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Abstract:
Entry into an industry often clusters in regions where the industry is already concentrated, which is suggestive of agglomeration economies. Regional public research activities may exert another attracting force on entrants into science-based industries. Empirically these proximity effects are confounded by other influences on where entrants originate and locate. This paper begins to disentangle the effects of agglomeration, public research, and the supply of capable entrants for the German laser industry. Our findings indicate that the industry's geography was shaped by the local availability of potential entrants rather than localization economies. The impact of public research increased over time.

Keywords: Industry clusters, agglomeration economies, public research, entry, heritage.

JEL classifications: L26, M13, R30.

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1. Introduction

The geographical concentration of industries has gained much attention in recent years. Still, the factors and processes underlying cluster formation and development are imperfectly understood. Major problems result from ambiguous effects present in regional clusters that make it difficult to identify particular factors and disentangle intertwined relationships.

Beginning with Alfred Marshall (1920), theories of geographical concentration have been advanced that highlight agglomeration economies, i.e. positive externalities resulting from co-location (cf., e.g., Belleflamme et al., 2000; Brenner, 2004). However, not all observable clustering is necessarily the result of agglomeration economies. Recent work suggests that prominent clusters in historical as well as contemporary industries may primarily have been brought about by diversification and spin-off activities that enabled the transfer of organizational competences between specific firms and industries located in a region (Klepper, 2007, 2008; Buenstorf and Klepper, 2008). According to this "heritage theory" of cluster formation (Buenstorf and Klepper, 2008), geographical imbalances are perpetuated because regions with more and better incumbent firms have a larger "birth potential" (Carlton, 1979) for new entrants, and geographically concentrated entry may be observed even if there are no objective advantages of locating in the respective regions.

In science-based industries, firm origination and entry may moreover be influenced by public research activities. There is a rich literature suggesting that regions with more and better public research are more successful in private-sector innovation (Jaffe, 1989; Salter and Martin, 2001). The prospect of beneficial knowledge spillovers may induce entrants to locate in research-intensive regions (Audretsch et al., 2005). Universities and other public research organizations also increase the regional pool of potential entrants, as their researchers may engage in entrepreneurial activities, (Shane and Stuart, 2002).

In this paper we study the geography of firm origination and entry in the German laser industry. We adopt the basic framework developed by Klepper and Buenstorf (2006) to empirically distinguish differences in regional birth potentials for new entrants from the effect of agglomeration economies, and extend it to account for the impact of

public research on firm origination and entry. Our dataset encompasses the full population of commercial producers of laser sources in Germany over the 40-year period from the industry's beginnings to 2003.

The German laser industry is well-suited for this type of analysis because entry has persisted throughout the industry's history. Entrants into the industry were heterogeneous in their backgrounds. Diversifying *de alio* entrants from other industries, spin-offs organized by former employees of existing laser producers, and academic startups formed by researchers of universities and public research institutes accounted for the bulk of entry (Buenstorf, 2007).

In the period under investigation, the industry experienced substantial environmental changes at the micro and macro levels. Germany's reunification in 1990 altered the sets of potential entrants as well as relevant locations. At a more micro level, a rise in the relative importance of spin-offs and academic startups is observable in the 1990s. To allow for these changes to have affected the dynamics of firm origination and entry, we distinguish between the two periods up to and after 1989 in the empirical analysis. This also enables us to study whether the influences on firm origination and entry changed as the industry became more mature.

We find that the vast majority of entrants into the German laser industry located close to their geographic "roots." The analysis of where entrants originated suggests that the geography of the industry has strongly been shaped by differences in regional birth potentials favoring or limiting the origination of the various types of entrants. Our results indicate a limited role of agglomeration effects. While the analysis does not suggest effective localization economies, there is some evidence of urbanization economies. The importance of public research apparently went beyond its role in supplying potential entrants, and increased systematically over the lifetime of the industry.

The next section develops the analytical framework underlying the study. Section 3 briefly introduces the German laser industry. Dataset and empirical approach are discussed in section 4. Section 5 presents our findings. Section 6 concludes.

2. Agglomeration, Spillovers, Heritage and Entry

We follow Figueiredo et al. (2002) in distinguishing the location of where entrants originate from their actual location of entry. Both *de alio* and *de novo* entrants have geographic roots, which below we will refer to as their location of origination or synonymously their "home region." For *de alio* entrants (diversifying pre-existing firms), this is the location of their prior production facilities. For *de novo* entrants, it is the prior workplace of their founder(s) – in our firm population, mostly a university or an existing firm in the laser industry.

Taking into account the geographic origins of entrants, agglomeration economies may induce regional concentrations of entry in two different ways. One possibility is that irrespective of where they originate, entrants are drawn to locate into agglomerated regions. If Marshallian localization economies (Marshall, 1920) are powerful drivers of location choices, entrants will want to co-locate with other firms in their industry, which allows them to benefit from knowledge spillovers, labor pooling, as well as closer ties to specialized suppliers and customers. Entrants may also be induced to locate in more urbanized regions featuring a diverse set of economic activities, where business services are easier to source and innovation is spurred by the cross-fertilization of ideas across industries (Jacobs, 1969; Glaeser et al., 1992). Finally, the presence of universities within a region provides valuable advantages to the region and may, given geographical "stickiness" of knowledge, be a reason for establishing firms in close proximity (Zucker et al., 1998; Blind and Grupp, 1999). Regional public research activities should be particularly important in science-based industries such as laser manufacturing. Universities and other public research facilities are sources of knowledge spillovers as well as of human capital (Jaffe, 1989; Fritsch and Slavtchev, 2007). Proximity to public research moreover facilitates the cooperation with academics (Fritsch and Franke, 2004).

Empirical evidence suggests that agglomerated regions exert an attracting force influencing the location choices of new firms locating outside of their home region (Figueiredo et al., 2002), locations of branch plants (Smith and Florida, 1994; Head et al., 1995; Klier and McMillen, 2008), and also relocations of existing firms (Buenstorf and

Guenther, 2007).[1] Audretsch et al. (2005) show that entry of high-technology startups in Germany concentrated in the vicinity of universities.

However, the practical importance of regional factors attracting entrants from other regions is limited by the lack of mobility of firm founders. The majority of entrants locate close to where they originated (Figueiredo et al., 2002; Dahl and Sorenson, 2008). This indicates that entry outside an entrant's home region is costly, which may be due to economic or social factors. The tendency to enter in the home region notwithstanding, agglomeration economies or knowledge spillovers from public research may still lead to geographically concentrated entry, as they may increase the share of potential entrants in a region that actually find it profitable to enter. This constitutes the second process through which regional conditions may affect entry.

As long as there is a cost to entry outside the region of origination, regional conditions may also influence the *origination* of entrants. In the extreme case that all entrants locate in their home region, improving conditions in a region will only increase the share of potential entrants in this region that actually enter (but not the share of potential entrants elsewhere). As a consequence, among all entrants into the industry, the fraction of those that originate (and enter) in this region will also increase, which leads to concentration. Under less extreme conditions allowing for entry outside the home region, improving conditions in one region may induce potential entrants from this and other regions to enter there. Nonetheless, it can be shown that the effect is strongest for potential entrants in the respective region, because for them the improvement in regional conditions is not "filtered" by the cost of moving away from the home region (Buenstorf and Klepper, 2006). Again, this increases the fraction of entrants into the industry that originate in the respective region.

It would be premature, however, to attribute all inter-regional differences in the numbers of indigenous entrants to agglomeration economies or knowledge spillovers from public research (Buenstorf and Klepper, 2006). Unevenly distributed entry rates may simply reflect what Carlton (1979) refers to as the regional "birth potential" for new entrants. According to this account, which presupposes that entrants mostly locate in their

[1] The empirical record for new entrants is limited because information on where firms originate is often unavailable.

home region, regions primarily differ in the number of potential entrants rather than the share of potential entrants that actually enter.

Underlying the "birth potential" concept is the recognition that entry, particularly into sophisticated industries such as laser manufacturing, presupposes access to specific capabilities. To an important extent these capabilities have been acquired through the entrant's own past experience (Helfat and Lieberman, 2002). Entrepreneurship research has found that prior knowledge conditions opportunity discovery, as well as the specific way in which the discovered opportunity is exploited (Shane, 2000). Scientific expertise accumulated in public research is an important source of knowledge underlying opportunity discovery. In addition, existing firms in the industry enable their employees to acquire relevant knowledge and to become entrepreneurs (Klepper, 2001). In this way, they (involuntarily) make an important contribution to the regional birth potential of (spin-off) entrants. While the spin-off process causes a transfer of capabilities from the parent firm to the spin-off, capabilities may also be transferred within existing firms through diversification into related markets (Teece et al., 1994; Klepper and Simons, 2000).

Differences in regional birth potentials accordingly derive from regional differences in the endowments of sources of successful entrepreneurship and diversifying entry. The likelihood that spin-offs originate in a region increases with the number and quality of incumbent firms active in the same industry. Similarly, more diversifiers are expected in regions that have a larger number of incumbent firms in related industries, and the extent and quality of public research activities in a region should increase the likelihood of academic startups originating there. Put differently, if prior activities that enable new entry into the industry – i.e., shape the regional birth potential for new entrants – are unevenly distributed in space, then regional differences in firm origination are to be expected even if powerful agglomeration economies are absent.

Characteristically, a region may have a substantial birth potential for one type of entrant but not for another, for example if it has existing producers in the target industry (i.e., sources of spin-off activities) but no university that does research relevant for the industry (i.e., no source of academic startups). Our subsequent empirical analysis will be based on this premise that regional birth potentials may differ between types of entrants.

Not only may birth potentials for new entrants vary across regions, they also change endogenously over the lifetime of an industry. The "heritage theory" of cluster formation proposed by Buenstorf and Klepper (2008) suggests that the spin-off process gives rise to self-reinforcing differences in regional birth potentials, as the spin-offs spawned in a region become themselves sources of potential new spin-offs. The heritage theory can account for regional patterns of firm origination and longevity in the historical U.S. tire industry (Buenstorf and Klepper, 2008). Further corroborating evidence has been provided for the historical U.S. automobile industry and its famous concentration in and around Detroit (Klepper, 2007), as well as for the emergence of Silicon Valley as the global center of the semiconductor industry (Klepper, 2008).

In the remainder of this paper, we will assess the role of agglomeration economies, public research, and regional birth potential in the evolution of the German laser industry. To date, this industry has been characterized by sustained entry, but it developed to be much less strongly concentrated in space than the U.S. tire, automobile, and semiconductor industries.

3. The origination and location of entrants into the German laser industry

Our analysis encompasses the full population of German laser source manufacturers active between 1964 and 2003, a total of 143 firms. These have been identified through listings in laser buyers' guides, trade publications and trade fair catalogs, with substantial validation efforts to exclude importers and distributors (cf. Buenstorf, 2007, for a detailed description). We employ information on firms' location of entry as well as their geographical origins, and distinguish entrants into different categories according to their pre-entry experience. In addition, the firm population is divided into two groups based on their years of entry into the industry, reflecting the political and economic changes occurring after 1989 (cf. Table 1). 45 firms entered in the years up to 1989, whereas the group of later entrants consists of 98 firms.

In the pre-1990 group, 24 entrants (53%) were diversifiers from related industries or had previously been active as importers of foreign-made lasers, 12 (27%) were spin-offs from existing laser firms, 5 (11%) were startups organized by entrepreneurs coming from universities or public research institutes, and 2 (4%) were startups whose founders

had no apparent background in either the laser industry or in academia. Two entrants (4%) were of unknown background. For the post-1990 group the numbers are 32 (33%) for diversifiers/importers, 36 (37%) for corporate spin-offs, 23 (23%) for academic startups, 5 (5%) for other startups, and again 2 (2%) for unknown background. These numbers indicate that spin-offs and academic startups have become increasingly relevant in the German laser industry, while the relative importance of diversifying *de alio* entry have decreased over time. This is consistent with the notion of an endogenous and evolving birth potential for new entrants.

The majority of spin-offs are "involuntary" (Helfat and Lieberman, 2002) in that they are independent companies that were not started on the initiative of the parent firm's management. Their location choices can thus be presumed to be independent of the parent firms' prerogatives. Ten spin-offs were organized by individuals who had previously (co-) founded another laser firm, i.e. they are based on serial entrepreneurship within the laser industry.

To delineate regions in the geographical analysis, we utilize the official definition of currently 97 *Raumordnungsregionen* (ROR), which balances functional adequacy and data availability.[2] Entry is observed in 46 out of the 97 ROR (47 %), but mostly concentrates in a small number of regions. Munich is the leading region in terms of entrants (27 entrants or 19%), followed by Berlin (20 entrants or 14%) and Hamburg (eight entrants or 6%). Note that these are Germany's three largest cities.

Over time, a substantial geographical shift in activities is discernible. While Munich's share of entrants decreased from 27 % in the first period to 15% in the post-reunification period, the share of entrants in Berlin is higher after 1990 than it was before (18 % versus 4%). Qualitative evidence suggests that the rising number of laser entrants in Berlin reflects two separate developments. On the one hand, the *Technische Universität* Berlin located in the Western part of the city had been a prominent early center of laser research, but the director of its laser research group actively discouraged industry interaction and technology transfer activities (Albrecht, 2001). Accordingly, entry of laser firms from academic backgrounds in Berlin (as well as subsequent spin-off entry) became substantial only in the second period of analysis. On the other hand,

[2] *Raumordnungsregionen* aggregate *Landkreise* (NUTS-III regions) according to commuter flows.

several among the post-1990 entrants in Berlin can be traced back to laser research activities in the previously socialist East, where the *Akademie der Wissenschaften* had concentrated its laser research. When the *Akademie der Wissenschaften* was closed down after reunification, its former researchers became an important source of laser entrepreneurs in Berlin.

Six out of the 143 entrants in the German laser industry had origins outside Germany; most of them started as spin-offs of foreign laser producers (Buenstorf, 2007). We could not obtain reliable information about the backgrounds of another five firms, which leaves us with a total of 132 firms with known domestic origins. It is striking that the vast majority of these entrants located close to their geographic roots. 106 (80 %) entrants located in the same ROR in which they originated; 33 (83 %) in the period before 1990 and 73 (77 %) after 1990. Seven entrants located in a ROR contiguous to their home region.

Some of the location choices farther away from an entrant's home region reflect earlier personal or professional links to the respective region. For example, Kristian Hohla, a prominent spin-off founder and serial entrepreneur in the German laser industry, located his first firm not where his prior employer was based (Göttingen) but in Munich, where he had previously been employed in public research. Another spin-off founder in our dataset, Klaus-Michael Zimmermann, had worked for a laser producer located outside Hamburg, but started his own venture in his native city of Freiburg.

These patterns show that even in this industry, where entrepreneurial activities are generally more ambitious than in most of the trades or service industries, location choices are dominated by where entrants originate, or by other factors in the biography of entrepreneurs. This "home bias" is not necessarily an indication of haphazard or short-sighted location choices. In line with the conceptual considerations made above, it may indicate substantial costs of location outside the region of origination, which is consistent with the findings of Dahl and Sorenson (2008) and suggests that accounting for where an entrant originated is an important component of an appropriate location model. At the same time, given this tendency of entrants to locate close to their roots, understanding where entrants originate is the key to understanding the evolving geography of this

industry. Our subsequent econometric analysis will therefore study location choices as well as, in a second step, the factors shaping where entrants originated.

4. Analysis of entry and origination: approach and variables

In our analyses of location choice and origination we employ the conditional logit framework that, following Carlton (1983), is commonly used in studies of entry (cf., e.g., Shaver and Flyer, 2000; Figueiredo et al., 2002; Dahl and Sorenson, 2008). Our aim is to explain where entrants entered and originated, but not their changing number or the composition of firm types. This kind of information is exactly what the conditional logit provides. It estimates coefficients for the effects of regional characteristics such that for each known entrant *i*, the likelihood is maximized that it chose the location it actually entered in (analysis of entry), respectively the likelihood that it originated in its actual region of origination (analysis of origination).[3]

$$p_{ijt} = \frac{\exp\{\underline{x}'_{ijt-1}\underline{\beta}\}}{\sum_j \exp\{\underline{x}'_{ijt-1}\underline{\beta}\}}$$

Regional characteristics of all potential regions of origin *j* at time *t*-1 enter into the analysis, where *t* is given by the year that the respective entrant originated. Except for population density, all explanatory variables are normalized by using the regional percentages of the respective year (cf. Table 2 for descriptive statistics). We focus the analysis on the 132 firms that we know originated in Germany and use a set of six dummy variables to control for unobserved heterogeneity at the level of individual or grouped *Länder*.[4] In the pre-1990 period, the analysis includes all 75 RORs in West Germany and Berlin (West). In the second period, all 97 German RORs are included. We also present results from pooled models, in which early and late entrants are distinguished

[3] A well-known limitation of the conditional logit methodology is the assumption that the likelihood of individual choices is independent of irrelevant alternatives (IIA; cf., e.g., Wooldridge, 2002). To check whether our results are robust, we re-ran our models on restricted subsets of alternatives. In particular, we varied our models in three alternative ways, excluding, respectively, all regions without observed entrants into the industry, all regions in Northern Germany including Hamburg, and all regions in Bavaria. These experiments yielded very similar results to those reported below.

[4] The dummy variables are: Baden-Württemberg, Bayern, North Rhine-Westphalia, Northern Germany including Hamburg, Berlin/Brandenburg, Saxonia/Anhalt/Thuringia (post-1990 analysis only). The Hesse/Rhineland-Palatinate/Saar region is the omitted control group.

through interaction terms. These models are limited to a restricted choice set of West German regions (including (West) Berlin) and the entrants originating or entering there.

We first study potential effects of agglomeration and spillovers from public research on the locations where German laser manufacturers entered. Following Figueiredo et al. (2002), an indicator variable is used to control for the home region of each entrant. This provides a measure of how regional characteristics affect entry conditional on where entrants originated, which seems important given the pervasive "home bias" in location choice. Again following these authors, we also interact the measures of regional characteristics with the home region variable. In this way, regional characteristics are allowed to have different effects on entrants that locate in the region where they originated versus those that located elsewhere.

We then turn to a geographical analysis of origination, trying to separate effects of agglomeration from differences in regional birth potential. Doing so is complicated by the fact that both are driven by similar factors. For example, the regional presence of other firms active in the same market can give rise to Marshallian localization economies. At the same time, industry incumbents are the source of spin-off activities and thus a major determinant of the regional birth potential for new firms in the industry.

To distinguish both kinds of effects, we adopt the approach developed in Buenstorf and Klepper (2006), which is based on whether or not the effects of explanatory variables differ between the types of entrants. Specifically, we conjecture that since agglomeration economies and knowledge spillovers from public research affect the objective conditions faced by a prospective entrant in a given region, they should have similar effects on all entrants irrespective of their backgrounds. Without further assumptions, there is no compelling reason why differences in pre-entry backgrounds should affect firms' abilities to benefit from agglomeration and proximity to public research, and thus their expected profitability of entry in a given region. For example, traditional Marshallian localization economies stemming from labor pooling, specialized suppliers and knowledge "in the air" constitute positive externalities for all local firms. Accordingly, if the presence of industry incumbents in a region affected the origination of new entrants mainly through its effect on localization economies, i.e. on the expected profitability of entry, then we would expect this effect to be similar across the different

types of entrants. Similar arguments hold for urbanization effects as well as the benefits arising from the proximity to public research.

In contrast, the regional availability of potential entrants is type-specific. If only birth potential but no localization economies were at work, regions with more industry incumbents should have more potential spin-offs, while *ceteris paribus* the origination of diversifiers or academic startups should be unaffected. Diversifiers would instead be expected to originate in regions with large numbers of firms in related industries, and academic startups should originate where there are centers of laser research in universities and public research institutes.

We translate these considerations into the empirical analysis of firm origination as follows. We collected regional data on the number of active laser manufacturers, firms in laser-related industries, as well as relevant public research activity. To investigate whether the effects of regional characteristics differed across entrants with different backgrounds, we interact these variables with dummy variables denoting the various types of entrants (diversifiers, spin-offs, academic startups). Finding that the interacted regional variables only have significant effects on those types of entrants whose birth potential is shaped by them would be interpreted as evidence in favor of the heritage theory, whereas more uniform effects across types of entrants would suggest effective localization economies and spillovers from public research. We also include a measure of urbanization economies. The individual variables are defined as follows:

Laser manufacturers: The presence of other laser manufacturers in a region may underlie localization economies. In the origination analysis, laser manufacturers also measure the regional supply of potential spin-off entrants. This variable is constructed from our data on firm entry and exit years in the laser industry (Buenstorf, 2007), corrected for firm relocations across ROR boundaries.

Related firms: The regional presence of firms in related industries is expected to increase the number of potential diversifiers originating in that region. Our measure of related firms is based on the same primary sources employed to identify laser producers. However, here we counted all listed firms active in the broader optics sector (excluding active laser producers), as well as firms from potential customer sectors of laser producers (e.g., producers of laser equipment for health care applications). Foreign

producers are included if they were listed with a German address (and hence had at least a sales office in Germany, which determined the ROR they were assigned to). The total number of related firms over all years and regions is 2,046.

Laser-related public research: Universities and other public research facilities are sources of knowledge as well as of human capital. Through their effects on the expected profitability of producing in a region, universities may thus influence where firms originate and enter. Similar to agglomeration effects, these effects of university proximity would be expected to affect all types of entrants. In addition, universities also are important sources of potential entrants. Academic startups account for a substantial share of entry in the German laser industry. Following the heritage theory, their origination patterns, but not those of other types of entrants, should reflect the presence of laser-active universities in a region.

We measure regional laser-related research activity by counting all laser-related Ph.D. dissertations submitted at universities in the region, a total of 6,385 for the time period under investigation. This variable has the advantage that it also reflects research activities in non-university research organizations such as the Fraunhofer and Max Planck Societies.[5] We take our information about dissertations from the public catalog of the *Deutsche Nationalbibliothek* (DNB), which covers years of appearance and university affiliation as well as title and author of the dissertation. Depositing a copy of their dissertation at the DNB is mandatory for all Ph.D.s in Germany. Laser-related dissertations were identified on the basis of titles and keywords. Because of substantial short-run variation, we aggregate dissertation counts over a moving three-year window.

Population density: We use population density based on annual census data as our measure of urbanization economies. Urbanized regions are usually characterized by a well-developed infrastructure in terms of transportation, business services, and information exchange. Based on a more varied business environment, producers in urbanized regions may also be more innovative than those located in rural areas. Logarithms of population density are used because due to administrative reasons a few

[5] Since only universities have the right to grant Ph.D.s in Germany, Ph.D. students at non-university public research institutes obtain their degrees from (mostly local) universities.

urban *Raumordnungsregionen* have artificially high population densities (in particular, Berlin and Hamburg).

5. Results

We begin by analyzing whether the location choices of entrants into the German laser industry are suggestive of agglomeration economies and spillovers from research. To check the robustness of findings in the presence of substantial correlation among the explanatory variables (cf. Table 3), we estimate a series of alternative model specifications.

Our baseline model (Model 1 in Table 4) includes the measures of localization (laser manufacturers per region) and urbanization (population density). Sizable and significantly positive coefficients are estimated for both variables in both periods. In Model 2, we add the dissertation variable to the model specification. We obtain positive and highly significant coefficient estimates for this variable, suggesting that more entrants located in regions with more extensive laser-related research activities. The effect of laser research on location choices appears to be stronger for the later entrants.[6] Including the dissertation variable reduces the coefficient estimates for the agglomeration measures, particularly for the localization variable, which loses its significance. This indicates Model 1 may overestimate the effects of agglomeration.

In Model 3, we add the indicator variable denoting the region of origin of each entrant. Including this variable dramatically increases the explanatory power of the model, and the coefficient estimate of the indicator variable is highly significant. In contrast, none of the regional characteristics is still significant in either time period. Put differently, conditional on where firms originated there is no discernible influence of regional characteristics on where they located.[7] To probe this finding in a little more

[6] We also estimated a pooled model of location choices over the entire time period under investigation, using interaction terms to distinguish early versus late entrants. This yielded a significantly (at the 0.01 % level) larger coefficient estimate for the dissertation variable in the post-1990 period. No significant changes over time were found for the agglomeration variables.

[7] We also estimated an (unreported) variant of Model 1 that included the indicator variable denoting each entrant's region of origin, but not the dissertation variable. Similar to Model 3, this model suggested no systematic effects of agglomeration on entry (conditional on origination). In a pooled model using the same variables as Model 3 and restricting them to have the same effect over the entire time period under investigation, no significant effects were found except for the home region indicator.

detail, we estimate another model (Model 4) interacting regional characteristics with the home region indicator. This does not alter the qualitative results for the regional characteristics obtained in Model 3; apparently neither the decision to enter in the region of origination nor the choice among other locations was systematically affected by the regional characteristics included in our models. Throughout the models, the (unreported) individual *Länder* dummies are insignificantly different from zero.[8]

The main implication of the analysis of entry is that, in line with the qualitative evidence reported in section 3, location choices were dominated by where the respective entrant had originated. This indicates that understanding the factors shaping the origination of entrants is the key to understanding the evolving geography of the German laser industry. We therefore turn to analyzing the characteristics of regions where entrants originated, again using the conditional logit methodology (Buenstorf and Klepper, 2006).

The initial model of firm origination (Model 5 in Table 5) includes as explanatory variables the regional percentages of laser manufacturers and of laser-related dissertations. As was argued above, these variables might reflect two different influences on the origination of entrants. One possibility is that they measure, respectively, localization economies and knowledge spillovers from public research. Alternatively, in line with the predictions of the heritage theory, existing laser producers and public research activities might affect the origination of entrants through their effect on the pool of potential entrants. To distinguish between these explanations, we explore whether the two variables differ in how they affect the various types of entrants. To this purpose, both variables are interacted with dummy variables indicating spin-offs, diversifiers, and academic startups. We also allow for the regional presence of laser-related firms to influence the origination of diversifiers, which is what the heritage theory predicts. Again, the model is estimated separately for the time periods before and after 1990, with the set of *Länder* dummies included in the specification. Given the small number of other *de novo* entrants (start-ups with no apparent background in academics or the laser industry; cf. Table 1), they are dropped from the analysis.

[8] All entry models were re-estimated without the *Länder* dummies. Except for finding significant localization effects in the analog to Model 2, this had no qualitative effect on our results.

The estimation results indicate, in line with the predictions of the heritage theory, that the regional presence of established laser producers had a positive influence on spin-off origination in both periods. Regions with more laser-related firms experienced higher rates of origination of diversifiers, and the origination of academic startups was positively influenced by regional laser research activities.[9] Research activities moreover seem to have influenced the origination of diversifiers (in both periods) and of spin-offs (in the second period). This suggests that the impact of public research activities went beyond supplying potential laser entrepreneurs.

Thus, in Model 5 the number of laser manufacturers in a region is positively related only to the origination of spin-offs, but not diversifiers or academic startups (for which we even estimate a marginally significant negative coefficient estimate in phase 2). This is difficult to explain if the co-location of laser producers gave rise to substantial localization economies, because these should have benefited all entrants irrespective of their background. In contrast, our evidence suggests that public research activities not only spurred the origination of academic spin-offs, but also affected diversification and possibly spin-off activities.

We estimate another model (Model 6) testing for the presence of urbanization economies (measured by population density), which we also allow to have different effects on the alternative types of entrants. The results of this model suggest that more entrants originated in more urbanized regions. Significantly positive coefficients are estimated for all types of entrants except for spin-offs in the early time period. Even though German universities are mostly located in urbanized regions, including the urbanization measure only leads to minor changes in the coefficient estimates for the research variable. (The effect of laser research on spin-off activities in phase 2 loses its significance, however.)

In contrast to the previous models, in Model 6 we obtain in the pre-1990 period a sizable and significantly negative coefficient estimate for the region dummy denoting

[9] Since our theoretical considerations do not predict effects of laser-related firms on spin-offs or academic startups, in the interest of obtaining more precise estimates we refrained from including the respective interactions in Model 5. The (unreported) results of alternative model specifications including them indicate that the presence of laser-related firms is indeed related only to the origination of diversifiers, but not to the origination of the other types of entrants.

Berlin.[10] Given that Berlin had the highest population density of all German regions, and also was an important center of laser research (see section 3 above), the Berlin dummy might affect the overall results obtained in Model 6. We accordingly re-estimated the model without the *Länder* dummies (Model 7). The results of this model indeed suggest a much smaller role of urbanization economies, particularly in the early years before 1990. In addition, laser research no longer has a significant effect on the origination of academic startups in phase 1. These differences to Model 6 are consistent with what we know about laser research and (the lack of) laser entrepreneurship in pre-reunification Berlin (West).

Comparing the results of Models 5-7 across the two time periods suggests that the influences on the origination of entrants substantially changed as the industry matured. To analyze the temporal developments more systematically, we estimated a set of pooled origination models that cover the entire lifetime of the laser industry and distinguish entrants in the two time periods through interaction terms (Models 8-10 in Table 6). As was noted above, aggregating the two time periods requires that East German regions outside Berlin, as well as entrants originating there, be excluded from the analysis. Another difference to the earlier models is that the *Länder* dummies in Models 8 and 9 are constrained to have the same effect in both phases. The exception is again Berlin, for which two separate dummies were estimated for the pre- and post-reunification years (the latter including the surrounding Brandenburg).

The results of these models are generally similar to those obtained before. Given the larger number of entrants in the later period, the estimates of the *Länder* dummies are dominated by this period, somewhat compromising the precision of first-period results in Models 8 and 9. The second-period results are hardly affected by the exclusion of East German entrants and locations. However, our main interest in these models regards the development of effects over time, i.e. the differences between the coefficient estimates obtained for early versus late entrants. The most substantial differences are found for the effects of public research. Throughout Models 8-10, regional laser research activities influence the origination of both, diversifiers and academic startups, significantly

[10] Given its status as an independent *Land* as well as its insular location surrounded by socialist East Germany before 1990, Berlin cannot meaningfully be aggregated with other regions.

stronger in the later time period (the difference is significant at the 0.05 % or lower), suggesting stronger science-industry interactions after reunification.[11]

6. Discussion and conclusions

Entrants into high-tech industries such as lasers require capabilities that enable them to successfully compete. In the German laser industry, the majority of entrants came from three kinds of backgrounds: pre-existing firms in related industries (including laser import and distribution) diversified into laser manufacturing, spin-offs were organized by employees of laser incumbents, and academic startups were founded by scientists employed in public research. The small number of *de novo* entrants whose background was less intimately related to laser production or research is already noteworthy. It resonates with the notion of regional birth potential that figured prominently in the empirical analysis presented above, indicating that the number of potential entrants possessing the requisite capabilities to compete in the laser industry was indeed limited.

Investigating the geographical roots of entrants, we found that more than three-quarters of them located in the same region where they originated. This result runs counter to the view that contemporary high-tech entrants are highly mobile in space, and that jurisdictions compete in attracting these entrants. However, it resonates with earlier findings obtained in other empirical contexts (Buenstorf and Klepper, 2008; Dahl and Sorenson, 2008). It also suggests that where firms originate is a key determinant of where the respective industry ends up concentrating, a conjecture that was corroborated in the econometric analysis of entry. Our baseline models of entry illustrate the importance of controlling for where entrants originate. They seem to suggest a systematic influence of regional conditions on location choices, but no evidence of this influence remains after the entrants' home regions are accounted for in the analysis.

In the analysis of origination, substantial differences were found in what factors were associated with what type of entrant. The results of the analysis were in line with the predictions made by the heritage theory of origination. Diversifiers originated primarily where there were many related firms, spin-offs mostly originated in regions

[11] Marginally significant (at the 0.10% level) increases in coefficient estimates are obtained for the effect of related firms on diversification in Models 8 and 10, as well as for the effect of existing laser firms on spin-offs in Model 8. All other differences are insignificant at conventional levels.

with pre-existing laser firms, and academic startups originated in the centers of laser research. The pattern for diversifiers and spin-offs is very similar to what Buenstorf and Klepper (2006) have obtained for the historical U.S. tire industry. Our findings also resonate with those that Sorenson and Audia (2000) have obtained in the context of the U.S. footwear industry.

Overall, the empirical analysis suggests that localization economies may have played a less important role in the evolution of the German laser industry than might seem at first glimpse. Specifically, we found no evidence that the origination of either diversifiers or academic startups was favored by the presence of laser manufacturers. While this result could in principle be due to localization economies accessible only to spin-offs but not to other types of entrants, we see no convincing theoretical arguments for the existence of such type-specific externalities, and prefer the more simple account provided by the heritage theory. In contrast to the effects of existing laser firms, the effects of public research went beyond enhancing the supply of potential entrants. There is also evidence of effective urbanization economies affecting where entrants originated.

A powerful spin-off process can be observed in the German laser industry. Spin-offs account for one-third of all entrants in this industry, and were on average more long-lived than academic startups (Buenstorf, 2007). Higher spin-off rates have been found for more long-lived and more experienced firms, suggesting that incumbent laser firms were involuntary training grounds for prospective spin-off founders, with more learning opportunities present in better firms (ibid.). The present findings moreover indicate that spin-off origination was less strongly affected by public research activities than diversification, which is consistent with spin-offs drawing on their founders' own professional experience as their primary source of capabilities.

If entrants vary in their competences due to different pre-entry backgrounds (Helfat and Lieberman, 2002), then not only the geography of origination and entry, but also inter-regional differences in firm performance, may reflect firm heritage more than agglomeration economies. Consistent with this conjecture, prior statistical analyses (Klepper, 2007; Buenstorf and Klepper, 2008) indeed suggest that the superior performance of entrants in the historical centers of the U.S. automobile industry, Detroit, and the U.S. tire industry, Akron, was restricted to diversifiers and spin-offs spawned by

industry leaders. In contrast, entrants with more modest backgrounds did not perform better in these clusters than elsewhere. Likewise, firm survival in the German laser industry is not indicative of powerful effects of agglomeration (Buenstorf, 2008).

An account of the evolving geography of this industry can thus be given that is rather similar to the ones proposed for historical industries such as automobiles and tires, where, based on spin-off activities, existing industry centers had more and better entrants, which further reinforced their leading roles. In this way, early centers of the industry may grow through new entry, even if there are no powerful benefits of co-location.

In spite of the similarities in the factors shaping origination and entry, and in spite of the substantial share of spin-off entrants, the German laser industry has not attained the extreme level of regional concentration that characterizes the historical U.S. auto and tire industries. Two factors may help account for this contrast. First, the empirical analysis indicated that public research strongly affected where firms originated, both by providing academic startups and by influencing other entrants. The German university system is highly decentralized and mostly shaped by policies at the level of the federal *Länder*. Differences in university specializations and quality levels have traditionally been relatively small. Given these characteristics, public research most likely had a de-agglomerating effect on the German laser industry, particularly when its influence on the origination of entrants became stronger after 1990. Universities throughout the country spawned potential entrants with academic roots, and generated knowledge spillovers from which other entrants and pre-existing laser producers could benefit. Second, after Germany's reunification, additional potential entrants emerged both from public research (as in the case of the *Akademie der Wissenschaften* in Berlin) and as ("necessity") spin-offs from East Germany's defunct industries, which further limited the geographic concentration of the industry.

The general conclusion from our analysis is that determinants of firm origination in a present-day, science-based industry such as lasers are qualitatively similar to the ones observed in historical industries. While we found no evidence of effective localization economies, new entrants naturally clustered in existing industry centers based on diversification and spin-off processes. The most striking difference to historical industries such as automobiles and tires is the role of public research. Compared to the historical

U.S. industries, public research seems to have helped to limit the geographical concentration of the German laser industry. Germany has a large number of universities and non-university public research institutes, which for institutional and historical reasons are distributed throughout the country and tend to be relatively similar in terms of their curricula and overall quality. Further research is required to identify whether the de-agglomerating effect of public research is due to these national specificities, or whether it indicates a more generic difference between historical industries and more recent, science-based ones. Further research is also required to better understand the changes over time in science-industry interactions that are suggested by our empirical results. This requires an in-depth understanding of the dynamics of the innovation system in which the laser industry is embedded, and how this system evolved over time. We plan to study these issues in future work.

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Table 1: Numbers of entrants by pre-entry background and period of entry

	1960-1989	1990-2003	Total
Diversifiers/Importers	24 (53.3%)	32 (32.6%)	56 (39.2%)
Spin-offs	12 (26.7%)	36 (36.7%)	48 (33.6%)
Academic start-ups	5 (11.1%)	23 (23.5%)	28 (19.5%)
Other start-ups	2 (4.4%)	5 (5.1%)	7 (4.9%)
Unknown background	2 (4.4%)	2 (2%)	4 (2.8%)
Total	45	98	143

Table 2: Descriptive statistics (1960-1989/1990-2003)

	Mean	Std. Dev.	Min	Max
Laser producers per region (%)	1.300 1.031	5.716 2.646	0 0	100 25
Related firms per region (%)	1.331 1.031	5.040 2.408	0 0	47.134 32.642
Population density (log)	5.426 5.358	0.842 0.812	4.051 3.914	8.422 8.404
Dissertations per region (%)	1.177 1.031	2.783 1.865	0 0	33.333 12.693

Table 3: Correlations between variables (in entry regions, 1960-1989/1990-2003)

	Laser producers per region (%)	Related firms per region (%)	Population density (log)	Dissertations per region (%)
Laser producers per region (%)	1.000 1.000	0.639 0.650	0.129 0.354	0.444 0.646
Related firms per region (%)		1.000 1.000	0.140 0.245	0.520 0.444
Population density (log)			1.000 1.000	0.346 0.512
Dissertations per region (%)				1.000 1.000

Table 4: Analysis of entry locations

	Model 1		Model 2		Model 3		Model 4			
Time period	**1960-89**	**1990-2003**	**1960-89**	**1990-2003**	**1960-89**	**1990-2003**	**1960-89**		**1990-2003**	
							ROR of Origin	**Other ROR**	**ROR of Origin**	**Other ROR**
Origin					5.627*** (0.532)	5.660*** (0.336)	3.444 (3.952)		11.008*** (2.609)	
Laser producers	0.050*** (0.013)	0.125*** (0.022)	0.026* (0.014)	0.026 (0.032)	0.027 (0.032)	0.021 (0.059)	0.015 (0.054)	0.045 (0.043)	0.046 (0.071)	-0.062 (0.109)
Population density (log)	0.811*** (0.220)	0.484*** (0.141)	0.736*** (0.216)	0.250 (0.164)	0.464 (0.358)	-0.019 (0.240)	0.615 (0.521)	0.253 (0.507)	-0.509 (0.320)	0.317 (0.334)
Dissertations			0.128*** (0.031)	0.274*** (0.061)	0.063 (0.070)	0.044 (0.107)	0.120 (0.154)	0.024 (0.106)	-0.064 (0.124)	0.149 (0.158)
Region dummies	yes	yes	yes	yes	yes	yes	yes		yes	
Observations	3000 (40 firms)	8924 (92 firms)	3000 (40 firms)	8924 (92 firms)	3000 (40 firms)	8924 (92 firms)	3000 (40 firms)		8924 (92 firms)	
Log-likelih. Chi²	-144.857 55.68***	-347.464 146.82***	-137.088 71.22***	-338.671 164.41***	-43.972 257.46***	-128.678 584.39***	-43.587 258.23***		-124.234 593.28***	
Pseudo R²	0.16	0.17	0.21	0.20	0.75	0.69	0.75		0.70	

***, **, * indicating significance at 1%, 5% and 10% level respectively, standard errors in parentheses.

Table 5: Analysis of origination (separate estimations for each time period)

	Model 5		Model 6		Model 7	
Time period	**1960-1989**	**1990-2003**	**1960-1989**	**1990-2003**	**1960-1989**	**1990-2003**
Related firms *diversifiers	0.068*** (0.025)	0.141*** (0.054)	0.064*** (0.024)	0.127** (0.054)	0.038* (0.021)	0.136*** (0.050)
Laser producers *diversifiers	0.005 (0.027)	-0.128* (0.076)	-0.007 (0.027)	-0.132* (0.076)	0.016 (0.019)	-0.096 (0.070)
Laser producers *spin-offs	0.089** (0.040)	0.139*** (0.047)	0.078* (0.042)	0.125** (0.049)	0.076* (0.041)	0.171*** (0.043)
Laser producers *acad. startups	0.013 (0.061)	-0.094 (0.059)	0.002 (0.046)	-0.156** (0.075)	0.046 (0.038)	-0.110 (0.071)
Dissertations *diversifiers	0.144*** (0.048)	0.373*** (0.084)	0.130*** (0.047)	0.345*** (0.092)	0.085** (0.043)	0.300*** (0.088)
Dissertations *spin-offs	0.166 (0.144)	0.170* (0.089)	0.132 (0.165)	0.110 (0.113)	0.052 (0.166)	0.066 (0.104)
Dissertations *acad. startups	0.208* (0.113)	0.579*** (0.088)	0.198** (0.086)	0.542*** (0.097)	0.088 (0.070)	0.488*** (0.091)
Pop. density *diversifiers			0.643** (0.266)	0.449* (0.253)	0.349 (0.220)	0.264 (0.227)
Pop. density *spin-offs			0.235 (0.424)	0.570** (0.245)	0.172 (0.419)	0.360* (0.210)
Pop. density *acad. startups			1.129** (0.553)	0.739** (0.312)	0.718 (0.459)	0.555** (0.279)
Region dummies	yes	yes	yes	yes	no	no
Observations	2850 (38 firms)	8536 (88 firms)	2850 (38 firms)	8536 (88 firms)	2850 (38 firms)	8536 (88 firms)
Log-likelihood **Chi²**	-128.573 70.98***	-295.395 214.36***	-124.498 79.13***	-290.006 225.14***	-133.044 62.04***	-293.015 219.12***
Pseudo R^2	0.22	0.27	0.24	0.28	0.19	0.27

***, **, * indicating significance at 1%, 5% and 10% level respectively, standard errors in parentheses.

Table 6: Analysis of origination (pooled estimations; West Germany and Berlin)

	Model 8		Model 9		Model 10	
Time period	**1960-1989**	**1990-2003**	**1960-1989**	**1990-2003**	**1960-1989**	**1990-2003**
Related firms *diversifiers	0.054** (0.025)	0.159*** (0.057)	0.050** (0.024)	0.132** (0.054)	0.038* (0.021)	0.137** (0.050)
Laser producers *diversifiers	-0.006 (0.029)	-0.122 (0.078)	-0.016 (0.028)	-0.123 (0.076)	0.016 (0.019)	-0.098 (0.073)
Laser producers *spin-offs	0.067* (0.040)	0.169*** (0.049)	0.059 (0.043)	0.131*** (0.050)	0.076* (0.041)	0.168*** (0.045)
Laser producers *acad. startups	0.002 (0.066)	-0.092 (0.063)	-0.006 (0.048)	-0.151** (0.077)	0.046 (0.038)	-0.119 (0.075)
Dissertations *diversifiers	0.125*** (0.045)	0.347*** (0.089)	0.113*** (0.044)	0.351*** (0.096)	0.085** (0.043)	0.308*** (0.092)
Dissertations *spin-offs	0.121 (0.147)	0.115 (0.102)	0.082 (0.169)	0.133 (0.115)	0.052 (0.166)	0.071 (0.106)
Dissertations *acad. startups	0.178 (0.120)	0.547*** (0.092)	0.167* (0.088)	0.546*** (0.099)	0.088 (0.070)	0.484*** (0.093)
Pop. density *diversifiers			0.764*** (0.261)	0.444 (0.271)	0.349 (0.220)	0.275 (0.242)
Pop. density *spin-offs			0.399 (0.421)	0.541** (0.253)	0.172 (0.419)	0.389* (0.218)
Pop. density *acad. startups			1.243** (0.555)	0.747** (0.333)	0.718 (0.459)	0.596** (0.292)
Region dummies	yes		yes		no	
Observations	8775 (117 firms)		8775 (117 firms)		8775 (117 firms)	
Log-likelihood **Chi²**	-375.745 258.80***		-366.828 276.64***		-372.487 265.32***	
Pseudo R^2	0.26		0.27		0.26	

***, **, * indicating significance at 1%, 5% and 10% level respectively, standard errors in parentheses.