Received: 25 June 2020 | Revised: 9 February 2021 | Accepted: 21 April 2021

DOI: 10.1111/jors.12543

RESEARCH ARTICLE

JOURNAL OF REGIONAL SCIENCE WILEY

Innovation in Malmö after the Öresund Bridge

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Abstract

We analyze the effect of the Öresund Bridge, a combined railway and motorway bridge between Swedish Malmö and the Danish capital Copenhagen, on inventive activity in the region of Malmö. Applying difference-in-difference estimation on individual-level data, our findings suggest that the Öresund Bridge led to a significant increase in the number of patents per individual in the Malmö region as compared with the two other major regions in Sweden, Gothenburg, and Stockholm. We show that a key mechanism is the attraction of highly qualified workers to the Malmö region following the construction of the bridge.

KEYWORDS

agglomeration effects, bridge, cross-border regions, innovation, inventors, Öresund, patents, transportation infrastructure

1 | INTRODUCTION

The results in Krugman's (1991) seminal paper on-demand pooling effects suggest that investments in physical transportation infrastructure benefit regional performance by reducing transportation costs and thereby stimulating co-location (cf. Klepper, 2007). Since then, a host of empirical evidence on the beneficial role of transportation infrastructure has accumulated, analyzing various dimensions of economic performance. Fernald (1999) shows that roads and interstate highways affect industrial productivity. Others find positive effects on growth

(Chandra & Thompson, 2000), employment growth (Duranton & Turner, 2012; Percoco, 2016), urbanization (Atack et al., 2009), firm entry (Percoco, 2016), trade (Donaldson, 2018 Duranton et al., 2014), regional wealth (Banerjee et al., 2012), and the reallocation of residents and economic activity within the region (Ahlfeldt et al., 2015; Baum-Snow, 2017). There is also evidence that infrastructure investments influence regional innovation activities positively (Agrawal et al., 2017; Klein & Luu, 2003; Parent & Riou, 2005).

Despite the overall positive effects documented by the literature, we know little about the underlying mechanisms. An important question not addressed by the literature is whether innovation increases because knowledge flows more efficiently into the region or because of inflows of human capital to the region (cf. Duranton & Turner, 2011). The relative importance of the two mechanisms has important and distinctive implications for policy. While improved efficiency of knowledge flows is socially desirable, the attraction of human capital may come, at least partially, at the expense of the regions from which the human capital originated. In this study, we contribute to the literature by assessing the importance of the effects of infrastructure improvements on regional innovation and by identifying the share of the effect that is attributable to the inflow of human capital from other regions. Our theoretical considerations are tested by an empirical analysis focusing on the opening of the Öresund Bridge between Denmark and Sweden.

The Öresund "region" labels the land areas surrounding the Öresund strait, which constitutes the border between Sweden and Denmark. It covers an area of 20.859 km^2 and consists of roughly three parts: the metropolitan area of Copenhagen, its suburban area, and Scania (Skåne) on the Swedish side (see Figure 1). However,

FIGURE 1 Öresund region. *Source*: Anderberg and Clark (2013) [Color figure can be viewed at wileyonlinelibrary.com]

it is important to note that the term "Öresund region" does not describe an administrative region. as relevant political and administrative powers remain firmly embedded in national structures on either side of the national border. The Öresund region is thus not a functional region in the sense of an integrated labor market.

Before the opening of the Öresund Bridge, the two countries were only connected across the Öresund strait through ferry traffic, implying that traveling was inflexible and inconvenient. Therefore, the Danish and the Swedish part of the Öresund region were largely separated labor markets, which can be seen from a relatively low number of 2600 daily commuters in 1999, the year before the bridge was opened. Despite the fact that the bridge reduced travel time between Malmö and Copenhagen by only 10 min (to 35 min), the number of daily commuters reached 19,800 in 2008 as it established a direct connection between the two cities. A large share of the new commuters were former Danish residents who settled on the Swedish side, benefitting from large housing price differences between the two countries (Örestat, 2020). Also, Swedish residents started to commute more intensively responding to a labor shortage on the Danish side (Örestat, 2020). Although these commuter figures appear low compared with the 70,000 people who commuted daily between Malmö and its surroundings and the 225,000 people within the Greater Copenhagen Area who travel to and from Copenhagen every day (OECD, 2003), the bridge offered more varied modes of transportation and, importantly, direct access to an international airport—the Copenhagen Airport, for residents on the Swedish side.

The Öresund region was already before the construction of the bridge of great economic importance. In 1999, one year before the bridge was inaugurated, the total GDP of the Öresund region amounted to US$ 130 billion. The Swedish part of the region contributed 11% to Sweden's total GDP (OECD, 2003, p. 65). Despite their geographical proximity, the regions of Copenhagen and the Malmö differed significantly in terms of industrial structure. Before the bridge, in particular, in the city of Malmö itself, declining traditional industries characterized the local economy, although the neighboring city of Lund had a strong presence of science- and engineering-based industry (Nauwelaers et al., 2013, p. 16). At the same time, Copenhagen had a much stronger emphasis on technologies such as biotech, pharmaceuticals, and knowledge-intensive services. After the opening of the bridge, the Swedish part of the Öresund region began to prosper and saw an increase in GDP of 21% and an increase in employment of 17% between 2000 and 2010 as compared with 12% and 4%, respectively, for the Danish side.[1] Business research and development (R&D) expenditure as a percentage of GDP reached 3.5% in the South of Sweden as compared with the 2.5% Swedish average in 2009 (Nauwelaers et al., 2013, p. 18). The Malmö region ranked fourth among OECD metropolitan areas for patent intensity in 2013 and is now described as a "host for creative industries" (Nauwelaers et al., 2013, p. 16).

The simultaneous occurrence of the opening of the bridge and subsequent economic development, while suggestive, requires careful analysis to reach a causal interpretation. This paper uses a unique micro-level individual data set to investigate the effect of the bridge on the patent productivity of the inventive labor force in the region of Malmö. Many evaluations of infrastructure projects analyze the regional level. While these studies focus on regional contextual factors and their interactions with regional policies, the individual level allows us to get insights into people's behavioral response to policy changes or infrastructure projects. An individual-level analysis is required to answer our research question, which aims at disentangling the effect of human capital inflow embodied in talented workers from intangible knowledge inflows in response to the bridge.

Our identification strategy relies on a difference-in-difference approach where we compare the patent productivity of individuals with an educational background prone to patenting located in the Malmö region to their counterparts in Gothenburg, Sweden's second largest region, and Stockholm, the largest region and the capital of Sweden.[2] We use individual-level data from the longitudinal integrated database for health insurance and labor

[1]The information is taken from Orestat database: http://www.orestat.se/sv/oresundsdatabasen-engelsk.

[2]The regional units Stockholm, Gothenburg, and Malmö are functionally based on commuting patterns (local labor market regions) and follow the definition of Tillväxtverket, the Swedish Agency for Economic and Regional Growth (Tillväxtverket, 2020). The full list of municipalities in each of the three regions is given in the Supporting Information Appendix. Notably, Uppsala belongs to the Stockholm region and Lund and Helsingborg to the Malmö region.

market studies (LISA), a database covering all individuals residing in Sweden, provided by Statistics Sweden (SCB). These data are linked to the population of Swedish inventors, which one of the authors of this study identified from addresses in the patent data from the European Patent Office (EPO).[3]

The results of our study show that the average number of patents produced by individuals in the region of Malmö increased by 30%–35% (depending on estimation) as compared with the control regions. We find that 78% of the increase can be explained by individuals that moved to Malmö after the completion of the bridge. Our results, hence, suggest that the dominant effect of the bridge on innovation stems from the attraction of human capital.

2 | HISTORY OF EXISTING EVIDENCE ON THE ÖRESUND BRIDGE

Despite the short geographical distance between the countries Denmark and Sweden, it took many decades from discussions to building a bridge over the Öresund strait. At the beginning of the 1990s, the Swedish and Danish government started to seriously discuss the construction of a bridge. Despite environmental concerns, an agreement was finally signed, and the bridge was officially opened on July 1, 2000. Long-term crises on the Swedish side associated with the de-industrialization of Malmö and the Danish capital Copenhagen were factors that contributed to a willingness to increase investments in the region. Investments to increase accessibility of the Danish capital, Western Jutland, Germany, and mainland Sweden were seen as important to raise its economic potential. Thus, a decision had been taken to build the Storebælt bridge between Zealand and Funen (inaugurated in 1998), which would in turn, further raise the benefits of an Öresund bridge. Many inquiries had investigated the prospects for the bridge. Much of the focus in these inquiries was on passenger volumes and environmental effects. Critics were worried that noise pollution would rise, that larger traffic volumes would raise emissions, and about water flows to the Baltic sea.

To finance the undertaking, the states opted for a fee-based solution where motorized vehicles would pay comparably large fees for crossing, whereas public train transportation would pay less. Official inquiries focused little on the effects of the Öresund Bridge on knowledge production, research, and innovation. The focus on transportation, volumes, and costs was natural given its consequences on government budgets. The Swedish inquiry (SOU, 1989) mentions that the bridge should lead to higher levels of trade, increased integration of business across the sound, integration of labor and housing markets, increased travel abroad through Copenhagen airport.

Academic scholars started to investigate potential effects on knowledge production, knowledge flows, and innovation. Johansson (1988) argues that the Malmö region (in his analysis, the municipalities Malmö, Lund, Staffanstorp, Lomma, Burlöv, and Svedala) would develop strongly based on the increased connectivity given by the Danish international airport in Copenhagen. Other arguments were based on the increased competitiveness given to product development in manufacturing and services, attained through the ability to reach customers more easily, learn about their preferences and obtain knowledge internationally more easily. Especially advanced service jobs would benefit.

Another strong proponent for the advancement of knowledge creation and also creativity is the work by Andersson and Wichmann Matthiessen (1993), who wrote an influential book about the prospects for knowledge creation in the region that would result from the bridge. The authors rely on an international comparison with prominent regions that built their success on innovation. Examples of expected benefits that the authors highlight are increased collaboration in science, among businesses, and in the healthcare sector. Andersson and Wichmann

[3]Note that our sample consists of individuals with an educational background that enables patenting. In contrast, we use the term inventor to describe a person who appears at least once in her lifetime as inventor on a patent document.

Matthiessen (1993) conclude that a strong potential existed for increased collaboration within the region as well as with the outside world, but also highlighted the need for complementary infrastructure investments to connect the regions on the Swedish side to fully benefit from the possibilities for interaction generated by the Öresund Bridge. Moreover, they indicated a need for political institutions to be adapted to the changing landscape. The full potential of the bridge is yet to be realized as the region remains politically fragmented and unable to create unified institutional and administrative framework conditions.

This still holds despite attempts to create cross-border institutions, the most prominent being the formation of the Öresund University. Started in 1997, this initiative aimed to integrate research and education between the universities in the region involving 150,000 students and 14,000 staff in 2009.[4] For various reasons, including the lack of anchoring of activities at Lund University (Glimberg, 2001), the introduction of student fees in Denmark and the funding which was still coming from national sources, the project was, however, stopped in 2010.

It is thus not a priori clear to what extent the Öresund bridge can be expected to have contributed to knowledge creation and innovation. On the one hand, the region has now a more integrated labor market and improved accessibility, in particular on the Swedish side. On the other hand, there appears to have been a lack of (successful) investments in (cross-border) knowledge infrastructures. Therefore, we review the nascent literature on the importance of infrastructure on innovation, with an emphasis on potential theoretical explanations.

2.1 | Innovation and transportation infrastructure

Traditionally, investments in physical transportation infrastructure have been suggested to improve agglomeration economies, arising from demand pooling effects and reduced transportation costs, thereby strengthening supply in an economy (Klepper, 2007; Krugman, 1991). The literature has documented positive effects of transportation infrastructure on a variety of economic outcomes. Roads and interstate highways, for instance, have been shown to affect industrial productivity (Fernald, 1999) and economic growth (Chandra & Thompson, 2000), employment growth (Duranton & Turner, 2012), urbanization (Atack et al., 2009), employment growth and firm entry (Percoco, 2016), the inflow of new workers (Duranton & Turner, 2011), trade (Donaldson, 2018; Duranton et al., 2014), regional wealth (Banerjee et al., 2012) and the reallocation of economic activity within the region (Ahlfeldt et al., 2015; Baum-Snow, 2017).

The idea that investments in transportation infrastructure could also benefit innovation has not received the same level of attention, probably because the link between investments into concrete and innovation appears to be indirect. Only recently has the innovation-spurring effects of transportation infrastructure been discussed more extensively, and empirical estimates indicate sizeable effects (Agrawal et al., 2017; Klein & Luu, 2003; Parent & Riou, 2005). This literature shows that investments in transportation infrastructure directly affect the rate and timing of knowledge exchange between places by reducing travel costs.

Focusing on 335 European regions over the period 1989–1999, Parent and Riou (2005) show that infrastructure polarizes knowledge spillovers. Well-connected places learn more from each other than their geographic proximity suggests, while places which are geographically close to each other but lack the support of advanced transportation infrastructure show learning at a lower rate than expected. Using data on metropolitan areas in the United States, Agrawal et al. (2017) show that regional highways result in an increase in regional patenting because of facilitated knowledge flows between previously less well-connected places. Focusing on air transportation, Catalini et al. (2019) find that, in response to the opening of a new route by Southwest Airlines, scientific collaboration among chemists increased by between 30% and 110%. Finally, Wang et al. (2018) show that a 10% improvement in road density increases the average number of approved patents per firm by 0.71% because of market size enlargement (in terms of sales) and facilitation of knowledge spillovers from star innovators within a city.

[4] https://sv.wikipedia.org/wiki/%C3%96resundsuniversitetet.

While empirical evidence on the role of transportation infrastructure on innovation has accumulated, a theoretical rationale is often lacking. In this subsection, we make an effort to provide a unified view on the link between transportation infrastructure and innovation by drawing on the concept of knowledge recombination. Our framework suggests the existence of microeconomic effects of improved transportation infrastructure that benefit the innovation processes in a region through increased efficiency and by attracting skilled human capital to the region. The former effects do not negatively affect neighboring regions and therefore provide a source of additionality in terms of innovation. Those effects that work through the mechanism of attracting skilled human capital could result in an improved allocation of labor, although negative effects on the regions that lose human capital cannot be ruled out. Providing evidence on the role of the inflow of human capital is the main goal and contribution of this paper.

Since Schumpeter's famous works, innovation has been considered to be based on the recombination of existing knowledge. Still today, the idea of recombination is as topical as ever in innovation studies and is discussed at various levels, including the innovation team (Haas & Ham, 2015), sectors or technologies (Gruber et al., 2013), but also geographical regions (Choudhury & Kim, 2019; Wagner et al., 2019). The central importance of recombination of knowledge has a number of theoretical implications for transportation infrastructure investments. First, the innovative potential of a given pool of knowledge increases with the size of the pool because the number of (possibly valuable) recombinations increases. Second, as knowledge cannot be transferred, and thus recombined, without costs, even within a region, the innovative potential also depends on the accessibility of the knowledge. In other words, the innovative potential of a regional unit should be positively affected by its transportation infrastructure because the actors can more easily exchange and combine knowledge from other actors.

We argue that there are at least two types of mechanisms through which knowledge reaches a region following an investment in infrastructure. The first group of mechanisms provides additionality effects because they are based on making the exchange or recombination of knowledge more efficient. The second type of mechanisms work through the redistribution of people across regions, for example, when human capital is attracted to the focal region. Such redistribution effects could be of concern for policymakers depending on whether they create additional value, for example, by improving employee-employer matching across regional borders, or whether they merely redistribute human capital from one region to another.

2.2 | Additionality mechanisms

The additionality of transportation infrastructure projects results from intra-regional increases in the efficiency or the returns to scale of the innovation process. A primary mechanism that speaks in favor of additionality relates to the stickiness of knowledge. Even if knowledge is legally unprotected, it typically has tacit components that make it difficult to be transferred from one actor to another (Szulanski, 2000). Thus, transferring and exchanging knowledge requires close geographical proximity (Jaffe et al., 1993). Improved transportation infrastructure does not reduce the geographical distance, but it improves accessibility by reducing transportation costs and travel time. Accessibility within the region but also of knowledge pools outside of the region is improved. This is likely to hold for the Öresund region after the Öresund Bridge, where the bridge has drastically improved accessibility between the two regions. Another important factor, in particular, for the Swedish side is the better access to Copenhagen's international airport, which may benefit the Malmö region by the facilitating access to international knowledge pools (and even nationally, in particular to the Stockholm-Uppsala region). One implication is that previously unexplored potentials for knowledge recombination emerge as transportation costs (and allegedly the costs of knowledge recombination) decline.

A substantial literature from the 1990s and the 2000s has made arguments in this vein, which crystallized in the hope that firms, universities, and other innovation-relevant actors would move closer together and thereby contribute to improved knowledge sharing. Several authors centered around Jönköping International Business School conducted studies focused on accessibility (Weibull, 1976). While the role of accessibility had been investigated for matters related to productivity and commuting (e.g., Johansson & Forslund, 1995; Ohlsson, 2002), in the 2000s only, this concept was used to improve our understanding of the importance of proximity to knowledge. The findings of this literature largely confirm an important role of proximity to R&D and human capital for patent production (e.g., Andersson & Ejermo, 2005; Gråsjö, 2006; Johansson & Karlsson, 2019). While this prior literature aimed at understanding the effects of proximity it did not focus on changes in accessibility, e.g., through changes in road travel times.

Another important additionality mechanism relates to indivisibilities resulting from the use of shared inputs. Highly differentiated innovation processes require the use of specialized inputs such as sophisticated technology and services, including market research, product testing, patent lawyers, and the availability of financing (Feldman, 1994; Porter, 1998), which are often shared among firms to achieve scale effects (Helsley & Strange, 2002). Small regions are often not able to sustain such inputs because the small market size limits the demand. Innovation therefore typically clusters in larger metropolitan regions (Audretsch & Feldman, 1996; Carlino & Kerr, 2015; Feldman & Kogler, 2010). Improved research infrastructure can increase the effective market size by reducing transportation costs and therefore attract specialized shared inputs to the region. This, obviously, already holds true for incremental improvements to transportation infrastructure such as a better road system, but it is even more likely to result from large infrastructure projects such as the Öresund Bridge, which connects two formerly distinctly separate regions through a big one-off investment.

Finally, urban economists as well as labor market economists have stressed that colocation creates thicker labor markets that provide access to specialized human capital (Berliant et al., 2006), increasing the chance of better matches between employers and employees (Berliant et al., 2006; Strange et al., 2006; Wheeler, 2001). Better employer-employee matches include matches between inventors or scientists and high-tech firms and, hence, increase innovativeness within the region.

The mechanisms described above share the feature that they increase the efficiency of innovative activities in a region without compromising them in other regions. The type of mechanism described in the next section, in contrast, does not genuinely increase innovative efficiency. These mechanisms work by attracting qualified human capital to the focal region instead, thereby redistributing human capital across regions.

2.3 | Redistribution mechanisms

Rational agents respond to incentives set by costs and returns accruing to their actions. Because additionality effects are based on costs reductions of transportation and an increasing knowledge exchange as well as the provision of shared inputs, individual agents adapt their behavior. For example, individuals living in other regions may be attracted to the Öresund region because of the larger labor market (Niedomysl & Hansen, 2010) and also local amenities (Glaeser et al., 2001; Heuermann & Schmieder, 2018). Thus, transportation infrastructure may induce second-order effects for innovation which work largely through the inflow of highly skilled employees from other regions.

While it is certainly true that cross-border relocation of human capital increases the match quality between employers and employees in the target region, one undesired side effect can be an associated loss of human capital in the donor region. From a policy perspective, attraction mechanisms could, therefore, be of concern. A priori, it is unclear whether and to which extent benefits for one region outweigh potential losses through redistribution effects of human capital for another region. It is also unclear whether such redistribution diminishes innovation in the donor region in the first place.

3 | EMPIRICAL MODEL SPECIFICATION

Our analysis aims at investigating the impact of the Öresund Bridge on innovation produced by individuals located in the region of Malmö. To identify a causal effect, we use a difference-in-difference (DiD) approach where we consider the year 2000, the year of the inauguration of the bridge, as the starting point of the treatment. Specifically, we compare individuals that were exposed to the treatment (the bridge), to a comparable set of individuals who were not directly affected by the treatment. Here, we focus on comparable individuals residing in Gothenburg and Stockholm. To create clean treatment and control group, we require that all our individuals in the sample are observed both in 1999 and 2000 and are unambiguously either treated or untreated throughout the entire observation period. Our treated individuals reside in the Malmö region in 1999 and 2000. A control individual is residing in Gothenburg and Stockholm in either year 1999, 2000, or both years.

To implement our model, we introduce two restrictions to the sample of the entire population of residents in Sweden. First, we focus only on those individuals with an educational background in natural sciences, technology, or medicine (NTM). Second, we restrict the sample to the three urban regions Malmö (treatment region), Gothenburg, and Stockholm (control regions). The control regions were chosen, since together with the region of Malmö, they are the most important centers of inventive activity (Ejermo, 2004) and the three largest metropolitan areas in Sweden, with more than half of Sweden's population residing there during the period of our study.[5]

To disentangle the accessibility and the labor inflow effect, we track individuals who move from the control regions to the Malmö region during the period of our study 1993–2007. A newcomer to the Malmö region is defined as an individual who ever resided in the region for the first time in 2000 or after. Those movers identify which share of the total effect of the bridge can be attributed to the relocation of human capital to the Malmö region.

Since we are interested in analyzing the effect of the Öresund Bridge on innovation, we use the number of patent applications as our dependent variable. Using patent applications as a measure of innovation has the advantage of having a direct measure of inventive output. Input-based measures such as R&D expenses have the drawback of not capturing the success of the innovation process. Most important for our analysis, patents can, in contrast to R&D, be pinpointed with great geographical precision and be measured on the individual level, which enables us to control for many aspects of the inventive process.

We use a fractional count of patents as our dependent variable, that is, we weight the patent application by the number of inventors, to account for the contribution of the individual inventors.[6] This weighting ensures that regional inventors do not receive disproportional credit for patents which are coinvented.

Our empirical specification of the main model reads:

$$Patents_{i,t} = \alpha + \beta_1 1Post_{i,t} + \beta_2 Malmö_i + \beta_3 Malmö_i \times Post_{i,t} + \beta_4 X_{i,t} + \varepsilon_{i,t},$$

where $Patents_{i,t}$ is our measure of fractional patent count for individual i in year t. $Post_{i,t}$ is a dummy variable that takes the value 0 for the pre-bridge period 1993–1999 and 1 for the period 2000–2007. $Malmö_i$ is a time-invariant dummy indicating whether the individual is part of the treatment group. $Malmö_i \times Post_{i,t}$ is the interaction term of $Malmö_i$ and $Post_{i,t}$. It captures the treatment effect on the treated, that is, the potential increase in patent applications per inventor in the Malmö region after the bridge has been built. The coefficient α is an intercept, $X_{i,t}$ a set of control variables, and $\varepsilon_{i,t}$ the error term.

To distinguish the effect of relocation of human capital to the Malmö region from knowledge accessibility effects, we employ a second specification:

$$Patents_{i,t} = \alpha + \beta_1 Post_{i,t} + \beta_2 Malmö_i + \beta_3 Malmö_i \times Post_{i,t} + \beta_4 NEW_i + \beta_5 NEW_i \times Post_{i,t} + \beta_6 X_{i,t} + \varepsilon_{i,t}.$$

The variable NEW_i is time-invariant and set to one for individuals who moved to Malmö after the opening of the bridge for the very first time. The interaction term with the variable $Post_{i,t}$ allows the bridge effect to vary. If β_5 is significantly different from zero, the effect of newcomers after the bridge differs compared with non-newcomers.

[5]Authors' calculation. *Source*: https://www.scb.se/en/finding-statistics/statistics-by-subject-area/population/population-composition/population-statistics/#_Tablesandgraphs.

[6]For example, a patent application with two inventors is counted as 0.5 patent applications for each individual.

Together with β_3, the coefficient therefore informs us about how much of the overall effect of the bridge can be attributed to newcomers to the region.

We estimate both models using count data models to account for the nature of the dependent variable (Hausman et al., 1984).[7] We show pooled cross-sectional regressions without individual fixed effects as well as pre-sample mean (PSM) estimations which account for unobservable individual-specific factors, such as differences in talent or taste for patenting (Blundell et al., 2002). The PSM is defined as the average of the dependent variable of the five years before the first sample year, that is, the period 1987–1992. In addition, we use fixed effects Poisson models, quasi-maximum likelihood Poisson models, which correct unobserved time-constant heterogeneity. We also use negative binomial models with and without fixed effects and pooled ordinary least square (OLS) models to show robustness of our findings.

4 | DATA

The main data source is the longitudinal integrated database for health insurance and labor market studies (LISA), an annual longitudinal data set maintained by Statistics Sweden with rich information on individuals living in Sweden, such as information on the residence area and workplace. We merge the individual-level data with patent data from the European Patent Office (EPO). The matching of patents to individuals was done in a project by one of the authors for the Swedish agency of Growth Policy Analysis in 2011 and was updated in January 2015 (Ejermo, 2011). An analysis of the demographic characteristics of Swedish inventors and a description of the matching process is provided by Jung and Ejermo (2014).

Applying the restrictions to the sample described in the previous section, from LISA we select all residents of the regions of Malmö, Stockholm, and Gothenburg with an educational background in natural sciences, technology, or medicine (NTM), which amounts to 2,093,544 individuals in the period 1993–2007.

Table 1 shows descriptive statistics for the NTM sample. The average number of patent applications in Malmö increased by 140% after the construction of the bridge. In the control regions, the growth in patent applications corresponds to 50%, which already suggests that the Öresund Bridge might have had an effect on innovation.

Table 1 also shows the age of the individuals, the patent application stock, and the firm size of the employers of the individuals as extracted from LISA, which we use as control variables in later regressions. The patent stock is defined as: Patent stock_t = patent $\text{stock}_{t-1} \times (1 - 0.15)$ + patent applications_t, where we assume a depreciation rate of 15% per year. Table 1 also displays an increase in the patent stock over time which can be driven by an increase of patent output by local inventors or by individuals relocating to the respective region. Regarding the age variable, Table 1 shows a mechanical increase since we observe our individuals before and after the inauguration of the bridge. Lastly, we observe a decline in firm size of the individuals' employers, which is stronger in the Malmö region than in the control regions.

5 | RESULTS

5.1 | The common trend assumption

To infer a causal relationship between the Öresund Bridge and the increase in patents of the individuals in the Malmö region, it is crucial to test whether the patenting activity of individuals in the Malmö region and the control

[7] Our dependent variable is a fractional variable and, hence, does not contain integers only. Count data models are nevertheless appropriate because the distribution of the variable resembles those of count data.

TABLE 1 Descriptive statistics

	Variable	Before 1993–1999 Mean (*SD*)	After 2000–2007 Mean (*SD*)	Change (%)
Malmö	Patents	0.0005 (0.0255)	0.0012 (0.0458)	140
	Age	39.7961 (11.7514)	42.6272 (11.9568)	7
	Patent stock	0.0021 (0.058)	0.0049 (0.1282)	133
	Firm size	4.8231 (2.3855)	4.3724 (2.4458)	−9
Gothenburg/Stockholm	Patents	0.0008 (0.0329)	0.0012 (0.0416)	50
	Age	38.7407 (11.7493)	41.7801 (11.8376)	8
	Patent stock	0.0031 (0.0825)	0.0053 (0.1195)	71
	Firm size	5.0408 (2.6449)	4.6624 (2.6686)	−29

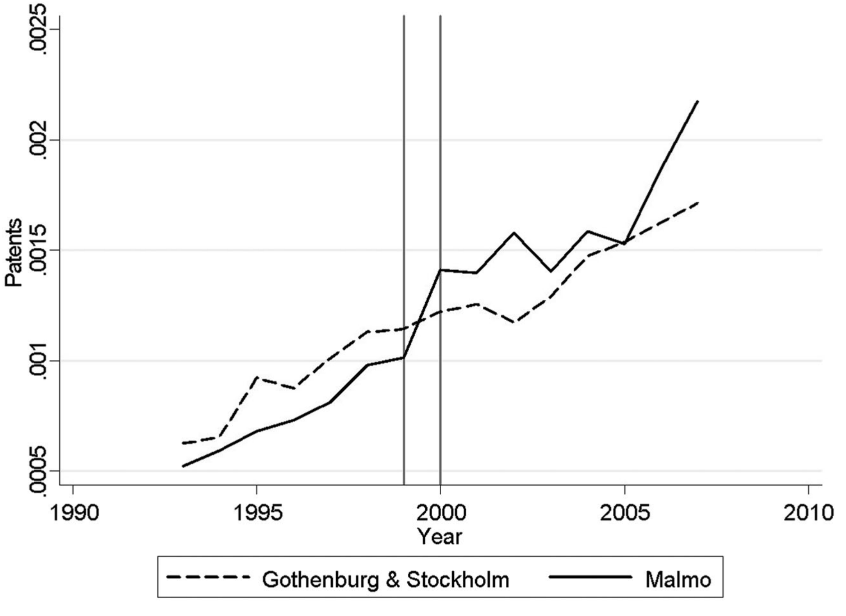

FIGURE 2 Evolution of patents per person over time

regions was following a common trend over time before the year 2000. Testing the common trend assumption is important to avoid confounding the pre-existing trend differences with causal effects induced by the bridge.

We start with a visual inspection of the trends. Figure 2 shows the evolution of patent applications per inventor in the treatment and control regions over time. A common upward trend is visible until the year 1999, 1 year before the bridge was opened. After the inauguration of the bridge, patenting of the individuals in the Malmö region increased more strongly relative to the other regions.

While Figure 2 relies on the raw data, Table A.2 in the Supporting Information Appendix provides a formal test of the common trend assumption. Here, we show *F*-tests for joint significance of regressions in which we replaced the *Post* dummy with individual year effects. The interaction of the individual year dummies with the Malmö region dummy informs us about a common trend before the bridge. The estimated coefficients confirm a common trend before the year 2000 as they are jointly not statistically significant as indicated by an *F*-test. After 2000, the

TABLE 2 The impact of the Öresund bridge on number of patent applications

Model	(1)	(2)	(3)	(4)	(5)	(6)
Estimator	Poisson	Poisson	Quasi-ML Poisson fixed effects	Negative binomial fixed effects	OLS	OLS fixed effects
Post	0.4418***	0.4571***	0.4644***	0.4664***	0.0006***	0.0006***
	(0.0288)	(0.0286)	(0.0274)	(0.0205)	(0.0000)	(0.0000)
Malmö	−0.2503***	−0.2257***		−0.1061	−0.0002***	
	(0.0603)	(0.0612)		(0.6475)	(0.0000)	
Malmö × Post	0.2989***	0.3022***	0.2736***	0.2666***	0.0003***	0.0003***
	(0.0622)	(0.0622)	(0.0607)	(0.0460)	(0.0001)	(0.0001)
PSM		4.8056***			0.5724***	
		(0.2185)			(0.0387)	
Constant	−6.8909***	−6.9534***		2.6345***	0.0007***	0.0010***
	(0.0280)	(0.2185)		(0.2799)	(0.0000)	(0.0000)
Observations	10,899,187	10,899,187	131,492	131,492	10,899,187	10,899,187

Abbreviations: OLS, ordinary least square; PSM, pre-sample mean.

Note: Robust standard errors are in parentheses (except for Quasi-ML Poisson fixed-effects and Negative binomial fixed effects).

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

interactions of the Malmö region dummy and the year dummies become statistically significant, suggesting that the Öresund Bridge had an effect.

5.2 | Main results

The estimation results presented in Table 2 show that the Öresund Bridge has increased patenting by individuals in the Malmö region. The different estimators show a robust, positive, and significant effect of the interaction term (*Post* × *Malmö*). This suggests that individuals with an appropriate educational background for patenting in the Malmö region became more productive in terms of patent applications than comparable individuals in the control regions after the opening of the bridge. The effect size is also quite robust to the employment of different estimators (see Models 1–6). The increase in the average number of patents for people in Malmö, compared with individuals in Stockholm and Gothenburg, corresponds to 30%–35% for Models 1–4.[8] For the Poisson model in column 1, this corresponds to an increase of 0.00017 patents per person and year ((e(0.298) − 1) × 0.0005 baseline patents per year and inventor, see Table 1) or 542 patents in total (0.00017 × 3,120,079 inventor year observations in Malmö after the bridge).

The positive and significant coefficient for the variable *Post* in Table 2 indicates an increase in patenting over time. The negative coefficient of the Malmö dummy (Models 1, 2, and 5) indicates a lower baseline level of patenting than in the other regions over the entire time period. The effect vanishes once individual fixed effects are included (Models 3 and 4, unsurprisingly considering its low variability over time). The pre-sample mean (Models 2 and 5) has the expected positive

[8]These percentages are derived from the nonlinear regressions' coefficient of *Malmö* × *Post* interaction, by an exponential transformation of the coefficient subtracted by the constant 1, then multiplied by 100, expressed in the following equation: $\hat{\beta_3}\% = (e^{\hat{\beta_3}} - 1) \times 100$where $\hat{\beta_3}$, is the estimated coefficient of *Malmö* × *Post* interaction.

TABLE 3 The impact of the Öresund bridge on number of patents—Addition of control variables

Model Estimator	(1) Poisson	(2) Poisson	(3) Quasi-ML Poisson fixed effects	(4) Negative binomial fixed effects	(5) OLS	(6) OLS fixed effects
Post	−0.0267	0.0400	0.0138	0.0245	0.0002***	−0.0003***
	(0.0310)	(0.0317)	(0.0515)	(0.0420)	(0.0001)	(0.0001)
Malmö	−0.1401**	−0.1210		−1.4204**	−0.0002**	
	(0.0626)	(0.0698)		(0.7169)	(0.0001)	
Malmö × Post	0.3339***	0.3222***	0.2337***	0.2278***	0.0007***	0.0005***
	(0.0690)	(0.0698)	(0.0794)	(0.0639)	(0.0001)	(0.0001)
Age	0.0784	0.0844	0.5075***	0.5070***	0.0003***	0.0005***
	(0.0107)	(0.0107)	(0.0235)	(0.0166)	(0.0000)	(0.0000)
Age_sq	−0.0011	−0.0012	−0.0046***	−0.0046***	−0.0000***	−0.0000***
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0000)	(0.0000)
Lag_log_Pstock	0.3471***	0.3419***	−0.0466***	−0.0478***	0.0081***	0.0006***
	(0.0023)	(0.0023)	(0.0034)	(0.0023)	(0.0003)	(0.0000)
Log_size	0.1002***	0.1037***	0.0640***	0.0621***	0.0003***	0.0002***
	(0.0061)	(0.0060)	(0.0119)	(0.0089)	(0.0000)	(0.0000)
PSM		1.0340***			0.3025***	
		(0.1167)			(0.0451)	
Constant	−3.6329***	−3.8387***		−9.0388***	0.1256***	−0.0015*
	(0.0061)	(0.2831)		(0.7047)	(0.0041)	(0.0008)
Observations	4,942,436	4,942,436	75,679	75,679	4,942,436	4,942,436

Note: Robust standard errors are in parentheses (except for Quasi-ML Poisson fixed-effects and Negative binomial fixed-effects).

Abbreviations: OLS, ordinary least square; PSM, pre-sample mean.

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

sign indicating that unobserved individual factors such as talent or a taste for patenting (which increased pre-sample patent output) have a positive effect on the individuals' patent productivity.

5.3 | Addition of control variables

Table 3 shows that the results hold when we control for the individuals' age, age squared, the logarithm of the patent stock lagged one period, past productivity in terms of the patent stock, and the firm size of the employer. The treatment effect (*Post* × *Malmö*) is still statistically significant and positive and barely decreases in coefficient size.

The control variables have the expected signs. We find a nonlinear effect of age (for Models 3–6), which shows that inventor productivity increases over the life cycle up to a certain point, after which it decreases (Levin & Stephan, 1991). The lagged patent stock variable is negative. Lastly, firm size has a positive effect. This may be reflective of large firms offering valuable resources which inventors can draw upon.

TABLE 4 The effect of inflow of labor on the number of patents

Model	(1)	(2)	(3)	(4)	(5)	(6)
Estimator	Poisson	Poisson	Quasi-ML Poisson Fixed effects	Negative Binomial Fixed effects	OLS	OLS Fixed effects
Post	0.4342	0.4496***	0.4597***	0.4616***	0.0006***	0.0006***
	(0.0288)	(0.0287)	(0.0274)	(0.0203)	(0.0000)	(0.0000)
Malmö	−0.2506***	−0.2253***		−0.1476	−0.0002***	
	(0.0603)	(0.0613)		(0.6521)	(0.0000)	
Malmö × Post	0.3064***	0.3098***	0.2784**	0.2714***	0.0003***	0.0014***
	(0.0622)	(0.0623)	(0.0607)	(0.0460)	(0.0001)	(0.0003)
NEW	−0.0224	0.0286		−1.3085	0.0000	
	(0.1749)	(0.1742)		(1.0150)	(0.0002)	
NEW × Post	0.8272***	0.8204***	0.5095***	0.4920***	0.0019***	0.0014***
	(0.2174)	(0.2171)	(0.2061)	(0.1595)	(0.0006)	(0.0003)
PSM		4.8083***			0.5724***	
		(0.2184)			(0.0387)	
Constant	−6.8906***	−6.9540***		2.6754***	0.0007***	0.0009***
	(0.0282)	(0.0269)		(0.2913)	(0.0000)	(0.0000)
Observations	10,899,187	10,899,187	131,492	131,492	10,899,187	10,899,187

Note: Robust standard errors are in parentheses (except for Quasi-ML Poisson fixed-effects and Negative binomial fixed-effects).

Abbreviations: OLS, ordinary least square; PSM, pre-sample mean.

**p* < 0.1; ***p* < 0.05; ****p* < 0.01.

5.4 | Labor inflow as mechanism

This section analyzes whether the attraction of human capital (Duranton & Turner, 2012; Puga, 2008) is responsible for the positive effect of the bridge or whether original residents of the Malmö region realize positive effects from the integrated area (De la Roca & Puga, 2017). We, therefore, estimate Model (II), which adds a variable indicating newcomers to the region of Malmö (*NEW*) as well as an interaction with the variable *POST*, which informs us whether and to which extent individuals relocating to the region of Malmö after the inauguration of the Öresund Bridge contribute to the overall positive effect of the bridge on the patent output of individuals.

Table 4 shows the results. It appears that newcomers to the region of Malmö (*NEW*) are less productive than residents over the complete sample period. However, individuals that move to the Malmö region are significantly more productive in terms of patent applications after the Öresund Bridge was built and are also more productive than incumbent residents as a comparison between the estimated effect for the term $Malmö_i \times Post_{i,t}$ and $NEW_i \times Post_{i,t}$ indicates. On average, the effect of newcomers is stronger after the year 2000 and contributes with 78% to the relative increase in patents in Malmö, compared with the control regions.[9] Therefore, we conclude that the increase in patent applications in the Malmö region is largely attributable to an inflow of human capital.

[9]These percentages are derived from the nonlinear regressions' coefficient of $New_i\ Post_{i,t}$ and $Malmö_i \times Post_{i,t}$ by calculating the associated increases in patents following the formulae above and then calculating shares.

While it is true that not all selection and agglomeration effects are cleanly separated in this analysis, we think that the decomposition of the overall effect on Malmo from before-the-bridge residents and those that arrive later has some value in this regard because those that reside before are less susceptible to selection, which probably hints to an agglomeration effect. However, admittedly whether the inflow of individuals should be regarded as selection or agglomeration can be a matter of dispute, as their choice to settle in Malmo is an endogenous decision.

6 | CONCLUSION

This paper investigates the effect of the opening of the Öresund bridge on the innovativeness of the Swedish region of Malmö. Results from difference-in-difference estimations that compare the patent applications output of individuals in the Malmö region to the patent records of individuals in the regions of Stockholm and Gothenburg reveal that the Öresund Bridge has led to an increase in the Malmö region's patent filings of 30%–35%. The inflow of human capital in the form of new highly skilled individuals to the Malmö region explains 78% of the total increase in patent applications.

The literature argues that individuals new to the region increase the size, degree of specialization, and diversity of the local labor pool (Strange et al., 2006). The thickening of the regional labor market allows for better employer-employee matches (Berliant et al., 2006; Strange et al., 2006; Wheeler, 2001) and increases the productivity of individual inventors. This helps explaining the large effect of new inventors to the region on regional patenting.

Our results suggest that the increase of talent in the Malmö region, whether arriving before or after the bridge was built, was caused by an outflow of knowledge workers in Gothenburg and Stockholm. The outflows in Gothenburg and Stockholm need not imply a zero-sum game in which Malmö gained at the expense of other regions because the attraction of human capital across regional borders may have resulted in better matches. That is, we cannot know whether these individuals would counterfactually have been more or less innovative had they stayed. In addition, our analysis does not account for talent inflow to the control regions from elsewhere or the flow of human capital from Malmö to the control regions. However, it does not seem unreasonable to assume that there was some element of human capital loss implied for Gothenburg and Stockholm. Policymakers should therefore evaluate how the benefits accruing to the Malmö region compare to potential losses of human capital elsewhere. Because our analysis has only provided some first indications on potential trade-offs focusing on a specific mechanism, a more complete picture of all mechanisms behind an increased regional patent productivity following an infrastructure improvement project is of high relevance for policymakers. For a complete policy evaluation, one would need to account for all regional inflows and outflows of knowledge workers. Moreover, an additional experimental attraction factor could allow for a proper counterfactual analysis. However, such additional types of (natural) experimental data are unlikely to exist in connection with infrastructural projects.

Data limitations prevent us from exploiting the bilateral relationship between both sides of the Öresund. Despite the richness of our data set, it only provides information on Swedish residents. Therefore, for future research, it would be of great interest to understand how each part of the binational region benefits or affects the other part.

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How to cite this article: Ejermo, O., Hussinger, K., Kalash, B., & Schubert, T. (2021). Innovation in Malmö after the Öresund Bridge. *Journal of Regional Science*, 1–16. https://doi.org/10.1111/jors.12543