American Economic Review*, **86,** 630-40.

Bairoch, P. (1988) *Cities and Economic Development: from the Dawn of History to the Present*, Mansell, London.

Baptista, R. and Swann, P. (1998) Do firms in clusters innovate more?, *Research Policy*, **27,** 525-40.

Baten, J. (2003) Creating firms for a new century: determinants of firm creation around 1900, *European Review of Economic History*, **7,** 301-29.

Beaudry, C. and Breschi, S. (2003) Are firms in clusters really more innovative?, *Economics of Innovation and New Technology*, **12,** 325-42.

Beer, J.J. (1959) *The Emergence of the German Dye Industry*, University of Illinois Press, Urbana, IL.

Borscheid, P. (1976), *Naturwissenschaft, Staat und Industrie in Baden, 1848-1914,* Klett, Stuttgart.

Breschi, S., Malerba, F., and Orsenigo, L. (2000) Technological regimes and Schumpeterian patterns of innovation, *The Economic Journal*, 110, 388-410.

Brezis, E.S. and Krugman, P. (1993) Technology and the Life-cycle of Cities, Working Paper No. 4561, NBER, Cambridge, MA.

Caves, R.E. (1982) *Multinational Enterprise and Economic Analysis*, Cambridge University Press, Cambridge, MA.

Dosi, G. (1988) The nature of the innovative process, in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds), *Technical Change and Economic Theory*, Pinter Publishers, London.

Erker, P. (1990) Die Verwissenschaftlichung der Industrie: Zur Geschichte der Industrieforschung in den europäischen und amerikanischen Elektrokonzernen 1890-1930, *Zeitschrift für Unternehmensgeschichte*, **35,** 73-93.

Fischer, W. (1989) Staat und Wirtschaft im 19. Jahrhundert, in O. Borst (ed.), *Wege in die Welt. Die Industrie im deutschen Südwesten seit Ausgang des 18. Jahrhunderts*, Deutsche Verlagsanstalt, Stuttgart.

Frank, H. (1994) *Regionale Entwicklungsdisparitäten im deutschen Industrialisierungsprozess 1949-1939: eine empirisch-analytische Untersuchung*, LIT Verlag, Münster - Hamburg.

Glaeser, E.L., Kallal, H.D., Scheinkeman, J.A., and Shleifer, A. (1992) Growth in cities, *The Journal of Political Economy*, **100,** 1126-52.

Handbuch (1992) *Handbuch der Baden-Württembergischen Geschichte*, vol. III, Klett Cotta, Stuttgart.

Homburg, E. (1992) The emergence of research laboratories in the dyestuff industry, 1870-1900, *British Journal for the History of Science*, **25,** 91-111.

Jacobs, J. (1970) *The Economy of Cities*, Penguin, London.

Kaiserliches Patentamt (various years), *Verzeichnis der im Vorjahre erteilten Patente*, Carl Heymanns Verlag, Berlin.

Kocka, J. and Siegrist, H. (1979) Die hundert größten deutschen Industrieunternehmen im späten 19. und frühen 20. Jahrhundert: Expansion, Diversifikation und Integration im internationalen Vergleich, in H. Horn and J. Kocka (eds) *Recht und Entwicklung der Großunternehmen im 19. unf frühen 20. Jahrhundert,* Vandenhoeck & Ruprecht, Göttingen.

Krugman, P. (1991) *Geography and Trade*, MIT Press, Cambridge, MA.

Kuznets, S. (1962) Inventive activity: problems of definition and measurement, in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity,* University Press, Princeton, NJ.

Liebenau, J. (1988) Patents and the chemical industry: tools of business strategy, in J. Liebenau (ed.), *The Challenge of New Technology: Innovation in British Business since 1850*, Gower, Aldershot.

Marshall, A. (1890, Ninth Variorum ed. 1961), *Principles of Economics*, vol. 1, Macmillan, London.

Meyer-Thurow, G. (1982) The industrialization of invention: a case study from the German chemical industry, *Isis*, **73,** 363-381.

Morck, R. and Yeung, B. (2001) The economic determinants of innovation, Occasional Paper No. 25, Industry Canada Research Publications Program, Ottawa.

Moser, P. (2005) How do patent laws influence innovation? Evidence from nineteenth-century world's fairs, *The American Economic Review*, **95,** 1214-36.

Murmann, J.P. (2003) *Knowledge and Competitive Advantage: The Coevolution of Firms, Technology, and National Institutions*, Cambridge University Press, Cambridge, MA.

Nelson, R.R. and Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*,

Harvard University Press, Cambridge, MA.

Pavitt, K. (1984) On the nature of technology, mimeo, SPRU, University of Sussex.

Porter, M.E. (1998) Clusters and the new economics of competition, *Harvard Business Review*, **76,** 77-91.

Romer, P. (1986) Increasing returns and long-run growth, *Journal of Political Economy*, **94,** 1002-37.

Schankerman, M. and Pakes, A. (1986) Estimates of the value of patent rights in European countries during the post-1950 period, *The Economic Journal*, **96,** 1052-76.

Shaver, M.J. and Flyer, F. (2000), Agglomeration economies, firm heterogeneity and foreign direct investment in the United States, Working Paper, New York University.

Scherer, F.M. (1983) The propensity to patent, *International Journal of Industrial Organization*, **1,** 107-28.

Scherer, F.M. (1984), Using linked patents and R&D data to measure inter-industry technology flows, in Z. Grilliches (ed.), *R&D, Patents and Productivity*, University of Chicago Press, Chicago.

Schumpeter, J.A. (1936) *The Theory of Economic Development*, Harvard University Press, Cambridge, MA.

Schumpeter, J.A. (1942, sixth ed. 1987), *Capitalism, Socialism and Democracy*, Unwin, London.

Sokoloff, K.J. (1988), Inventive activity in early industrial America: evidence from patent records, 1790-1846, *Journal of Economic History*, **48,** 813-50.

Statistisches Reichsamt (1909), *Statistik des Deutschen Reichs*, Putthammer & Muehlbrech, Berlin.

Streb, J. (2003) Shaping the national system of inter-industry knowledge exchange. Vertical Integration, licensing and repeated knowledge transfer in the German plastics industry, *Research Policy*, **32,** 1125-40.

Streb, J., Baten, J., and Yin, S. (2006) Technological and geographical knowledge spillover in the German industrialization, 1877-1918, *Economic History Review*, **59**, 347-73.

Streb, J., Wallusch, J. and Yin S. (2007) Knowledge spill-over from new to old industries. The case of German synthetic dyes and textiles (1878-1913), *Explorations in Economic History* (forthcoming).

Winter, S.G. (1984) Schumpeterian competition in alternative technological regimes, *Journal of Economic Behaviour and Organizations*, **5,** 287-320.

Unpublished sources

Verzeichnis der einer besonderen Aufsicht unterliegenden Fabriken und diesen gleichgestellten Gewerbebetrieben (1895, 1906), unpublished manuscripts, State library Karlsruhe and University Library Freiburg.

Fig. 1. Potential influences on patenting of firms in our model

Table 1. Firms in Baden and Germany (industry %)

Industry	Baden	Germany
Stone	10.4	15.5
Metal processing	22.5	11.1
Machinery/Instruments	9.6	11.6
Chemicals	1.4	1.9
Textiles	6.6	11.8
Paper	4.5	3.7
Leather	2.0	2.3
Wood	10.8	11.9
Food and tobacco	21.8	13.6
Apparel	5.1	8.5
Printing	4.4	4.5
Other	3.6	3.7

Note: Baden: firms with 10+ workers in 1906; Germany: firms with 11+ workers in 1907;

Sources: Baden: Verzeichnis (1906); Germany: Statistisches Reichsamt (1909), volume 213-1, p. 42-3.

Table 2. Number of important patents per firm in Baden

Patent per firm	Number of firms	Proportions
0	2,325	96.59
1	38	1.58
2	12	0.50
3	7	0.29
4	3	0.12
5	7	0.29
6	4	0.17
7	1	0.04
8	2	0.08
9	1	0.04
12	1	0.04
13	1	0.04
14	1	0.04
16	1	0.04
18	1	0.04
27	1	0.04

43	1	0.04

Source: Original composite dataset – see text.

Table 3. Top 25 patenting firms in Baden, active in 1906

Pat. [a]	Firm name	Year[b]	Place	Workers[c]	Industry
43	Lanz, Heinr.	1859	Mannheim	1924	Agric. machinery
27	Schnabel & Henning	1869	Bruchsal	737	Machinery
18	Bopp & Reuther	1872	Mannheim	815	Machinery, metal foundry
16	Geiger'sche Fabrik	1891	Karlsruhe	80	Bureau equipment
14	Bad. Maschinenfabrik AG, vorm. Sebold, H	1854	Durlach	480	Machinery
13	Kromer, Theodor	1868	Freiburg	93	Locks
12	Verein Chem. Fabriken	1854	Mannheim	802	Chemicals
9	Metallschlauchfabrik Pforzheim	1899	Pforzheim	90	Iron and steel
8	Eisenwerke Gaggenau	n.a.	Gaggenau	1044	Iron and steel
8	Boehringer, C.F. & Söhne	1859	Mannheim	452	Chemicals
7	Junker, Karl & Ruh, August	1868	Karlsruhe	615	Sewing machines and ovens
6	Fahr, J. G.	1870	Gottmadin-gen	150	Machinery
6	Ungerer, Karl Friedr.	1895	Pforzheim	17	Machinery
6	Schiesser, Jacques	1876	Radolfzell	545	Apparel
6	Spinnerei & Weberei Steinen	1836	Steinen	519	Cotton spinning & weaving
5	Maschinenfabrik vorm. Gritzner AG	1872	Durlach	2880	Machinery
5	Eirich, G.	1863	Hardheim	18	Machinery
5	Deutsche Metallpatronenfabrik	1873	Karlsruhe	1696	Munition
5	Stotz & Cie, Elektrizitaetsges. mbh	1891	Mannheim	93	Installation of electrical light & power
5	Strebelwerk Gmbh	1899	Mannheim	576	Iron foundry and machinery
5	Unionwerke AG	1891	Mannheim	304	Machinery
5	Vögele, Joseph	1836	Mannheim	337	Machinery
4	Benz & Cie Rhein. Gasmotorenfabrik AG	1882	Mannheim	922	Machinery
4	Hoffmann, F. & La Roche & Co.	1896	Grenzach	103	Chemicals
4	Schell, Wilh. Jr.	1896	Offenburg	93	Stone/Glass

Key: a= number of important patents; b= year of establishment; c= total number of workers in 1906.

Source: Original composite dataset – see text.

Table 4. Important patents per workers by industry in Baden

SIC		Patents 1907-13	Workers 1906	Patents per worker
20	Food products	2	9,319	0.02
21	Tobacco	3	13,264	0.02
22	Textile	17	29,524	0.06
23	Clothing	1	2,286	0.04
24	Lumber and wood products	0	3,730	0
25	Furniture	3	2,514	0.12
26	Pulp, paper and cardboard	1	7,134	0.01
27	Printing and publishing	1	4,867	0.02
28	Chemicals	25	4,695	0.53
29	Petroleum and coal products	0	36	0
30	Rubber and plastic products	3	3,955	0.08
31	Leather and leather products	1	4,669	0.02
32	Stone, Clay and glass products	6	13,932	0.04
33	Primary metal industry	18	5,624	0.32
34	Fabricated metal products	27	6,277	0.43
35	Industrial machinery and equipment	190	20,189	0.94
36	Electronic and other electric equipment	9	2,673	0.34
37	Transportation equipment	1	1,315	0.08
38	Instruments and related products	4	3,902	0.1
39	Miscellaneous manufacturing industries	17	22,136	0.08
	Total	329	162,041	0.2

Source: Original composite dataset – see text.

Table 5. Determinants of important patents per workers in Baden

Regression no.	**1**	**2**	**3**	**4**	**5**	**6**
Method	TSLS IV	TSLS IV	OLS	Tobit	Tobit	Tobit
Firms	All	All	All	All	With Patents	Small Firms
Mean of dependent variable	0.1030	0.1030	0.0838	0.0838	2.4605	0.0323
Industry dummies	Yes	No	No	No	No	No
Firm size (employees, logs)	0.0806*** (0.030)	0.0766*** (0.028)	0.0821*** (0.018)	1.786*** (0.36)	0.149 (0.18)	1.736 (1.76)
Employment in innovative firms, same industry (logs)	0.0203* (0.011)	0.0275*** (0.008)	0.0149** (0.006)	0.289** (0.14)	0.185* (0.093)	0.481 (0.37)
Employment in non-innovative firms, same industry (logs)	-0.0023 (0.011)	-0.0176* (0.010)	-0.0153*** (0.006)	-0.376** (0.19)	-0.0451 (0.14)	0.291 (0.66)
Employment in other industries (logs)	-0.0290 (0.042)	-0.0083 (0.041)	0.0275 (0.024)	0.670 (0.48)	0.268 (0.24)	5.229** (2.33)
Previous patents (dummy)	1.264*** (0.300)	1.393*** (0.310)	1.290*** (0.280)	6.260*** (1.28)		6.945 (4.36)
Herfindahl[a] (employees)	0.0120 (0.009)	0.0091 (0.010)	0.0024 (0.006)	0.0634 (0.30)	0.219 (0.23)	-1.528 (0.97)
Urbanization	0.0014 (0.002)	0.0012 (0.002)	-0.0002 (0.001)	-0.0063 (0.036)	-0.0142 (0.025)	-0.281** (0.13)
Pupils in technical education[a]	-0.9450 (0.840)	-1.3140 (0.820)	0.0318 (0.540)	30.23 (24.50)	4.416 (20.59)	189.9** (89.2)
Rhine (dummy)	0.0241 (0.035)	0.0026 (0.033)	0.0057 (0.021)	0.453 (1.41)	0.741 (1.27)	4.617 (3.78)
Taxes (dummy)	-0.0233 (0.049)	-0.0068 (0.042)	-0.0108 (0.029)	-1.754 (1.31)	-0.504 (1.27)	-7.565* (4.22)
Wage (logs)	0.2440 (0.220)	0.2230 (0.220)	0.0678 (0.150)	-0.702 (5.63)	2.011 (4.09)	-3.201 (13.3)
Age[a] (logs)	0.0122 (0.047)	-0.0109 (0.045)	-0.0565* (0.034)	-1.543 (1.500)	-2.444*** (0.90)	-2.809 (3.72)
Constant	-1.378 (1.11)	-1.268 (1.14)	-0.727 (0.75)	-17.75 (27.7)	-10.80 (20.16)	-43.54 (62.8)

Observations	1156	1156	2407	2407	82	1690
R-squared	0.27	0.24	0.15	0.19	0.07	0.11

Notes: Robust standard errors in parentheses. Symbols *, **, *** besides parameter estimates indicate, respectively, statistical significance at the 10%, 5% and 1% levels. TSLS (Columns 1 and 2) and OLS (Column 3) are estimated with standard errors adjusted for heteroscedasticity. R-squared refers to the Pseudo-R-square in the case of the Tobit regressions (Col. 4 to 6); a = variable rescaled for presentation purposes by dividing it by 100.

Columns 1 and 2: instrumented variable = Firm size; Instruments = Employment in innovative firms, same industry; Employment in non-innovative firms, same industry; Employment in other industries; previous patents; Herfindahl; Urbanization; Pupils in technical education; Rhine; Taxes; Wage; Age; all industry dummies log employment in 1895.

Industry dummies included: SIC 20 (Food and kindred products); SIC 21 (Tobacco products); SIC 22 (Textile mill products); SIC 23 (Apparel and other finished products made from fabric and similar materials); SIC 24 (Lumber and wood products); SIC 25 (Furniture and fixtures); SIC 26 (Paper and allied products); SIC 27 (Printing, publishing and allied products); SIC 28 (Chemicals and allied products); SIC 29 (Petroleum, refining and related industries); SIC 30 (Rubber and miscellaneous plastics products); SIC 31 (Leather and leather products); SIC 32 (Stone, Clay, Glass and Concrete products); SIC 33 (Primary metal industries); SIC 34 (Fabricated metal products); SIC 35 (Industrial and commercial machinery and computer equipment); SIC 36 (Electronic and other electrical equipment and component); SIC 37 (Transportation equipment); SIC 38 (Measuring, analysing and controlling instruments; Photographic and optical goods; Watches and clocks).

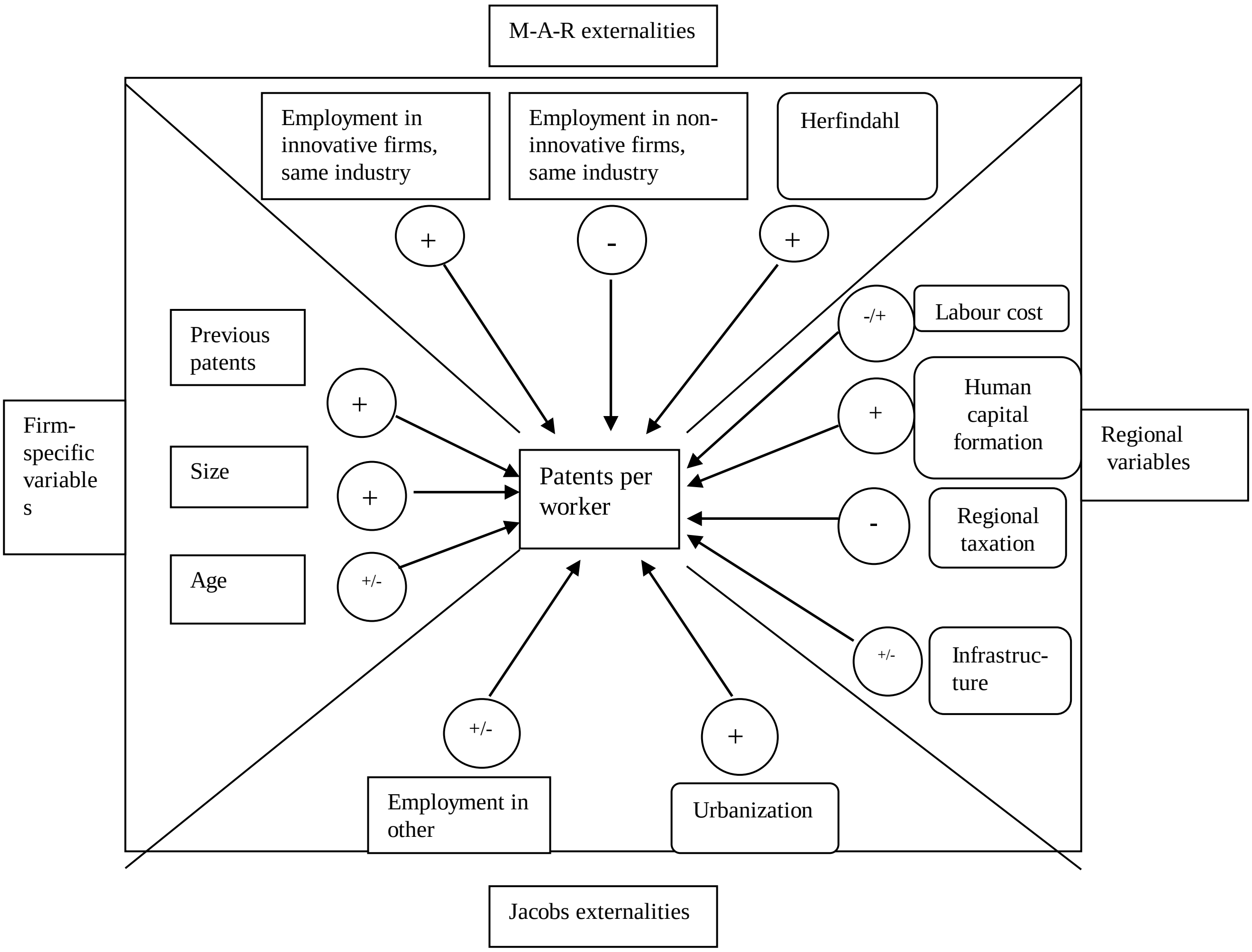
Joint F-Test of Industry Dummies

$F(19, 1124) = 1.19$

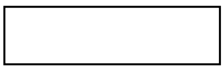
$Prob > F = 0.2557$

F-Test of all industry dummies is insignificant.

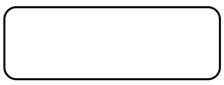
Fig. 1. Potential influences on patenting of firms in our model



Legend



Individual firm variable, or industry-and-region specific



Regional variable