The Consequences of Radical Patent-Regime Change*

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Abstract:

We analyze the effect of patent-regime change on innovation by exploiting a quasi-natural experiment: the forced adoption of the Prussian patent system in territories annexed after the Austro-Prussian War of 1866. Compared to other German states, Prussia granted fewer patents because of a more rigorous technical examination and stricter novelty requirements. To test how the forced adoption of the more restrictive Prussian patent law affected innovation, we use novel hand-collected data on patents and world's fair exhibits. More precisely, we use world's fair exhibits as a proxy for non-patented innovation. First, we find that the forced adoption of the Prussian patent law caused a massive decline in patenting in annexed territories. Second, we find an increase in world's fair exhibits per capita in annexed territories after the patent-regime change, suggesting that the adoption of the Prussian patent system was conducive to non-patented innovation. We show that increased technology diffusion is a plausible channel for the positive effect of patent-regime change on innovation.

Keywords: Innovation, Intellectual Property, Patents, Patent Law, Technological Change

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1 Introduction

The question of whether patent law fosters or hampers inventive activity is essential to understand the long-run determinants of innovation and, consequently, economic growth. In 2021, the public debate about the societal benefits of patents gained momentum in light of the development of mRNA-based COVID-19 vaccines. Critics argue that patenting slowed down the worldwide ramp-up of vaccine production, thus preventing a fast containment of the pandemic, while the defenders of patenting argue that the fast development of COVID-19 vaccines is a testament for the incentivizing function of the current patent system. Yet, analyzing the causal effect of patenting on innovation is empirically challenging due to the lack of exogenous variation in patent laws. Therefore, we exploit a quasi-natural experiment in economic history: the consequences of a forced patent-regime change in 19th-century Germany. The results suggest that the adoption of a patent system with a more rigorous technical examination and stricter novelty requirements, allowing only a relatively low number of patents with short terms, is beneficial for innovation.

The forced patent-regime change was a result of the Austro-Prussian War of 1866. After its victory, Prussia enlarged its territory through the annexation of formerly independent states (among them the Kingdom of Hanover). In all annexed states, the Prussian patent system was introduced directly after the annexation, replacing the existing patent systems. For inventors in these territories, the patent-law change implied the reduction of patenting costs because patent fees were considerably lower in Prussia, while the economic value of a patent increased due to an enlarged domestic market. However, the probability of a successful patent application decreased because the Prussian patent law set stricter novelty requirements and was thus more restrictive. By using a novel hand-collected data set, we show that this patent-regime change caused a significant drop in the number of newly granted patents in annexed territories. Consequently, it became harder for firms to use patents for the creation of market-entry barriers so that the adoption of the Prussian patent law fostered competition and the free diffusion of knowledge. To test whether this patent-regime change affected inventive activity positively, we use new hand-collected data on World's Fair exhibits as a proxy for non-patented innovation, as suggested by Moser (2005). The results show a statistically significant increase in the number of world's fair exhibits after the adoption of the Prussian patent law, suggesting that the patent-regime change, which increased competition and knowledge diffusion, fostered innovation.

19th-century Germany provides an almost ideal setting to analyze the economic effects of patenting because of distinct regional variations in patent laws before the introduction of the nationwide German patent law in 1877. Before 1877, the German states granted patents based on individual rules, and there was no mutual acceptance of patents (Donges and Selgert, 2019a). The adoption of the

Prussian patent system in annexed territories preceded the full patent-law harmonization for about ten years. Immediately after the annexations, the Prussian government ordered not only the introduction of its patent law but also the dissolution of all formerly independent patent authorities, but there was no general legal harmonization. Differences in civil law, for instance, remained within Prussia until the introduction of the nationwide German civil code in 1900 (Acemoglu et al., 2011). Therefore, our historical setting allows us to isolate the effect of the patent-regime change from other institutional factors that may affect innovation. Since geo-strategic rather than economic motives drove all annexations, we consider the timing and geographical dimension of this legal transplant as exogenous, making it a quasi-natural experiment to test the effect of patenting on innovation.

To study this exogenous patent-regime change, we use a newly constructed data set. First, we use patent data that we hand-collected from original archival records. The data set includes all domestic patents filed between 1855 and 1877 in Prussia and four neighboring states that Prussia annexed in 1866 (Kingdom of Hanover, Electorate of Hesse (Hesse-Kassel), Duchy of Nassau, and Free City of Frankfurt am Main).[4] By applying a difference-in-difference model with yearly district-level data, we show that the number of patents per capita dropped significantly after the adoption of the more restrictive Prussian patent law. This decline was not driven by a single industry but affected almost the whole manufacturing sector. Yet, we also find a shift towards a higher share of instrument patents in annexed territories, and we find a higher share of patents filed by inventors with university background. We show that the decline in patenting is unlikely a result of alternative channels such as war-related distortions, other institutional reforms, migration, or discrimination against inventors from annexed territories.

Second, to create a proxy for innovation that differs from patents, we hand-collected data on the number of products exhibited at the World's Fairs in London (1862), Vienna (1873), and Philadelphia (1876) from original exhibition catalogs. By using a difference-in-differences model with yearly district-level data, we find a significant and robust increase in the number of World's Fair exhibits after the adoption of the Prussian patent law. Yet, there are differences across technology and product groups. Since we rule out alternative explanations such as market integration due to railway construction and political unification, the creation of national identity, and other institutional reforms, we interpret the increase in World's Fair exhibits in annexed territories as evidence for a positive effect of the patent-regime change on innovation.

We provide evidence that increased technology diffusion due to a lower number of patents on production technologies is a plausible channel that explains the positive effect of patent-regime change on innovation. By using patent stocks as a measure for the amount of protected technology, we show

[4] Domestic patents are patents filed by domestic inventors (individuals or firms). We do not include foreign patents (patents filed by foreign inventors) in order to avoid double counting.

that an increase in the patent stocks in a specific technology group is associated with a decrease in world's fair exhibits in this group. Put differently, we find an increase in world's fair exhibits of a specific technology group when the patent-regime change caused a reduction of the relevant patent stock.

By exploiting a historical event that caused a patent-regime change, we add to the empirical literature on the effect of IP protection on innovation (for an overview, see Moser, 2013). Recent empirical research questions the necessity of patents for stimulating inventive activity. Based on historical data, Moser (2005) shows that patent law did not stimulate innovation per se but instead shaped the direction of technical change, and Rhode (2021) provides evidence that patents were not necessary to stimulate the creation of new seeds in the Antebellum American South. By using modern data, Galasso and Schankerman (2014) show a positive effect of patent invalidation on subsequent research measured by patent citations, and Sampat and Williams (2019) find no quantitatively important effect of patents on human genes on follow-on innovation. Recent research also analyzes other types of IP protection. For example, Giorcelli and Moser (2020) study the effect of copyrights on creativity, and Hanlon and Jaworski (2019) show how IP rights concerning airframe designs affected innovation.

We also shed light on the debate about the usefulness of patent data for empirical research (for an overview, see Griliches, 1990). Typically, economists use patents as an indicator of inventive activity. However, patents only reflect a subset, since firms can, for example, keep their production techniques secret instead of filing a patent (Moser, 2012). This strategy is particularly useful when it is difficult to enforce patents in court or in the case of high, if not prohibitive patent fees, as in England during the industrial revolution (Mokyr, 2009). Thus, when using patents as a proxy for innovation, differences in the possibility to keep inventions secret or any legal restrictions (e.g., exclusion of patents in specific industries) have to be considered. Legal Differences make it particularly challenging to use patents for cross-country comparisons. In this regard, our paper provides a setting that shows how patented and non-patented innovation may vary when there are differences in patent law.

More generally, the paper relates to the influential literature on the importance of institutions. Following the seminal work of North (1990), empirical studies show a link between the quality of institutions and economic development (e.g., Acemoglu and Robinson, 2012; Acemoglu et al., 2011). However, the argument that institutions *cause* growth is controversial since a reverse effect is also plausible (e.g., Glaeser et al., 2004). Thus, for a better understanding of the effect of institutions on growth, we have to analyze the channels through which institutions cause growth. One plausible channel is innovation (Donges et al., 2021), which could be in turn affected by patent laws. The findings of this paper suggest that the adoption of a more restrictive patent system, under which the state grants relatively few patents, may increase the diffusion of knowledge and technology, foster competition, and, consequently, innovation. Since the adoption of the Prussian patent law also decreased patent fees, making patenting affordable for a larger part of the society, it was akin to the introduction of an *inclusive* institution tearing down economic entry barriers. Thus, there are similarities to the US patent system of the 19th century, which the literature considers conducive for the creation of innovation because of its “democratic” spirit (Khan, 2005; Khan and Sokoloff, 2004).

The paper proceeds as follows. We first provide an overview of the patent controversy–the discussion about the opposing effects of patents on innovation. In section 3, we describe the historical background. We explain our research design and the data set in section 4. In section 5, we test the effect of the patent-regime change on patenting. Next, in section 6, we test the effect of the patent-regime change on World’s Fair exhibits, which we use as a proxy for (non-patented) innovation. We then discuss potential mechanisms in section 7, and conclude in section 8.

2 The Patent Controversy

In the literature, there is a vigorous debate about the usefulness of patent protection for technological development. Economic theory provides arguments for either a positive or a negative effect of patents on innovation (for an overview, see Hall and Harhoff, 2012).

According to the “classical” view, patents are a contract between an inventor and the society: In exchange for a temporary monopoly right, the inventor agrees to reveal an invention to the public allowing for its free use after the patent expires. The monopoly is considered necessary for stimulating inventive activity since knowledge is a non-rivaling good. Thus, without patents, the private rate of return of an invention would be considerably lower than the social rate of return, and, consequently, the production of innovation would be below the social optimum. Patents can solve this problem by raising the private rate of return (Arrow, 1962). Patents also allow for the trade of intellectual property, thereby creating a market for inventions (Khan and Sokoloff, 2004; Khan, 2005). Such a market enables private inventors or small firms with limited assets and credit constraints to put their inventions into practice. It may, in turn, increase inventive activity and, thus, the stock of commercially useful knowledge.

In contrast, opponents of the patent system highlight growth-impeding effects. Boldrin and Levine (2010, 2013) stress the anti-competitive and rent-seeking nature of patents. This argument is particularly valid for “fundamental” patents that protect basic innovations. By controlling such patents, firms can block follow-up innovations and achieve a leading edge over competitors or even monopolize markets. In this regard, firms may also misallocate capital to gain a patent portfolio that allows blocking competitors through litigation (for a survey, see Hall and Harhoff, 2012).[5] There are also welfare losses due to rent-seeking, such as lobbying for stricter patent laws to impede new firms entering the market.[6]

According to critics of patents, competition may be the best incentive for innovation and productivity growth (Bessen and Maskin, 2009; Boldrin and Levine, 2010, 2013). However, Aghion et al. (2005) show an inverse U-shape relation between competition and innovation. Thus, the effect of patents may be sensitive to the degree of competition. That is, patent protection may increase social welfare when competition is too intense because, otherwise, first-mover advantages from innovation diminish too fast to incentivize innovation. The contrary may be true in markets with low competition.

Empirical evidence on the effect of patent protection on innovation is also ambiguous, and the literature suggests differences between industries. Concerning emerging industries with continuous technical change, Hall and Harhoff (2012) provide a survey on studies arguing that rewards to first-mover advantages seem to be critical, but not patents. However, there is evidence for a positive correlation between patent protection and innovation in some industries (e.g., pharmaceuticals). Galasso and Schankerman (2015) show industry-specific differences concerning the effect of patenting on downstream innovation. Heterogeneous effects may be a result of different imitation costs relative to the costs of innovation (Mansfield et al., 1981). In industries with a low ratio of imitation to innovation costs, first-mover advantages might diminish fast, creating disincentives for investment in R&D. When imitation costs are high, these disincentives might be smaller. Another positive aspect of patents is the public disclosure of inventions. Gross (2019) provides evidence that keeping inventions secret may delay follow-up inventions. Thus, the effect of patents on knowledge diffusion is also ambiguous.

The ambiguity of patent protection fuels the economic policy debate since the mid-19th century (Machlup and Penrose, 1950). Throughout the last 150 years, policy advice ranged from abolishing patents to implementing strong international intellectual property rights (Lerner, 2002). In this context, the literature discusses the design of an optimal patent system (Hall and Harhoff, 2012). Such a system should set incentives to encourage innovation for a large fraction of the society, but it should make new useful knowledge also easily accessible. In this regard, there should be low patent fees, a short patent term, a strict examination of novelty, and, at best, the state should grant patents only for innovations with high R&D sunk costs, low imitation costs, and inelastic demand (Boldrin and Levin, 2013; Nordhaus, 1969). That is, an optimal patent system should be open to all classes of society and should ensure the diffusion of patented technologies. It should furthermore only protect the kind of innovation where first-mover advantages are low and not sufficient to produce the socially optimal amount of innovation.

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[5] According to Boldrin and Levine (2010), James Watt provides an example for this strategy. They argue that Watt has delayed technological progress in steam engines successfully by blocking innovation with patents.

[6] The German chemical industry that pushed the imperial government to reform the patent law in 1891 is an often-cited example, see, e.g., Boldrin and Levine (2013), Hall and Harhoff (2012), and Murmann, (2003).

There are also different views concerning the optimal policy to trigger a catching-up process towards technological leaders. According to Lerner (2002), backward countries should implement weak patent regimes to foster the diffusion of knowledge from abroad. By contrast, Branstetter et al. (2006) show that multinational firms transferred more technology to foreign subsidiaries when the receiving countries strengthened patent laws. More recently, Auriol et al. (2019) argue that the incentives to protect intellectual property depend on the stage of the development and the size of an emerging country. The latter findings are especially relevant for this paper, since Prussia was still an economically backward country in the mid-19th century, lagging behind England and other industrial forerunners.

3 Historical Background

Before 1877, every German state used its individual patent system. Most states enacted rules regarding the granting of patents in the first half of the 19th century. However, the patent systems differed concerning the application and examination process, patent fees, patent terms, and the discrimination against foreigners (for details, see Donges and Selgert, 2019a). Among the states of the Zollverein (the German customs union founded in 1834), there were several attempts to harmonize patent laws. However, apart from vague guidelines regarding the definition of patentable objects and the trade with patented goods, all further harmonization attempts failed until 1877. In particular, there was also no mutual acceptance of patents. Hence, an inventor had to apply for a patent separately in each state of the Zollverein. Moreover, a patented invention in one Zollverein state did not imply that the same invention would also get a patent in a second state. Patent-friendly states granted a relatively high number of patents per capita, while others, in particular Prussia, pursued a more restrictive policy, granting only few patents. In the following, we first describe the patent system in Prussia and then turn to Hanover and the Hessian states (Hesse-Kassel, Nassau, and Frankfurt am Main), which Prussia annexed after the Austro-Prussian War of 1866 (see Figure 1).

[Insert Figure 1]

3.1 The Prussian Patent System

The Prussian patent system was based on a state decree (*Publikandum*) that the government enacted in 1815.[7] This decree was the first to set formal rules that the administration had to apply when granting patents. Later, in 1845, the government incorporated this patent *law* into the General Trade Regulation

[7] For the overview of the patent system, we rely on information from Heggen (1975) and Donges and Selgert (2019a).

Act of 1845. It remained in place until the introduction of the nationwide German patent law in 1877 and applied in all provinces so that there were no differences in patent law within Prussia.[8]

An essential characteristic of the Prussian patent law was the technical examination of each patent application by a commission of experts. This commission had to evaluate whether the invention was novel and relevant enough to get a patent. In practice, the Prussian officials applied a rigorous definition of novelty. When the basic idea of the invention was already publicly available, for example, published in a scientific journal, the Ministry rejected the application because it lacked novelty. Even when only a small circle knew an innovation, a rejection was likely. Consequently, this policy set high barriers to get an invention patented. In some cases, the Ministry even rejected inventions that the literature considers as technologically influential. The Siemens-Martin process for the production of steel, for example, did not receive a patent in Prussia (Heggen, 1975).

In the early years of the Prussian patent system, the patent term was also subject to an individual decision of the Ministry. As in the case of novelty examination, the Ministry used the report of the technical commission to base its decision. According to the law, the patent term could range between six months and 15 years, but the Ministry started to standardize the patent term in the 1850s (Donges and Selgert, 2019a). Until 1870, the standard patent term was five years, and then it was reduced to three years. An extension up to the maximum of 15 years was possible, but the patentee had to apply for it separately, and extensions were relatively uncommon.

Patenting costs were relatively low. Inventors only had to pay a stamp and writing fee for the submission of an application, which costed between one and 2.5 *Thaler*, while the average yearly income of artisans and workers was around 104 *Thaler* in the mid-19th century.[9] In contrast to other countries, there were no additional fees or taxes charged in the case of a successful patent application. The Prussian state even paid the costs for the patent publication and the work of the technical commission. In other German states, for example, in the Grand-Duchy of Baden, the patentees had to bear these costs themselves (Donges and Selgert, 2019b).

Concerning the technical examination and relatively low patent costs, the Prussian system was similar to the US patent system at the time (for the US, see Khan and Sokoloff, 2006). What made the two patent systems different is the strict definition of novelty that set higher requirements to get a patent in Prussia. The restrictive policy reflects the prevalence of economic liberalism within the Prussian

[8] In contrast, there were regional differences in civil law until 1900. In most parts of Prussia, the General State Laws for the Prussian States (*Allgemeines Landrecht*) was applied, while the French civil code was applied in the Province of the Rhine. This difference resulted from the French occupation in the late eighteenth century and the subsequent transplant of French institutions that persisted even after the French occupation (Acemoglu et al., 2011). However, French influence did not affect the design of the Prussian patent law (Donges and Selgert, 2019a).

[9] In the 1850s, one *Thaler* was equal to 0.53 USD (exchange-rate based on the silver value of both currencies). For patent costs, see Röhrich (1863) and Stolle (1855); for information on average incomes, see Gömmel (1979).

administration. In Prussia, many officials supported open markets and opposed the creation of entry barriers after the dissolution of guilds. These "free-trade" liberals lobbied massively against patents, since, from their point of view, patents were a new form of restriction, hampering the free flow of ideas. Although the liberals were influential, they could not push through a general abolition of patents against the supporters of patents, who argued that patents were necessary to create incentives for innovation. Thus, the Prussian patent system was a compromise between patent opponents and supporters. As a result, the barriers to *applying* for a patent were low because of only low application costs. However, the barriers to *receive* a patent were high since the Ministry rejected most patent applications.[10] In this regard, the governments in Hanover and the Hessian states pursued a distinctly different patent policy.[11]

3.2 Patent Laws in Hannover and the Hessian States

In Hanover, the royal government started to regulate the granting of patents in the late 1830s.[12] Later, in 1847, it incorporated a patent law in the Hanoverian Trade Act. The patent law of 1847 was a reaction to an agreement of the Zollverein member states in 1842. In this agreement, the Zollverein states agreed on (vague) guidelines that the patent authorities should apply when granting a patent. The Zollverein agreement restricted patents to new inventions and set rules concerning the trade with patented goods. However, it did not induce any further harmonization of patent laws, and distinct differences remained until 1877 (Donges and Selgert, 2019a). Even though Hanover did not join the Zollverein until 1854, the government incorporated the guidelines of the Zollverein agreement in its patent law. The Hessian states (Hesse-Kassel, Nassau, and Frankfurt am Main) adopted these rules after 1842. While Hesse-Kassel introduced a (formal) patent law in 1852, the governments of Nassau and Frankfurt am Main continued to grant patents based on administrative ordinances. However, economically, the latter were similar to patent laws.

In all four states, the government instructed a technical commission to examine the novelty of an invention. However, the examination was less strict than in Prussia, and the administration applied a broader definition of novelty. In Hanover, for example, the patent authority allowed the disclosure of an invention before the patent application provided the disclosure included only a small circle. In contrast, the Prussian patent authority would have considered such an invention as not novel and, consequently, rejected the patent application.[13] The Hanoverian administration was more patent-friendly and

[10] According to Heggen (1975), only around 10 percent of all applications passed the technical examination in the 1860s and 1870s. The contemporary literature of the nineteenth century reports similar approval rates.

[11] Another characteristic of the Prussian patent system was the discrimination of foreigners. In general, inventors from countries outside the Zollverein were not allowed to file a patent in Prussia (Donges and Selgert, 2019a).

[12] In the following overview, we mainly rely on information from Gehm (2004) (for Hanover) and Gehm (2012) (for Hesse-Kassel) as well as on archival sources (in particular for Nassau and Frankfurt am Main).

[13] There are several archival sources illustrating the differences in patent policy. For example, in 1865, the firm "Schäffer and Buddenberg" got a Hanoverian patent for a water meter, although the basic working principle of the water meter was

considered patents as an essential means to foster inventive activity. This view reflects an approach that was less competition-friendly than in Prussia. Prussia opened its economy already in 1807 by dissolving guilds and introducing freedom of trade (*Gewerbefreiheit*), while the process of economic liberalization lasted much longer in Hanover and the Hessian states (Acemoglu et al., 2011). Consequently, in Hanover, there were fewer reservations about trade restrictions and the creation of monopolies than in Prussia. The governments of the Hessian states pursued similar policies as Hanover so that the technical examination of patents and the definition of novelty was also less strict than in Prussia.

Concerning the different examination systems, state capacity also mattered. Compared to Prussia (19.2 million inhabitants in 1864), Hanover was a state of medium size (1.9 million inhabitants), but Hesse-Kassel (745,063 inhabitants), Nassau (468,311 inhabitants), and Frankfurt am Main (92,244 inhabitants) were relatively small.[14] A thorough technical examination by a permanent and well-funded commission, as it was the case in Prussia, would have overstrained the administrative capabilities of these states. Thus, the patent authorities in Hanover and the Hessian states relied on non-permanent experts that they recruited temporarily from other departments of the public administration or business associations.[15] By contrast, in Prussia, the technical commission consisted of full-employed, highly paid officials with academic education–a system that was less prone to cronyism and corruption.[16]

Compared to Prussia, there were also significant differences in patent costs. In Hannover, patent fees ranged between six and 31 *Thaler*, Nassau charged on average about 20 *Thaler*, and Frankfurt am Main about 8.5 *Thaler*. In Hesse-Kassel, patent fees ranged between five and 200 *Thaler*, even though such very high fees were not standard (Donges and Selgert, 2019a). These figures show that the Prussian patent fee was by far the lowest. When accounting for the differences in market size, the patent fees charged in Hanover and the Hessian states appear even more expensive. Relative patent fees were particularly expensive in Frankfurt am Main. In this city-state, the fee was rather low in absolute terms (only 8.5 *Thaler*), but expensive when considering the small size of the market, on which it was valid.

To conclude, the patent systems in Hanover and the Hessian states differed from the Prussian patent system in three respects. First, Hanover and the Hessian states applied a broader definition of novelty so that the chances to get an invention patented was higher than in Prussia. Second, the patent authorities applied a less sophisticated technical examination than in Prussia because free-trade

common knowledge. Interestingly, the same firm also tried to patent the water meter in Prussia, but the Prussian technical commission rejected the application because of a lack of novelty; see correspondence in: Niedersächsisches Landesarchiv (NLA), Hann. 95, N. 264.

[14] All numbers refer to the year 1864. Population data is from HGIS-Germany, see Appendix A2 for more information.

[15] For Hanover: NLA, Hann. 95, N. 264 and Hann. 134, N. 2407; for Hesse-Kassel: report of the Gewerbeverein about the patent application of Henschel and Sohn, Kassel September 18, 1847, collected in: Hessisches Staatsarchiv Marburg (HSM), 27 a II, N. 187.

[16] Details on the staff employed in the technical commission, in: Patentgesetzgebung in den Zollvereinsstaaten, Bd. 6, in: GStA PK, III. HA MdA II, Nr. 1319.

supporters had less influence, and the size of the states was much smaller so that there were not the same administrative capabilities as in Prussia. Third, Hanover and the Hessian states charged significantly higher patent fees than Prussia, in particular when taking differences in market size into account.

3.3 The Adoption of the Prussian Patent Law

In 1866, directly after the Austro-Prussian War, Hanover, Hesse-Kassel, Nassau, and Frankfurt am Main came under Prussian rule. While state borders disappeared, institutional differences between Prussia and the newly gained provinces remained for a longer time, since the Prussian administration did not harmonize the legal system until the introduction of a nationwide German civil code in 1900. By contrast, it unified the patent system immediately after the annexations by dissolving all former patent authorities and adopting the Prussian patent law in all new provinces.[17] Consequently, the Prussian Ministry of Trade and Commerce only granted patents for the entire monarchy (including all newly gained territories) after the annexation, which means that it was not possible to get a patent that was valid only in a single province (e.g., in Hanover).[18] Because of the larger territory and the expected increase in patent applications, the Prussian government also increased its staff at the technical commission in 1866.[19] However, the overall costs of adopting the Prussian patent system were relatively low because the administration did not rely on subordinate administrative bodies (e.g., regional patent offices) but only on a central patent administration in Berlin. This factor may explain why it was possible to harmonize the patent system in such a short period. Apart from that, keeping the old patent authorities in power would have undermined the restrictive policy of the Prussian patent authority so that it was rational to introduce the Prussian patent law immediately.

Since there were distinct differences before 1866, the adoption of the Prussian system was a radical patent-regime change in those territories that got under Prussian rule. In the archives, we find correspondences concerning the treatment of patent request. These sources provide evidence that the likelihood to get a patent decreased after the annexation because of stricter novelty requirements under the Prussian patent system. For example, in October 1866, Frank Marquard from New Jersey requested the extension of his existing patent, which he had filed in Hanover, to the entire Prussian Kingdom, but the Prussian patent authority denied his pledge arguing that his invention (cleaning gutta-percha and

[17] All patent applications from Hanoverian citizens were forwarded to and decided by the Ministry of Commerce and Trade. The correspondence is collected in Niedersächsiches Landesarchiv Hannover (NLA), Preußisches Zivilkommissariat (Hann. 116), Number 153, (henceforth cited as NLA, Hann. 116, N. 153).

[18] Ministry of Trade and Commerce to Generalgouvernement, Berlin October 23, 1866, in: NLA, Hann. 116, N. 153.

[19] Details on the staff employed in the technical commission, in: Patentgesetzgebung in den Zollvereinsstaaten, Bd. 6, in: GStA PK, III. HA MdA II, Nr. 1319.

natural rubber with chloroform) lacked novelty.[20] In another case, the Prussian technical commission denied the novelty of a peat press that a Hanoverian citizen wanted to patent.[21]

The adoption of the Prussian patent law was not caused or driven by a preceding change in inventive activity or by the emergence of new technologies. Instead, it was the indirect result of an exogenous event—the Austro-Prussian War. This circumstance makes it an almost ideal setting to study the economic consequences of a patent-law change on patenting and innovation.

3.4 The Austro-Prussian War

The Austro-Prussian War was a consequence of the political rivalry between Austria-Hungary and Prussia that characterized the period after the Congress of Vienna (1815). Both great powers claimed supremacy over the German Confederation, but the struggle between Austria-Hungary and Prussia remained non-violent for an extended period. In 1864, Prussia and Austria-Hungary even joined their forces to fight against Denmark in the Second Schleswig War of 1864. The Germans prevailed, and Denmark had to cede its southern possessions (the Duchies of Schleswig, Holstein, and Lauenburg). After the war, Prussia and Austria-Hungary administered these territories jointly. However, disputes about the future territorial organization caused a flare-up of the Austro-Prussian conflict and created the casus belli (Wehler, 1995, pp. 283-301). In summer 1866, Prussia initiated its military campaign against Austria-Hungary with the invasion of Holstein. Austria-Hungary demanded military assistance from the states of the German Confederation. A majority of them formally joined the coalition against Prussia, but most of them without showing strong military commitment. This situation allowed the concentration of Prussian forces, which ultimately defeated the Austro-Hungarian army in the decisive battle of Königgrätz on 3 July 1866. At the end of July, the war ended with a Prussian victory.

Directly after the war, Prussia annexed the territories of Hanover, Hesse-Kassel, and Frankfurt am Main, which all had joined the Austrian coalition against Prussia. Prussia also gained full control over Schleswig-Holstein, which it had administered jointly with Austria-Hungary since 1864. By controlling these territories, Prussia was able to close the gap between its western provinces—the Rhineland and Westphalia—and the Prussian mainland in the east (see Figure 1). The motives for this territorial expansion were rather geostrategic than economic. Bismarck considered even more extensive annexations. However, William I, King of Prussia, pushed him to pursue a more moderate policy in order to avoid conflicts with other European monarchs and to facilitate the subsequent political rapprochement between Prussia and the southern German states (Schmitt, 1975). The Kingdom of

[20] Ministry of Trade and Commerce to Generalgouvernement, Berlin December 4, 1866, in: NLA, Hann. 116, N. 153.
[21] Prussian technical commission, around January 3, 1867, in: NLA, Hann. 116, N. 153.

Saxony, for example, remained an independent state, although it was a former Austro-Hungarian ally and a promising target because of its highly developed economy.

The Austro-Prussian War lasted less than two months, and the main combat operations took place in Bohemia. Consequently, there were hardly any war-related destructions—neither in the Prussian mainland nor in the newly gained territories—, and the number of casualties and losses was relatively low when compared to later conflicts. Most of the German rulers, which formally had followed Austria-Hungary's call to arms, opposed sending troops and tried to avoid military confrontations with Prussia (Schmitt, 1975). There was also an aversion against war among Germans, and the idea of a German nation under Prussian lead was popular. As a result, the annexations faced hardly any resistance, and the occupation had no long-lasting negative consequences on local economies. War-related distortions pertained only to summer 1866, and the German economies experienced a boom after the war (Wehler, 1995, p. 96). These circumstances allow us to consider the Austro-Prussian War as an exogenous event that caused a patent-regime change in the territories that came under Prussian rule.

4 Research Design and Data

To investigate the economic consequence of patent-regime change, we apply a two-step strategy. First, we test how the adoption of the Prussian patent law affected patenting, measured by the number of newly filed domestic patents per capita. Second, we test whether this change affected non-patented innovation. Following Moser (2005), we take World's Fair exhibits as a proxy for the latter. In the next subsections, we describe the data and its sources in more detail.

4.1 Domestic Patents

Collecting patent data for the period before 1877 is a time-intensive and challenging task since there are no consistently published and easily accessible patent registers available. We hand-collected the data from original, mostly hand-written patent lists that are kept in the General State Archive in Karlsruhe. The German patent authorities compiled these lists and used them for the mutual exchange within the Zollverein between 1845 and 1877. Yearly patent lists are available for each patent-granting state of the Zollverein. These lists contain all granted patents (over 17,800) and include information about the patentees (name, place of residence, and occupation), dates of issue, patent terms, and short technical descriptions of the patents. We digitized these lists and created a data set, including all available information for each patent. Moreover, we used the technical descriptions to assign a technology group to each patent.[22]

[22] See Appendix A2.2 for more details on the data and the definition of technology groups.

We use patents granted in Prussia and four states that Prussia annexed in 1866 (Hanover, Hesse-Kassel, Nassau, and Frankfurt am Main).[23] Since the Prussian government dissolved all former patent authorities after the annexations, the patent lists of Hannover, Hesse, Nassau, and Frankfurt am Main are only available until 1866. For the later period, the Prussian lists include all patents granted to inventors from these territories. We only consider *domestic* patents (patents granted to domestic individuals or firms) and drop all *foreign* patents (patents granted to foreign individuals or firms). By excluding foreign patents, we avoid double-counting patents in the pre-1866 period, for example, when a Prussian inventor patented the same invention in Prussia and Hanover. We assigned the places of residence of the patentees to the corresponding administrative districts. We then aggregated the number of patents by year and district. In total, the data set contains yearly information for 34 administrative districts. Thereof, 26 in old Prussian provinces, six in Hannover, while Hesse-Kassel and Nassau (including Frankfurt am Main) represent one district, respectively.[24]

To test the effect of patent-regime change, we focus on time windows of eleven years before (1855-65) and after (1867-77) the annexations. During these two periods, we observe in total over 1,900 domestic patents filed by individuals or firms from the districts of our sample. We start in 1855, one year after Hanover entered the Zollverein so that we include only member states that were part of the customs union (all other states in the sample had joined earlier). Thus, we avoid problems associated with different trends in the pre-treatment period, since the incentives to file a patent in Hanover may have increased when the state entered the Zollverein.

4.2 World's Fair Exhibits

To investigate the economic consequences of patent-regime change on a non-patent-based proxy of innovation, we follow Moser (2005) and use World's Fair exhibits. Our data set includes information for one World's Fair that took place before the patent-regime change, London (1862), and two exhibitions for the period after the patent-regime change, Vienna (1873) and Philadelphia (1876).[25]

We hand-collected the data from the original exhibition catalogs of 1862, 1873, and 1876.[26] For each exhibit, the catalogs list information about the exhibitor (name and places of residence), a brief description of the exhibited goods, and the related technology group. In the empirical analysis, we include exhibitors from the old Prussian provinces and from territories that came under Prussian rule in

[23] Due to data availability, we do not include the Prussian province Schleswig-Holstein (under Danish rule before 1866) and the small Prussian exclave Hohenzollern (which was located south of Wuerttemberg).

[24] We merge Nassau and Frankfurt am Main because the territories formed one administrative district after the annexations. This is also justified by the fact that both states used similar patent laws before 1866.

[25] In 1867, there was a World's Fair in Paris. However, we do not consider data for this exhibition because it took place less than one year after the treatment so that a significant effect on innovation is very unlikely.

[26] See appendix A2.3 for more details on the data.

1866 (Hanover, Hesse-Kassel, Nassau, and Frankfurt am Main). As in the case of patents, we assigned the places listed in the exhibition catalogs to the corresponding districts and then aggregated all exhibits by districts. Overall, the panel-data set contains yearly information for 34 districts. In our sample, we observe over 1,300 exhibits for 1862, over 3,200 for 1873, and about 500 for 1876.

4.3 Patents vs. World's Fair Exhibits

Patents and World's Fair exhibits represent two different measures of innovation. In the German states, patents were mainly filed to protect investment goods such as new machine tools (e.g., steel cutting machines) or production processes (e.g., chemical processes). These types of inventions represent the vast majority, around 90 percent, of all patents in our sample, while there were almost no patents on intermediates or consumer goods (see Table 1).

[Insert Table 1]

We explain this pattern with the specific design of the German patent systems under the free-trade rules of the Zollverein. In 1842, the member states of the Zollverein agreed on guidelines concerning the granting of patents. In particular, this agreement prohibited restrictions on the trade with patented products to avoid misusing patents to circumvent the Zollverein's free-trade rules. However, it explicitly excluded machinery, machine parts, machine tools, and machine-like consumer durables (e.g., musical instruments) from these rules (Donges and Selgert, 2019a). Thus, from a commercial perspective, it made little sense to patent goods that differed from the latter categories, which we illustrate with the following example:

Assume that a steel-foundry owner invented a new type of high-quality steel sheet in Hanover. Under the Zollverein rules, it would have been possible to file a patent for this steel sheet, but the free-trade rules did not restrict the sale of the same product imported from another Zollverein state. Put differently, domestic competitors could have imported the same type of steel sheet from Prussia and sell it without any restrictions in Hanover. Therefore, patenting the machine tools that were necessary to produce this type of steel sheet in as many German states as possible (including the home state) was a superior strategy, given the higher degree of patent protection.

While most of the patents were filed for investment goods, World's Fair exhibits span a much broader set of innovative products, including also intermediates, as well as durable and non-durable consumer goods. Furthermore, the World's Fairs were places to present regional-specific commodities such as coal, mineral ores, and agricultural products, which could not get patented.[27] The latter type of

[27] For example, in 1862, the *Hörder Bergwerks und Hütten Verein* (one of the larger mining companies of the Ruhr district) presented "coal and speciemens of intermediate rocks" (1862, exhibit no. 746). An example for the exhibition of agricultural

goods did not necessarily represent innovative products, even though the availability of new production techniques (e.g., mining equipment) may have affected their production. Moreover, World's Fairs also included the exhibition of artwork (e.g., oil paintings), scientific research results, or information about a country's culture and traditions. To identify the different types of products, we assigned a product group to each exhibit. In the empirical analysis, we exclude all commodities and cultural exhibits (e.g. artwork), since it is unlikely that the patent-regime change affected the provision of these goods.[28]

In Table 2, we show the distribution of exhibits by product groups for each World's Fair included in the data set. Consumer goods account for the largest fraction, followed by intermediates, while the share of investment goods is relatively small, which contrasts the large share of patents filed for the latter. The fact that we observe a much broader set of innovation than in our patent data is consistent with the findings of Moser (2005, 2012), who shows that only a small fraction of all US exhibits was actually patented. It also reflects recent findings of Domini (2020), showing for the case of the 1911 World's Fair in Torino that exhibits and patents were rather disjoint sets of innovation.

[Insert Table 2]

The exhibitors at the World's Fairs include private companies, individuals, and public entities. Formally, the participating countries enrolled all exhibits. The countries' local organization boards corresponded with the World's Fair organizers to settle important issues such as display space, transport, and tariffs. National selection committees advertised the exhibitions and invited potential exhibitors, while private businessmen and chambers of commerce supported the committees by providing an overview of companies with innovative products that were worth exhibiting. Formally, the national selection committees made the last decision whether to accept an exhibitor or not, but, in practice, companies and private organizations selected themselves into the exhibition (Kroker, 1975).

The organizers of the 1862 exhibition in London stipulated that exhibits should have been produced after 1850, which means that the exhibits should be innovative products and produced with the newest production techniques (Hollingshead, 1862, p. 50). Similarly, the organizational statute of the 1873 fair in Vienna stated that the exhibition should represent the "cultural life of the present" and "promote progress" (Kaiserliche Commission, 1873). Since the World's Fairs were a platform used by the participating countries to present their economic power, the national selection committees were not only concerned with presenting an encompassing picture of their national industry but also of their technological prowess (Kroker, 1975, pp. 28-30). Apart from that, the individual exhibitors had strong economic incentives presenting their innovative products in order to acquire new customers, raise their

goods is "red wheat, flour, hasty-barley, and oats for sowing" (1873, exhibit no. 630) presented by The Wiesbaden Directors of the Association of the Nassau Farmers and Forest Cultivators.

[28] In the Appendix, we present additional results including also commodities and cultural exhibits.

profile, or sell licenses for the use of their inventions (Domini, 2020; Kroker, 1975, pp. 58-64). Therefore, World's Fair exhibits represent either innovative products (e.g., machines) or products manufactured with cutting-edge production technologies (e.g., high-quality textiles).

Patents may have restricted the diffusion of cutting-edge production technologies and, thus, the ability to produce innovative products that were exhibited at the World's Fairs. By contrast, strong patent protection may have also increased the incentives to invent such technologies and the public disclosure through patenting may have facilitated the diffusion of technology. Thus, the net effect of patent protection on innovation is not obvious. In the following chapters, we study this link between patenting and innovation by using the exogenous adoption of the Prussian patent system in annexed territories.

5 Effect of Patent-Regime Change on Patenting

Figure 2 shows the mean number of domestic patents granted yearly per million inhabitants between 1855 and 1877. We distinguish between districts that Prussia annexed in 1866 and districts that were part of Prussia's old provinces. In annexed territories, we observe, on average, a higher number of patents per million inhabitants before 1866, but the mean is lower after the patent-law change. By contrast, there is no similar drop in Prussia's old provinces. This pattern suggests a negative effect of patent-regime change in annexed territories. In the following, we provide evidence that the observed decline in patenting is statistically significant and that the patent-regime change caused this decline.

[Insert Figure 2]

5.1 Descriptive Statistics

Table 3 presents summary statics for the number of domestic patents per million inhabitants in the old Prussian provinces and annexed territories, respectively. The table distinguishes between the period before (1855-65) and after the patent-regime change (1867-77). We drop 1866, since the Austro-Prussian War took place in the middle of this year and war-related distortions may have affected inventive activity and the decision to file a patent in the short run.

[Insert Table 3]

Before 1866, the mean yearly number of domestic patents per million inhabitants was 3.07 in old Prussian provinces and 5.76 in territories that came under Prussian rule in 1866. Put differently, the latter territories granted, on average, about 88 percent more domestic patents per million inhabitants than

Prussia. However, this ratio reversed after 1866. The mean number of patents per million inhabitants increased in old Prussian provinces to 4.19, while it declined to 2.18 in annexed territories.[29]

5.2 Main Results

To study the effects of patent-regime change on patenting, we employ a difference-in-difference model with district- and year-fixed-effects. The regression model takes the following form:

$$(1) \qquad ln(PPC_{it}) = \beta \, Annexed_i \; x \; T_{Post1866} + D_i + T_t + X'_{it} \gamma + \varepsilon_{it}$$

$ln(PPC_{it})$ is the natural logarithm of one plus the number of domestic patents per million inhabitants in district *i* and year *t*. We use the interaction $Annexed_i \; x \; T_{Post1866}$ to test how the forced adoption of the Prussian patent law affected patenting. $Annexed_i$ equals one if the district was part of a state that Prussia annexed in 1866, and zero otherwise, while $T_{Post1866}$ is one for all years after 1866, and zero for all years before 1866. β is the coefficient of interest that measures the effect of patent-regime change. In addition, we include district-fixed-effects (D_i) to account for time-invariant factors that may cause persistent regional differences in patenting and innovation,[30] and year-fixed effects (T_t) to account for the increase in inventive activity during the 19th century. X_{it} is a vector, including additional controls that vary over time and between districts, γ is the vector of coefficients, and ε_{it} the error term. We use robust standard errors clustered at the district level.

[Insert Table 4]

Table 4 reports results for the effect of the patent-regime change on patenting. In column (1), we report the coefficient for the basic specification, including district-fixed and year-fixed effects, but without additional controls estimated with OLS. We find a significantly negative effect of the patent law change on patents per capita. The magnitude of the coefficient of *Annexed State* $x \; T_{Post1866}$ implies that, after controlling for district- and year-fixed effects, the yearly number of patents per capita drops about 56 percent after the adoption of the Prussian patent law.[31] In column (2), we use the same specification but include four additional controls. We use *Population Density*, which is not only a proxy for economic development but also captures differences in human capital resulting from agglomeration effects because densely populated areas facilitate the exchange of knowledge and attract educated people.[32] By controlling for *Steel Production* and *Coal Mining*, we account for different growth trends in districts

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[29] Note that this decline is not driven by a decline in population but by a massive drop in patenting. In Appendix A1.1, we show separate summary statistics for the number of domestic patents and the number of inhabitants.

[30] Such factors include geographic characteristics affecting market access (Sokoloff, 1988), persistent differences in human capital (Becker and Woessmann, 2009; Cinnirella and Streb, 2017), or the inclusiveness of institutions (Acemoglu et al., 2011; Donges et al., 2019).

[31] Since we use a log-linear specification, we compute the percentage change for the effect of $Annexed_i \; x \; T_{Post1866}$ in the following way: $\Delta\% = 100(exp(-0.8323)-1) = -56.5$; for the transformation, see Van Garderen and Sha (2002).

[32] Note that district-level data on GDP per capita is not available for this period.

with mining and heavy industry. Finally, we use *Economic Liberalization* to control for differences in the year when economic freedom (*Gewerbefreiheit*) was introduced (Acemoglu et al., 2011). When adding these controls, the estimated coefficient of *Annexed State x* $T_{Post1866}$ changes only slightly and remains highly significant. In column (3), we test whether the effect also holds after excluding all eastern Prussian provinces (East Elbia), which lagged economically and might thus be an inadequate control group when analyzing the determinants of patenting and innovation.[33] However, the effect of *Annexed State x* $T_{Post1866}$ remains highly significant.

Given that there are many zero observations, which is a typical characteristic of disaggregated patent data, we use a fixed-effects Poisson estimation in columns (4) to (6) as an additional robustness test. In all three specifications, we take *Patents* (number of patents) as the endogenous variable, we include district- and year-fixed-effects, and, in addition, control for the district population. Column (4) reports the results for the basic model, column (5) for the model with additional controls, and column (6) for the model without East Elbia. The estimated coefficients of *Annexed State x* $T_{Post1866}$ are significantly negative, and the magnitudes of the effects remain large.

5.3 Event-Study Results

If the adoption of the Prussian patent law had *caused* the observed decline in the number of patents per capita, we would expect an immediate drop in the number of patents per capita, directly after the patent law change. In this subsection, we test this hypothesis by estimating the following regression model:

$$(2) \qquad ln(PPC)_{it} = \sum \beta_t \, Annexed_i \; x \; T_t + D_i + T_t + Trend_i + X'_{it} \gamma + \varepsilon_{it}$$

We use the same variable definitions as before. However, in contrast to all previous models, it interacts the dummy variable $Annexed_i$ with a series of year dummies T_t. We include interaction terms for each year in the period 1855-64 and 1867-77, and take 1865 as the reference year. Thus, we estimate 21 interaction coefficients. These coefficients indicate whether there is a significant difference in the number of patents per capita compared to the control group and after controlling for all other effects. We report the estimated coefficients in Figure 3. In Panel A of Figure 3, we report the results for the fixed-effects OLS model with *ln(PPC)* as the endogenous variable. The left graph (A1) shows the coefficients for the basic specification with district- and year-fixed effects, but no additional controls, and the right graph (A2) the coefficients estimated in the model with additional controls. In both graphs, we observe a significant drop in patenting, directly after the adoption of the Prussian patent law, and the

[33] There is a vast literature discussing the causes and consequences of economic backwardness within Prussia, in particular the role of human capital, see e.g. Becker and Woessmann (2009) and Cinnirella and Streb (2017).

coefficients remain significantly negative for subsequent years. We find a similar discontinuity when employing a the fixed-effects Poisson estimation with *Patents* as the endogenous variable (Panel B).

[Insert Figure 3]

5.4 Effect on the Composition of Patents by Technology Groups

To test whether the patent-regime change affected patenting differently across technology groups, we use the technical descriptions in the patent lists to assign a technology group to each patent. We classify the patents according to the industry of use and distinguish between 15 groups.[34] Since the average yearly number of patents is relatively small, we aggregated the patents at the district level for the pre-1866 and post-1866 period, respectively, to compute the share of patents of a specific technology group.

In Table 5, we test whether the share of patents of a specific technology group was significantly higher in annexed territories in the post-1866 period by using a fixed-effects OLS regression. In columns (1) to (6), we show results for six quantitively important technology groups ("Metals & Mining", "Chemicals", "Foodstuff & Kindred Products", "Machine-building & Transportation", "Instruments", and "Textiles"), respectively. These groups represent together about 60 percent of all patents filed in annexed territories in the pre-1866 period and about 86 percent in the post-1866 period. We only find a significant change in column (5), for the group "Instruments", which was a high-tech sector at the time, including optical and precision-mechanic equipment that was used in scientific and industrial research (Moser, 2005). The estimated coefficient implies an increase by 21.6 percentage points. Since, before 1866, the mean share of patents in this group was only about two percent in annexed territories, the magnitude of this effect is very large.[35] In contrast to all other quantitively relevant technology groups, the number of instrument patents also increased in absolute terms after 1866. One plausible explanation is that inventions in this group had a higher chance to pass the strict technical examination in Prussia than inventions in rather traditional fields such as textile production, where inventions were often only improvements of existing technologies, lacking the strict novelty requirements. To conclude, while the patent-regime change lead to significant decline in patenting, there was variation across technology groups, but this variation is mainly driven by the increase in instrument patents.

[Insert Table 5]

5.5 Effect on the Composition of Patentees by Social Background

The adoption of the Prussian patent system caused a decrease in patent fees but also introduced a stricter novelty examination. While the decrease in patent fees made patent applications affordable for larger

[34] See Appendix A2.2 for the more details on the classification of technology groups.
[35] See also Appendix A1.X, in which we show summary statistics for the shares for all technology groups.

parts of the society, the stricter novelty examination implicitly increased the human capital necessary for a *successful* application. First, innovation in industries at the technological frontier required more formal education than in traditional industries and the likelihood to pass the novelty examination may have been higher in the first than in the latter. Second, formal education facilitated the preparation of precisely-written patent specifications, which may have increased the chances to pass the examination. To test the net effect of the patent-regime change on the social composition of the patentees, we use information on their occupational background, which is reported in the patent lists, to categorize all patentees according to their social status and education. As in the case of technology groups, we aggregate the patents at the district level for the pre-1866 and post-1866 period, respectively, to compute the share of patents filed by a specific group of patentees.

In Table 6, we show results for the effect of the patent-regime change on the social background of patentees, using models with district- and year-fixed effects. In column (1), we take the share of patentees with occupations that are associated with the highest social status as outcome variable. This group includes factory owners, directors, estate owners, high-skilled employees with university education (e.g., chemists), and civil servants with university education (e.g., professors). The estimated coefficient is significant at the 10-percent level and implies an increase of patents filed by these patentees by 27.8 percentage points after 1866. Then, we split the share of patentees with high social status in two groups. In column (2), we estimate the effect of patent-regime change on the share of patents filed by all patentees with high social status and university education. The estimated coefficient is highly significant and indicates an increase by 33.6 percentage points. By contrast, we find no significant effect in column (3), in which we use the share of patents filed by patentees with high social status but without university education as outcome variable. These results suggest that there was a shift in the social composition towards a higher share of patentees with university education. Thus, even though patenting became more affordable due to lower patent fees, the share of patentees with lower social status (e.g., artisans or skilled workers) decreased after 1866 in annexed territories. This finding suggests that a successful patent application in Prussia required on average more formal education. The fact that we observe a higher share of instrument patents after 1866 is in line with this argument, given that patentees with higher education accounted for a relatively large fraction of these patents.

[Insert Table 6]

5.6 Alternative Explanations

We have shown that there was a significant decline in patenting after 1866. In the following, we explain why it is unlikely that other factors than the patent-regime change explain this decline.

War-related Distortions

First, a decline in patenting could be the result of economic depression after the Austro-Prussian War. However, there is no historical evidence for a longer-lasting economic depression in annexed territories that may have affected innovation and the incentives to file a patent negatively. Immediately after the war, there might have been negative consequences, but we account for this potential effect by excluding the year 1866 in all regressions. Also, we include controls such as steel production per capita, which should capture a potential decline in economic activity.[36]

Other Institutional Reforms

Second, it is unlikely that other institutional reforms than the adoption of the Prussian patent system explain the observed effect. There were differences in civil law, but these differences persisted until the introduction of the nationwide German civil code in 1900 (Acemoglu et al., 2011), and the trade law had already been harmonized in 1861 so that it was also not affected by the annexation.[37] The introduction of freedom of trade (*Gewerbefreiheit*) was another important reform. In 1869, it was established in the former territories of Hanover and Hesse-Kassel and led to the dissolution of guilds and other trade restrictions. Most other Prussian provinces had enacted freedom of trade already by 1810 (Acemoglu et al., 2011) so that we may interpret this institutional reform as a correlated shock. However, given that guilds impeded innovation and technical change (Donges et al., 2019; Ogilvie, 2014), we would expect a positive but not a negative effect of economic liberalization on patenting. Put differently, economic liberalization may have spurred both innovation and the incentives to file patents to establish new competitive barriers, which contrasts the negative effect that we find. Note that we also account for this reform by including the variable *Economic Liberalization* as an additional control in our regressions.

Migration

Third, it is unlikely that migration from annexed territories to other parts of Prussia explains the decline in patenting, since the population continued to grow, and there are no hints for such an effect in the literature.[38] Moreover, we find no evidence for a specific inventor "brain drain". Inventors migrated to large cities, in particular to Berlin, but such migration also happened before 1866, and there is no reason to believe that it accelerated in annexed territories after 1866. To further strengthen this argument, we checked whether there are individuals that reported different places of residence before and after the annexation. However, we find no evidence for systematic migration from new to old Prussian provinces.

[36] Apart from that, we show in section 6 of the paper that there is a significant increase in the number of World's Fair exhibits per capita, which provides further evidence against the hypothesis of a decline in economic activity and innovation.

[37] In 1861, the German states introduced a common trade law, the *Allgemeines Deutsches Handelsgesetzbuch*.

[38] See also the population figures that we report in Appendix A1.1.

Discrimination

Fourth, it is unlikely that the Prussian patent authority discriminated against inventors from annexed territories. Discrimination could explain the decline in patenting, but we find no hints for such a practice, neither in the archives nor in the historical literature.

Overall, there is strong evidence that the forced adoption of the Prussian patent law caused an immediate decline in patenting, even though the incentives to file a patent increased because of lower patent costs and an increase in the market size. In general, we would expect an increase in patenting when patent costs decrease, as was the case in the United Kingdom after the patent fee reform of 1884 (Kügler, 2019). However, the adoption of the Prussian patent law decreased the likelihood of a successful patent application because of a more sophisticated technical examination and a stricter definition of novelty. Thus, the net effect on patenting was negative.

6 Effect of Patent-Regime Change on Innovation

While we have shown that the adoption of the Prussian patent law led to a decrease in the number of patents in annexed territories, we now analyze the effect of patent-regime on a broader, non-patent-based proxy for innovation. There are two theoretically plausible effects, yet with different signs, so that the net effect of patent-regime on innovation is a priori not obvious. On the one hand, it could be that stricter novelty requirements and higher rejection rates have discouraged inventive activity in annexed territories after 1866, which may have resulted not only in fewer patents but also less non-patented innovation. On the other hand, the adoption of the Prussian patent system may have disrupted technological monopolies that had hampered the diffusion of new technologies and restricted competition so that we would expect innovation-enhancing effects. In the following, to test the *net* effects of the patent-regime change on a non-patent-based proxy for innovation empirically, we use data on products exhibited at the World's Fairs of 1862 (London), 1873 (Vienna), and 1876 (Philadelphia).

6.1 Descriptive Statistics

In Table 7, we report summary statistics for the number of world's fair exhibits per district and million inhabitants for Prussia (old provinces) and annexed territories in 1862, 1873, and 1876, respectively. Since we use world's fair exhibits as a proxy for innovation, we exclude unprocessed commodities (e.g., minerals) and all cultural products (e.g., artworks such as paintings). When compared with 1862, the total number of exhibits was higher in 1873 but lower in 1876, reflecting the different size of the exhibition area that was available for German exhibitors.[39]

Concerning the effects of patent-regime change, we are interested in the development of the mean number of World's Fair exhibits in annexed territories, when compared with Prussia (old provinces). In annexed provinces, the number of exhibits per million inhabitants was only 39.5 in 1862, while it was 58.4 in Prussia's old provinces. This ratio contrasts the relatively lower number of Prussian patents in this period that we have shown in section 5. However, in 1873, the ratio has reversed. In annexed territories, we observe, on average, about 124.8 exhibits per million inhabitants in 1873, compared to 110.6 in Prussia's old provinces. The picture looks similar for 1876, even though the total number of exhibits decreased. While there were, on average, 19.3 exhibits per million inhabitants from annexed territories, there were only 12.1 from old provinces. To conclude, the descriptive statistics suggests that innovation increased in annexed territories after the patent-regime change.

[Insert Table 7]

6.2 Main Results

In the following, we employ a difference-in-difference model to analyze the effects of patent-regime change on innovation. The regression equation takes the following form:

$$(3) \quad ln(ExPC_{it}) = \beta_1 \, Annexed_i \, x \, T_{1873} + \beta_2 \, Annexed_i \, x \, T_{1876} + D_i + T_t + X'_{it} \, \gamma + \varepsilon_{it}$$

$ln(ExPC_{it})$ denotes the natural logarithm of one plus the number of world's fair exhibits per million inhabitants in district *i* and year *t*. The interactions $Annexed_i \, x \, T_{1873}$ and $Annexed_i \, x \, T_{1876}$ are the treatment variables with $Annexed_i$ indicating districts that Prussia annexed in 1866 and the dummy variables T_{1873} and T_{1876} indicating the respective year of observation. We include district-fixed effects (D_i) to account for time-invariant differences in the ability to innovate, and we use time-fixed effects (T_t) to account for differences in the total number of world's fair exhibits. X'_{it} includes additional control variables, ε_{it} is the error term, and β_1 and β_2 are the coefficients of interest that measure the effect of patent-regime change. In all regressions, we use robust standard errors clustered at the district level.

In column (1) of Table 8, we present the basic specification, including only the interaction terms as well as district- and year-fixed effects. The effects of the treatment variables $Annexed \, x \, T_{1873}$ $Annexed \, x \, T_{1876}$ are both positive, which contrasts the decrease in patenting that we find in section 5. However, only the effect of $Annexed \, x \, T_{1873}$ is significant. Column (2) includes additional controls accounting for differences in population density, steel production, coal mining, institutional quality (measured with the

[39] In 1862 (London), the German exhibitors could only use an area of 8,200 square meters, but they could use 36,000 square meters in 1873 (Vienna). In the regressions, we use time-fixed effects to account for this effect.

years since the introduction of freedom of trade), and the distance between each district and the location of the respective world's fair. We use the latter control to account for potentially lower transaction costs for districts that were closer to the place of the world's fair, which might have affected the decision to exhibit a product. When controlling for these variables, the magnitudes of the estimated coefficients for *Annexed x* T_{1873} and *Annexed x* T_{1876} increased compared to column (1). Both coefficients are highly significant. The effect of *Annexed x* T_{1873} implies an increase in the number of World's Fair exhibits by about 320 percent after the adoption of the Prussian patent law, and the coefficient of *Annexed x* T_{1876} implies an increase of 190 percent.[40] The effects also remain significant and of similar size when excluding the under-developed districts in the Eastern part of Prussia (East Elbia) from the sample in column (3). As additional robustness tests, we use a conditional fixed-effects Poisson estimation in columns (4) to (6) with the number of exhibits (*Exhibits*) as outcome variable and the district population as additional control. In all three specifications, we find significantly positive treatment effects. Hence, there is evidence for an economically and statistically significant effect of the patent-regime change on world's fair exhibits, which we use as a proxy for innovation.

[Insert Table 8]

6.3 Effect on the Composition of Technology Groups

To figure out whether the patent-regime change affected the direction of technological change, we now focus on the share of exhibits related to a specific technology group. Following the approach in Table 5, we show the results for six quantitatively relevant technology groups ("Metals & Mining", "Chemicals", "Foodstuff & Kindred Products", "Machine-building & Transport", "Instruments", and "Textiles"). More precisely, we test whether the share of exhibits of a specific technology group changed as a result of the patent-regime change in the districts of observation. Table 9 shows the results.

We find evidence for a significantly negative effect on the share of exhibits in "Metals & Mining" in column (1) and we also find a negative effect on the share of exhibits in the group "Instruments" in column (5). By contrast, we find a significantly positive and quantitively large effect for "Foodstuff & Kindred Products" in column (3) and, in column (4), the effect on the share of exhibits in "Machine-building & Transport" is also positive and significant but relatively small. In columns (2) and (6) we find no significant effects for the groups "Chemicals" and "Textiles". Given the results of Moser (2005), we would expect a negative effect on innovation in machine-building, since this industry is associated with a rather high propensity to patent innovation. By contrast, we would expect a positive effect on innovation in foodstuff industries and instruments because we assume lower propensities to patent

[40] Since we use a log-linear specification, we compute the percentage change for the effect of *Annexed x* T_{1873} in the following way: $\Delta\% = 100(\exp(1.4358)-1) = 320.3$; for the transformation, see Van Garderen and Sha (2002).

innovation. Yet, while we observe indeed an increase in the share of foodstuff related exhibits, the effect on the share of machine-building is also positive and the effect on the share of instruments is negative. To conclude, we observe a shift in the relative importance of certain technologies, but we find no clear evidence for a shift towards technology groups with lower propensities to patent.

[Insert Table 9]

6.4 Effect on the Composition by Product Groups

Because of the legal constraints, in the German states, most patents were filed for investment goods including machines and production techniques (e.g., chemical processes). By contrast, world's fair exhibits represent a broader set of innovative products, including also intermediates (e.g., high-quality steel) and consumer goods (e.g., non-durables such as foodstuff and durables such as furniture). Given that the Prussian patent system was more restrictive, setting higher barriers to get a patent, we test whether the forced adoption of the Prussian patent system lead to a reallocation of inventive activity to product groups for which patenting was less relevant.

In the following, we distinguish between three product groups (investment goods, intermediates, and consumer goods) and compute the share of each group relative to all exhibits in a district in the respective year of observation. Then, we test whether the share of each product group changed as a result of the patent-regime change, using the same model as in the previous subsection. Table 10 shows the results. In column (1), we use the share of investment goods as endogenous variable. We find no significant effect for 1873 and only a small positive effect for 1876, but it is only weakly significant. In column (2), we find a significantly negative effect for intermediates in 1876. Last, in column (3), we test the effect on the share of consumer goods. The coefficients are positive for 1873 and 1876, but only significant for 1873. To conclude, we find no negative effect on the share of investment goods. Therefore, since investment goods were the type of goods that could be protected effectively under the Prussian patent systems, the results provide no evidence for a reallocation of inventive activity towards products for which patenting was less relevant. We only find evidence for a reallocation of inventive activity from intermediates to consumer goods in annexed territories. Put differently, after the patent regime change, world's fair exhibits from annexed territories were on average of higher value added. A potential explanation for this finding is better access to new production technology, since the Prussian patent system made it harder to protect production technology via patents, when compared with the patent systems that were in place before 1866.

[Insert Table 10]

6.5 Alternative Explanations

We have shown that there is a significant increase in the number of world's fair exhibits in annexed territories after 1866. However, to provide evidence for a *causal* link between the change in the patent system and the increase in exhibits, which we use as a proxy for innovation, we have to rule out correlated shocks that may provide alternative channels. In the following, we first conduct additional tests to rule out market integration via improved railway connections and political unification, since market integration can foster trade, economic growth, and innovation. Then, we discuss the emergence of German national identity as well as other institutional reforms that took place after 1866.

Market Integration via Railways

The expansion of the railway system fostered market integration within Prussia and, consequently, economic growth (Hornung, 2015). This raises the question whether the increase in World's Fair exhibits reflects eventually a growth effect that was related to railway construction. However, in the literature, we find no evidence for a link between the annexations and the development of the railway network, for example, by better connecting the Prussian railways with the railways in annexed territories. German states adapted the new railway technology very fast. The first railways emerged in the 1830s and developed into a network since the mid-1840s. Thus, the railway systems were already well connected at the end of the 1850s, long before the annexations.[41]

To further rule out railway construction as an alternative channel, we test whether the number of World's Fair exhibits also increased in (old) Prussian districts that bordered annexed territories. If there were a strong effect of market integration via improved railway connections, we would expect that these border districts also profited stronger from an improved connection. In column (1) of Table 11, we present the result of this test. We use the fixed-effects model with *ln(ExPC)* as the endogenous variable and all additional controls. To test for potential market-integration effects, we use the variables *Border Prussia x* T_{1873} and *Border Prussia x* T_{1876}. *Border* is a dummy variable that equals one for (old) Prussian districts that bordered annexed territories,[42] which we interact with the respective year dummies. The coefficients of *Border Prussia x* T_{1873} and *Border Prussia x* T_{1876} are not significant.[43] Hence, this test provides no evidence for an effect of market integration via better railway connections.

[Insert Table 11]

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[41] See the maps of the German railway network on IEG-Maps (https://www.ieg-maps.uni-mainz.de/map5.htm).

[42] In the west, the bordering districts were Münster, Minden, Arnsberg, and Koblenz; in the east, the bordering districts were Potsdam, Magdeburg, and Erfurt.

[43] We find a similar result when using a conditional fixed-effects Poisson model (see Table A5 in the appendix).

Market Integration via Political Unification

The annexations of 1866 and the formation of the North German Federation in 1867 were major steps in the process of political unification that eventually led to the foundation of the German Empire in 1871. However, the process of economic integration started much earlier. The major step to creating a common German market was the formation of the Zollverein in 1834, which Prussia had pushed forward (Keller and Shiue, 2014; Huning and Wolf, 2019). Hesse-Kassel joined the Zollverein already in 1834, Nassau in 1835, and Frankfurt am Main in 1836.[44] At the beginning of the 1850s, almost all German states were part of the customs union, and Hanover eventually joined in 1854. Thus, when Prussia annexed Hanover, Hesse-Kassel, Nassau, and Frankfurt am Main in 1866, their markets were already long integrated into the common market, making it less likely that market integration through political unification caused the increase in World's Fair exhibits.

To provide further evidence that the results are not driven by the economic effects of political unification, we use additional data on German states that were not affected by the annexations but may have also profited from potential market integration in the North German Federation and the Empire. If market integration were crucial for innovation, we would expect a similar increase in the number of World's Fair exhibits in these territories after 1867. To test this hypothesis, we extend the sample by including data for a group of other medium-sized and small German states that bordered Prussia but were not affected by the annexations of 1866.[45] We use the same model that we describe in section 6.2 but for the extended sample, and we include the interactions *Border State x* T_{1873} and *Border State x* T_{1876} to conduct a Placebo-control test. *Border State* is a dummy variable indicating whether a district was part of the group of control states mentioned above.

To allow for a comparison of the estimated coefficients, we first run the basic regression using the extended sample but without the Placebo-control variables. In column (2) of Table 11, we show the results for the fixed-effects OLS estimation with *ln(ExPC)* as the endogenous variable, district- and year-fixed effects, and additional control variables included. The effects of the treatment variables remain positive and significant. In column (3), we add the interactions *Border State x* T_{1873} and *Border State x* T_{1876}. The estimated coefficients for *Annexed x* T_{1873} and *Annexed x* T_{1876} are statistically significant, and the economic magnitudes of the effects remain relatively large. By contrast, we find no significant effects for the interactions *Control State x* T_{1873} and *Control State x* T_{1876}.[46] The result of this

[44] For the years of Zollverein entry, see the corresponding maps showing the Zollverein expansions, which are available on IEG-Maps (https://www.ieg-maps.uni-mainz.de/map4.htm).

[45] We include the following states: Kingdom of Saxony, Grand Duchy of Hesse (Hesse-Darmstadt), Grand Duchy of Mecklenburg-Schwerin, Duchy of Brunswick, Free Hanseatic City of Bremen, Free Hanseatic City of Hamburg, and Free Hanseatic City of Lübeck. In Appendix A2.1, we provide a map that shows the geographic location of these states.

[46] We find a similar result when using a conditional fixed-effects Poisson model (see Table A5 in the appendix).

Placebo-control test shows that there was no significant increase in the number of world's fair exhibits in states that may have also profited from market integration via political unification but were not affected by the annexations in 1866. If market integration had fostered innovation after the formation of the German Empire, we would expect a substantial increase in the World's Fair exhibits in these states. Most of these states were relatively small, so that the potential returns of market integration should have been high. However, since we do not find evidence for such an effect, it is also not likely that market integration drives the observed increase in World's Fair exhibits in annexed territories.

While there might be economic gains from market integration through political unification, we find no evidence that these gains explain the massive increase in the number of World's Fair exhibits in annexed territories. By contrast, the change in patent law provides a plausible explanation.

National Identity

The formation of the German Empire in 1871 might have reinforced the idea of national identity. At the World's Fairs of 1873 and 1876, the exhibition organizers listed all German exhibits under the label "German Empire". Greater national pride and awareness might have set higher incentives for firms to participate in the World's Fairs. However, in 1862 the German states already presented exhibits as Zollverein members, although each of them was still listed individually. In this regard, the international community most probably perceived these exhibitors already as "German".

If the formation of the German Empire still raised incentives to present, then it would have also done so in states of the German Empire that were not affected by the annexations. However, when including these states in the regressions (see column (3) of Table 11), we find no evidence for such an effect. Therefore, it is implausible that higher incentives to exhibit products due to a reinforced national identity explain the observed increase in World's Fair exhibits in annexed territories.

Other Institutional Reforms

After the annexations, the Prussian authorities implemented the Prussian patent system in all annexed territories. However, there was no full legal harmonization, so that other institutional differences persisted within Prussia. In particular, differences remained in the legal system until the nationwide introduction of the German civil code in 1900 (Acemoglu et al., 2011).

There were also major differences concerning the trade-regulation regime. Most parts of Prussia already had established freedom of trade (*Gewerbefreiheit*) in 1810 or shortly after (Acemoglu et al., 2011). This reform liberalized the economy by dissolving all guilds and other trade restrictions that had existed before. In other German states, the process of economic liberalization took much longer, e.g., in Hanover and Hesse-Kassel, which Prussia annexed in 1866. Only three years after the annexation, in 1869, freedom of trade was introduced in these territories as part of a broader reform that aimed at harmonizing trade regulation in the Northern German Federation. Since economic liberalization may affect innovation and economic growth positively, we control for this effect explicitly by including the variable *Economic Liberalization* (which measures the number of years since the introduction of freedom of trade) in all regression models with additional controls. After including this control variable, the effects of the treatment variables remain positive and highly significant (see column (2) in Table 7).

To further rule out the concern that the introduction of freedom of trade drives our findings, we make a placebo test with a group of control states. These states had introduced freedom of trade as well after 1862 as part of the liberalization process in the Northern German federation.[47] If the increase of World's Fair exhibits in annexed territories were the result of economic liberalization, we would expect a similar increase in these states after the introduction of economic freedom. In columns (4) and (5) of Table 11, we test this hypothesis by using these states as an additional control group. In column (4), we first show the baseline regression results for the fixed-effects OLS estimation with *ln(ExPC)* as the endogenous variable, district- and year-fixed effects, and additional controls. The estimated coefficients of *Annexed x* T_{1873} and *Annexed x* T_{1876} is highly significant. We then add *Guilds State x* T_{1873} and *Guilds State x* T_{1876} in column (5). *Guilds State* is a dummy that equals one for the control states (Brunswick, Hamburg, Lübeck, and Mecklenburg-Schwerin), where freedom of trade rules did not apply in 1862, and zero for all other states, and we interact *Guilds State* with the year dummies T_{1873} and T_{1876}. After including these interactions, the estimated effect of *Annexed x* T_{1873} and *Annexed x* T_{1876} remains highly significant. By contrast, we find no significant effect for *Guilds State x* T_{1873} and *Guilds State x* T_{1876}.[48] Hence, the number of World's Fair exhibits did not increase significantly after the introduction of economic freedom compared to Prussia. The results of this Placebo-control test show that there was no similar increase in world's fair exhibits in states that introduced economic freedom after 1862 but were not affected by the annexations. Thus, the introduction of freedom of trade does not provide a sound explanation for the substantial increase in the number of World's Fair exhibits in annexed territories.

7 Potential Channel: Technology Diffusion

We have so far shown that the adoption of the Prussian patent system affected patenting negatively, while we find a positive effect on world's fair exhibits, suggesting that the Prussian patent system was conducive for innovation. In the following, we provide evidence that increased technology diffusion is a potential channel for the observed increase in world's fair exhibits in annexed territories, since it became harder to protect production technology under the Prussian patent system.

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[47] We include data for the following states: Brunswick, Hamburg, Lübeck, and Mecklenburg-Schwerin.

[48] We find a similar result when using a conditional fixed-effects Poisson model (see Table A5 in the appendix).

As we have described in section 4.3, patents were mainly filed for investment goods. Thus, patenting may have restricted the provision and diffusion of modern production technology, which was required to manufacture innovative products of high quality that, eventually, were exhibited at the world's fairs. For example, patents on textile machinery could have lowered the supply for such machinery, increased its price, and, consequently, raised the amount of capital necessary to invest in these machines. Likewise, patents on critical components of specific machines could have lowered the supply of these machines and blocked follow-up innovation, thus restricting the development and diffusion of new production technologies. By contrast, it is also plausible that patents fostered technology diffusion, since a patent implied the public disclosure of the underlying invention, including detailed technical descriptions and drawings, which could be used by other inventors. Thus, the net effect of patenting on technology transfer is ambiguous. On the one hand, a large (absolute) number of patents granted in an economy should indicate a high level of protection but also a high potential for technology diffusion due to the disclosure effect. Whether the net effect is positive or negative depends on the design of the patent system. For example, if patents were filed on well-known technology, the benefits of its disclosure would be limited so that the negative effect related to the anti-competitive nature of patents should prevail. Given that the Prussian patent office pursued a policy with a strict novelty examination and given the low patent terms, we would expect that the adoption of the Prussian patent law was associated with a positive net effect on technology diffusion. To shed more light on this question, we now combine patent data with data on world's fair exhibits.

Since we are interested in the anti-competitive nature of patents, we aggregate all patents granted in each patent-granting state in a five-years period before the 1862 exhibition for each technology group, respectively. In contrast to the previous sections, we also include foreign patents, which also affected technology diffusion. We compute patent stocks for 15 different technology groups and three patent-granting states (Prussia, Hanover, and Hesse-Kassel), respectively.[49] Note that we use data on the state level, since patents restricted competition not only in the district where the inventor was located but in the whole state where the patent was valid. We then do the same for a five-year period before the 1873 exhibition. Since the Prussian patent system was adopted in all annexed states in 1866, we only get one patent stock per technology group for the latter period. Next, we compute the growth rates of the patent stocks between 1866 and 1873. Likewise, we aggregate the number of world's fair exhibits from exhibitors of the above-mentioned territories by technology group for 1862 and 1873, respectively, to compute the corresponding growth rates of exhibits.

[49] We do not include Nassau and Frankfurt, since we observe only patents in few technological groups in these states.

To provide evidence for the link between patenting and technology transfer, we compare the growth of the number of world's fair exhibits with the growth of the patent stock. The underlying idea is that the stock of patents related to a specific technology group has an effect on innovation within this group, which we measure with world's fair exhibits. If the disclosure effect is predominant, we would expect a positive relation. By contrast, if the anti-competitive nature of patents is predominant, we would expect a negative relation between changes in the patent stock and innovation.

Figure 4 illustrates the link between the growth of world's fair exhibits, *Δln(Exhibits)*, and the growth of the patent stock, *Δln(PatentStock*), between 1862 and 1873.[50] Data is for Hanover, the largest state that came under Prussian rule in 1866. Each dot represents one technology group. The size of the circles represents the size of the patent stock in each technology group. The data show a negative relation between the growth of the patent stock and world's fair exhibits.

[Insert Figure 4]

In Table 12, we show the results for an OLS regression for the effect of *Δln(PatentStock*) on *Δln(Exhibits)* for Hanover, Hesse-Kassel, and Prussia (old provinces).[51] We use robust standard errors and weight the observations by the mean patent stock to account for differences in the importance of patents across technology groups. In columns (1) to (3), we find a negative effect of the patent-stock growth for Hanover, Hesse-Kassel, and Prussia (old provinces), respectively. Yet, for Hesse-Kassel, for which we observe only ten technology groups, the effect is not significant. In columns (4), we show that the effect of the patent-stock growth is also negative and significant when we combine the three territories and add state dummies in the regression. We can interpret these results as evidence that, on average, an increase in patented production technology in a specific technology group is associated with lower innovation in this group.

[Insert Table 12]

To further illustrate the link between patented production technology and product innovation, we use the chemical industries in Hanover and Prussia as an example. In Hanover and Prussia, patents could be filed only to protect specific production processes, but not the products. This rule was applied before and after 1866. However, since the Hanoverian patent authority set lower novelty requirements, inventors could file a distinctly higher number of chemical-related patents in Hanover before 1866, when compared with Prussia. Table 13 shows that Hanover granted 16 chemical patents in the five-year period before the 1862 exhibition, while there were only nine patents in Prussia, even though the Prussia

[50] To compute the growth rates, we take the first difference of the natural logarithm of the respective variables.

[51] We use robust standard errors and weight the observations with the patent stocks

market was significantly larger and the patent fees lower, creating stronger economic incentives to apply for a patent in Prussia. By contrast, there were only ten chemical exhibits from Hanover (0.6 per patent), compared to 68 from Prussia (7.6 per patent). Put differently, in Hanover, it was easier to protect new production technologies, which may have hampered the diffusion and practical application of these technologies so that fewer firms were able to produce high-quality products that were adequate to be presented at the 1862 world's fair. In the five-year period before the 1873 exhibition, we observe nine chemical-related patents in Prussia, while the number of chemical-industry exhibits is 25 for Hanoverian districts and 130 for districts that were Prussian before 1866. Thus, the number of exhibits increased in Hanoverian districts by 150 percent, while it increased by 91 percent in old Prussian districts.

[Insert Table 13]

The larger participation of chemical firms from Hanover at the 1873 exhibition is in line with our argument that a reduction in the patent stock as a result of the patent-regime change fostered technology diffusion and, eventually, innovation. Because of lower technological entry barriers and faster technology diffusion, it is also likely that the adoption of the Prussian patent system stimulated competition. The increase in competition may have created additional incentives to invent new production techniques, which in turn may have further shifted the technological frontier. This argument reflects the findings of Murmann (2003), who makes the case that German chemical companies may have profited from fierce competition because of restrictive patent laws, while it was easier to establish patent monopolies in other countries. As a consequence, the German chemical companies improved cost-efficiency and became highly innovative in the long-run.

We have so far linked the change in world's fair exhibits in a specific technology group with the change of the patent stock of the same technology group, and the findings suggest a negative relation. However, we may underestimate the positive effects of technology diffusion on innovation because of general-purpose technologies that affected not only one industry but rather the whole economy. An important–if not the most important–general-purpose technology of this period was the steam engine (Rosenberg and Trajtenberg, 2004), which was continuously improved. For example, more efficient steam engines might have stimulated the invention of new steam-driven textile machinery. A lower number of patents on such general-purpose technology should have been beneficial for the spread of technology and, consequently, may have stimulated follow-up innovation. In line with this argument, we find a reduction in the patent stock, when considering again Hanover, the largest state that came under Prussian rule. While we observe 29 patents on steam-engine technology in the period 1857-61 (Hanoverian patent system), there were only 21 in the period 1868-72 (Prussian patent system). Thus, the broad increase in innovation, measured with world's fair exhibits, might have been partially driven by better access to general purpose technologies because of fewer patents.

To conclude, increased technology diffusion due to a reduction in the number of patents on relevant production technology is a plausible channel for the observed increase in non-patented innovation after the adoption of the Prussian patent system. Increased technology diffusion might have stimulated innovation directly, but also indirectly by establishing a more competitive environment that set higher incentives to innovate.

8 Conclusion

We have investigated the effect of patenting on innovation by exploiting the Prussian annexations after the Austro-Prussian War as a quasi-natural experiment. The adoption of the Prussian patent law caused a decline in patenting because of a more restrictive patent policy, in particular a stricter definition of novelty. However, we have shown that the number of world's fair exhibits, which represent the cutting-edge products of the time, increased significantly after the annexations and the effect of patent-regime change on world's fair exhibits is quantitatively large. We interpret this result as evidence that the adoption of the Prussian patent system was conducive to innovation. This finding contrasts the older historical literature (see, e.g., Heggen, 1975), claiming that the Prussian patent system has been inefficient and impeded innovation because only a small number of patents were granted. The fact that we observe an increase in innovation despite of a decline in patenting reflects the view of the more recent literature, highlighting that the existence of a patent system was not a precondition for innovativeness in the nineteenth century (Moser, 2005).

We find no clear evidence that the adoption of the Prussian patent law caused a general shift of inventive activity towards industries with lower propensities to patent. Moser (2005) shows that patent laws affected the direction of technological change. Innovation in machine-building, for example, was quantitively more important in countries with patent laws, while innovation in foodstuff industries and in the construction of scientific instruments was relatively more important in countries without patent laws. In light of these results, we would expect that the adoption of the restrictive Prussian patent system was associated with a relative decrease in machine-building innovation, since the barriers to get a patent increased, and a relative increase in innovation in foodstuff industries and scientific instruments if patenting was of less relevance in these industries. Indeed, we find more world's fair exhibits in foodstuff industries after the patent-regime change, reflecting the results of Moser (2005), but we find no evidence for a negative effect on machine-building innovation. We also find contrary results for scientific instruments. While, after 1866, scientific instruments accounted for a significantly larger share in annexed territories, the number of world's fair exhibits decreased in this technology group.

Increased technology diffusion due to a smaller number of patents under the Prussian system provides a plausible channel for the increase in innovation. We provide suggestive evidence for this channel by showing a negative relation between the growth of world's fair exhibits in a technology group and the growth of the related patent stock, assuming that larger patent stocks are associated with less intense technology diffusion. Finding that a lowering in the number of protected technologies is conducive to innovation is in line with research by Baten et al. (2017), who show that compulsory licensing can have a positive effect on innovation.

Starting as an economic and technological laggard at the beginning of the 19th century, Prussia was able to catch-up to the technological leaders of the time. Among other factors, Prussia profited from inclusive institutions, a well-educated workforce providing the human capital necessary for innovation and technical change, and the formation of the Zollverein helping to establish a common German market. However, the Prussian patent system may have also contributed to the creation of an environment that was conducive for innovation and, consequently, economic growth.

The results of this paper are not only important to understand the determinants of innovation in nineteenth-century Europe but raise also questions about the efficiency of the current patent systems. In contrast to today, it was presumably more difficult to file patents only with the aim to block innovation of competitors, since the Prussian patent authority set high barriers to get a patent and it applied a strict novelty criterion. Moreover, the standard patent term was only five years and the patent authority even lowered the patent term to three years in the early 1870s, while extensions were rather uncommon. Thus, even in the case of a successful patent application, the period in which the patentee could profit from its monopoly was much shorter than it is common today. Thus, the Prussian patent system possessed similar characteristics as the "optimal" patent system as proposed by Nordhaus (1969).[52]

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[52] Nordhaus (1969) argues that social welfare first increases with the patent term, but flattens after the patent terms reach a length between six and ten years. In the case of a longer patent term, the social costs of monopoly may offset the gains from inducing innovation.

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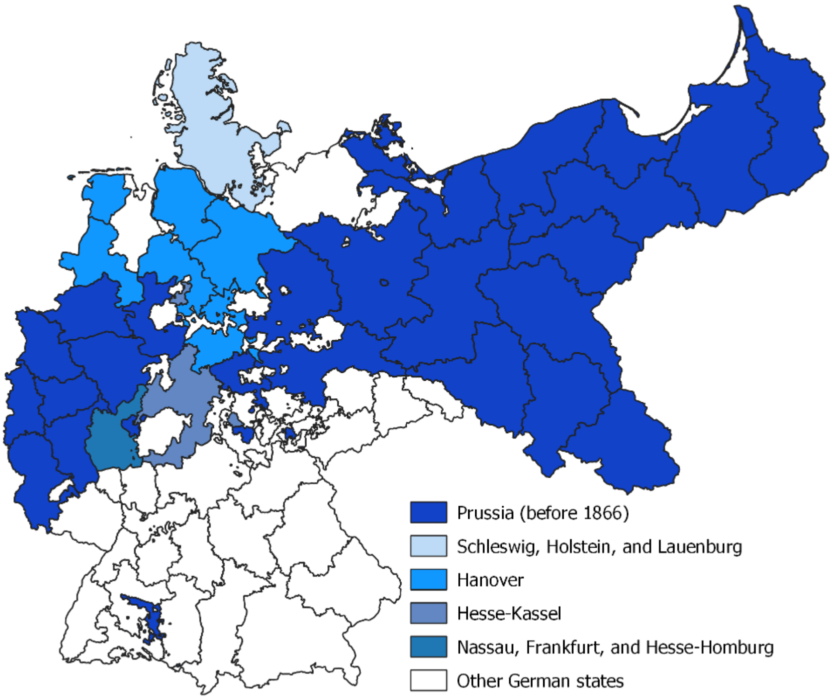
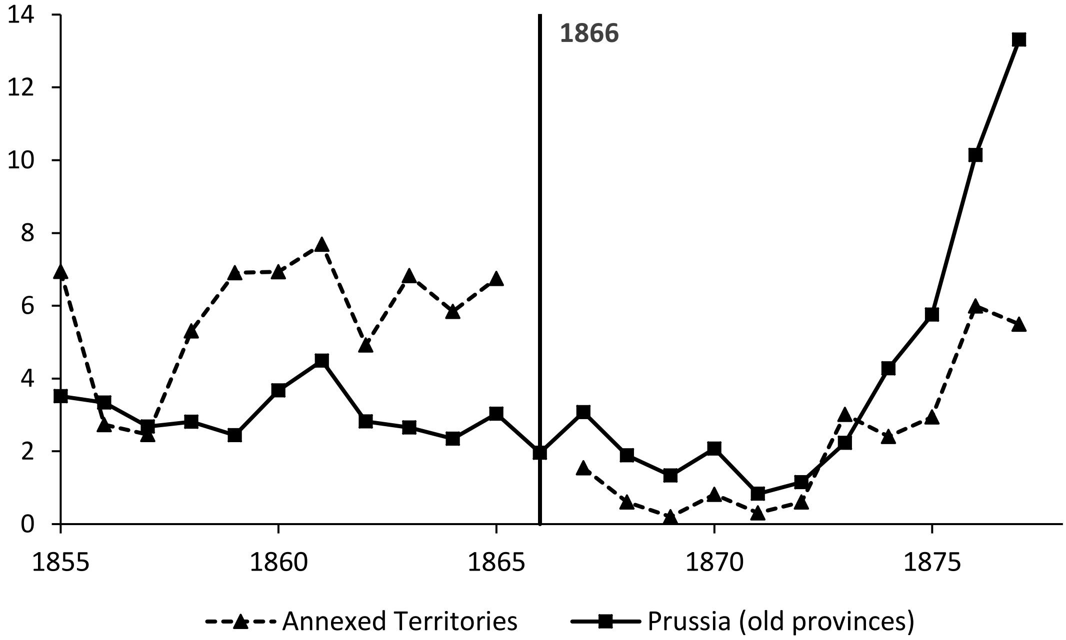
Figures

Figure 1: Prussian annexations after the Austro-Prussian War of 1866



Note: This map illustrates the Prussian annexations after the Austro-Prussian War of 1866. Black lines indicate borders of states and administrative districts.

Figure 2: Mean number of domestic patents per million inhabitants, 1855-1877

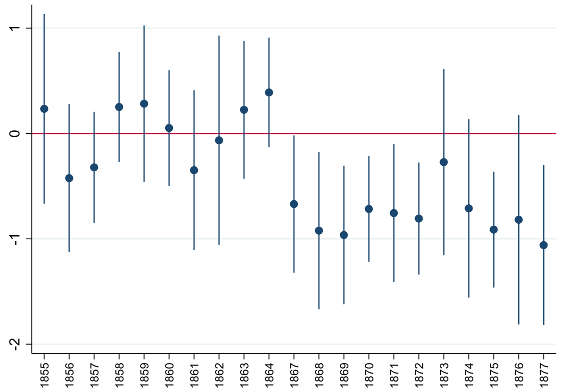


Note: This figure shows the development of the mean number of domestic patents per million inhabitants in districts that were part of annexed territories and districts that were part of old Prussian provinces for the period 1855-77. For annexed territories, we drop 1866 since the annexation took place in the summer of 1866.

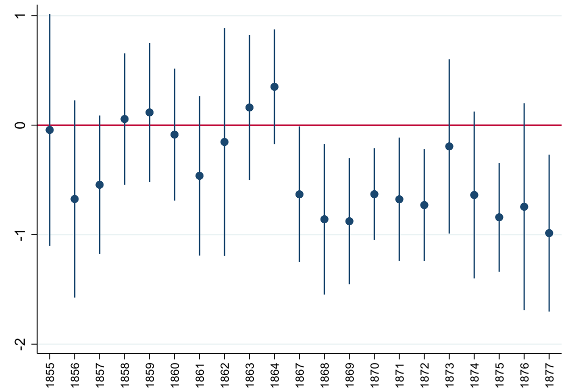
Figure 3: Event study on the effect of patent-regime change on patenting

Panel A: Fixed-effects OLS with Ln(PPC) as endogenous variable

A1: Basic specification

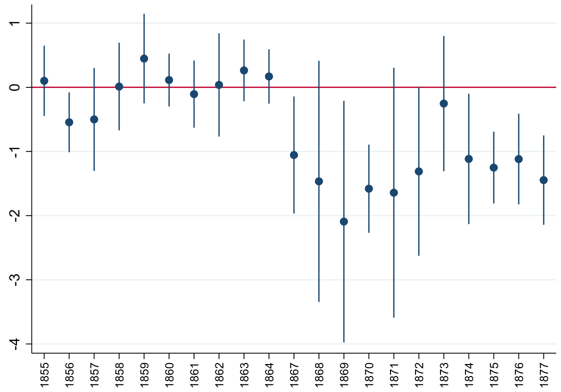


A2: Additional controls

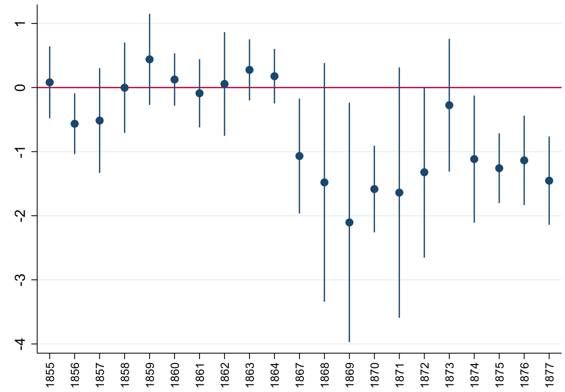


Panel B: Fixed-effects Poisson with patents as endogenous variable

B1: Basic specification

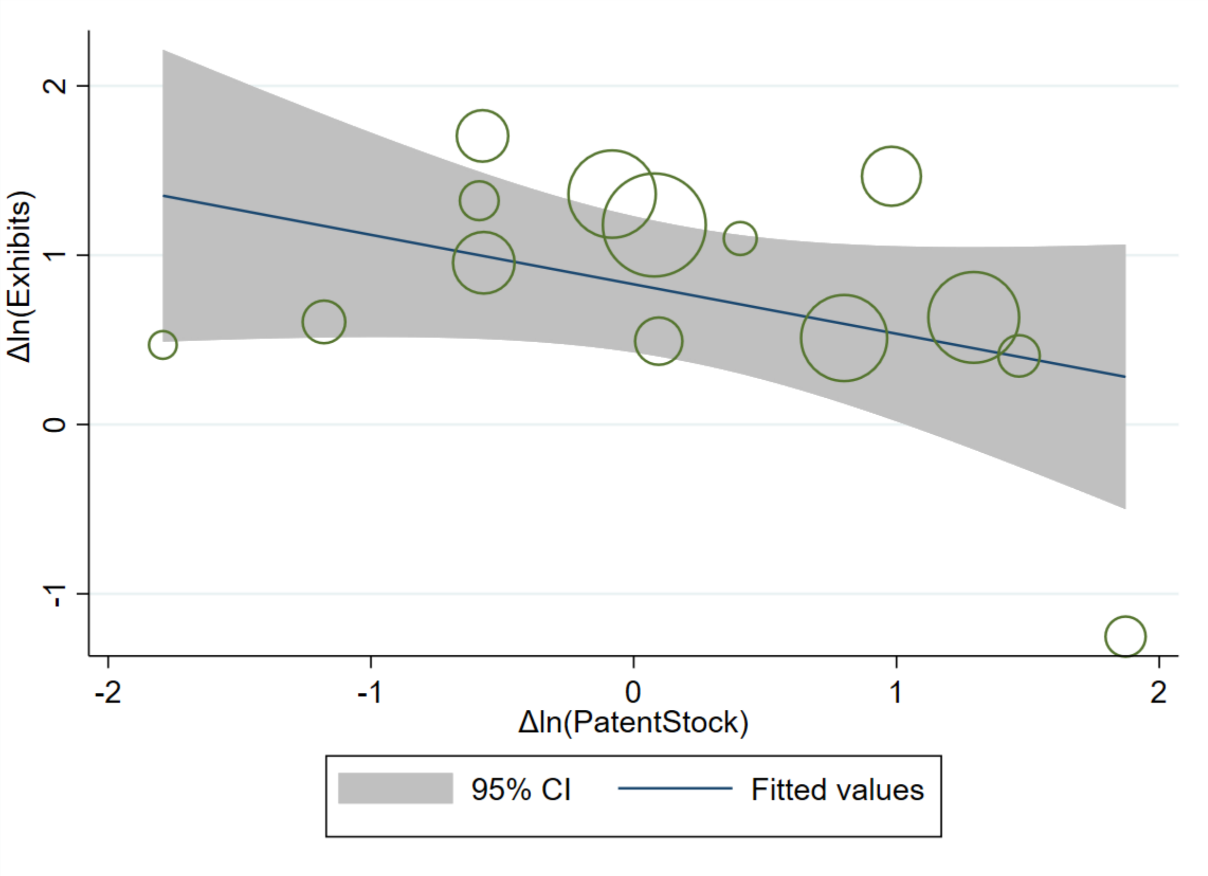


B2: Additional controls



Note: The dots show the point estimates for the coefficient of Annexed interacted with the respective time dummies, and the bars show the respective standard errors. We use the fixed-effects OLS estimation with Ln(PPC) as the endogenous variable in Panel A and the fixed-effects Poisson estimation with Patents as the endogenous variable in Panel B. In each specification, we control for district-fixed and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. In the specification with additional controls, we also add Population Density, Steel Production, Coal Mining, and Economic Liberalization as control variables. In Panel B, we also include Population as an additional control in both specifications. The reference year is 1865, and we drop observations in 1866, as in all other regressions.

Figure 4: The Effect of Patenting on World's Fair Exhibits by Technology Groups – Hanover



Note: This figure shows the relation between the change in world's fair exhibits of a specific technology group and the change of the related patent stock. Data are for Hanover. Δln(Exhibits) is the first difference of the natural logarithm of (1 + number of world's fair exhibits), which measures the change in the number of exhibits between 1862 and 1873. To compute the stock of patents related to each technology group, we aggregated all patents granted in the patent-granting state five years before 1862 and 1873, respectively. Δln(PatentStock) is the first difference of the natural logarithm of (1 + the patent stock), which measures the change of the patent stock between 1862 and 1873. The size of the circles reflects the mean patent stocks.

Tables

Table 1: Share of patents by type of invention relative to all domestic patents

	1855-1865		1867-1877	
	Machines and production techniques	Others	Machines and production techniques	Others
Prussia (old provinces)	0.92	0.08	0.86	0.14
Annexed territories	0.94	0.06	0.86	0.14

Note: This table presents the share of patents that describe patents that were related to machines, machine parts, (machine) tools, instruments and production techniques. We categorized the patents by using a text mining technique.

Table 2: World's Fair exhibits by product groups

	1862		1873		1876	
	Abs.	in %	Abs.	In %	Abs.	In %
Commodities and cultural exhibits	197	14.6	346	10.6	110	22.1
Investment goods	75	5.6	350	10.8	18	3.6
Intermediate goods	407	30.2	897	27.6	103	20.7
Consumer goods	594	44.1	1,397	43.0	245	49.2
Other exhibits	73	5.4	261	8.0	22	4.4
Total ex. commodities / cultural exhibits	1,149	85.4	2,905	89.4	388	77.9
Total	1,346	100.0	3,251	100.0	498	100.0

Note: Commodities include, e.g., minerals, and agricultural commodities such as wheat, and cultural exhibits include e.g., artwork such as oil paintings, exhibits related to the presentation of the educational system (e.g., curriculums, works of pupils) and the self-description of public organizations; investment goods include machines, machine parts, and tools; intermediates goods include goods that are used as inputs for the production of investment or consumer goods, e.g., cotton yarn or steel sheet; consumer goods include both durables (e.g., furniture) as well as non-durables (e.g., processed foodstuff, drinks, or clothing); other exhibits include exhibits related to the construction of buildings such as construction plans of buildings and models and the presentation of scientific results, e.g., scientific journals, models, maps and instruments that were mostly used in science and had no explicit commercial purpose.

Table 3: Summary statistics for the number of domestic patents per million inhabitants

	1855-65			1867-77		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Prussia (old provinces)	3.07	7.12	286	4.19	10.30	286
Annexed territories	5.76	7.24	88	2.18	3.52	88

Note: This table presents summary statistics for the number of domestic patents granted per million inhabitants by group of territories and for the periods 1855-65 and 1867-77, respectively. The observations are yearly and on the district level.

Table 4: Effect of patent-regime change on domestic patenting

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	Poisson	Poisson	Poisson
	Ln(PPC)	Ln(PPC)	Ln(PPC)	Patents	Patents	Patents
Annexed x $T_{Post1866}$	-0.8282*** (0.2211)	-0.8826*** (0.3109)	-0.9953*** (0.3296)	-1.2597*** (0.3628)	-1.1901*** (0.4379)	-1.2094*** (0.4610)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Population Control	No	No	No	Yes	Yes	Yes
Additional Controls	No	Yes	Yes	No	Yes	Yes
Clustering	District	District	District	District	District	District
N	748	748	484	748	748	484
Sample	Full	Full	Excluding East Elbia	Full	Full	Excluding East Elbia
Within R^2	0.33	0.33	0.38	.	.	.

Note: Note: This table shows results for the effect of the patent-regime change on domestic patenting. In columns (1) to (3), we use a fixed-effects OLS regression with Ln(PPC) (= natural logarithm of 1 + patents per million inhabitants) as the dependent variable. In columns (4) to (6), we use a fixed-effects Poisson regression with Patents (number of patents) as the dependent variable. The interaction Annexed x $T_{Post1866}$ estimates the effect of patent-law change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and $T_{Post1866}$ is a dummy variable indicating the post-1866 period. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering at the district level. In columns (2), (3), (5), and (6), we include the following additional control variables: Population Density (=inhabitants (in 1,000) per km²), Steel Production (=steel production per capita), and Coal Mining (= coal mining per capita), and Economic Liberalization (= years since the liberalization of trade). In columns (4) to (6), we add Population (= million inhabitants) as an additional control. In columns (3) and (6), and (9), we exclude the eastern Prussian provinces. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Effect of patent-regime change on the composition of patenting by technology group

	(1) Metals & Mining in %	(2) Chemicals in %	(3) Foodstuff & Kindred Products in %	(4) Machine-building & Transport in %	(5) Instruments in %	(6) Textiles in %
Annexed x $T_{Post1866}$	-2.9533 (7.2160)	-4.9564 (3.0585)	-4.5130 (9.0559)	13.2114 (15.0968)	21.6398* (12.2826)	-2.4784 (3.4829)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	District	District	District	District	District	District
N	68	68	68	68	68	68
Within R^2	0.01	0.29	0.07	0.11	0.19	0.16

Note: This table shows results for the effect of the patent-regime change on the composition of patents by technology groups. We use a fixed-effects OLS regression in all columns. In all columns, the share of patents related to a specific technology group (in %) is the dependent variable (e.g., in column (1), we test the effect of patent-regime change on the share of patents related to the group Metals & Mining). The interaction Annexed x $T_{Post1866}$ estimates the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and $T_{Post1866}$ is a dummy variable indicating the post-1866 period. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. See the Appendix for information on the classification of technology groups. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Effect of patent-regime change on the social background of patentees

	(1) High Social Status in %	(2) High Social Status with University Education in %	(3) High Social Status without University Education in %
Annexed x $T_{Post1866}$	27.8408* (14.4622)	33.62*** (11.0418)	-6.7959 (9.5075)
District FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Clustering	District	District	District
N	68	68	68
Within R^2	0.12	0.27	0.02

Note: This table shows results for the effect of the patent-regime change on the composition of patents with regard to the social background if the patentees. We use a fixed-effects OLS regression in all columns. We use the share of patents filed by patentees of high social status as endogenous variable in columns (1), the share of patents filed by patentees of high social status and university education in column (2), and the share of patents filed by patentees of high social status without university education in column (3). The interaction Annexed x $T_{Post1866}$ estimates the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and $T_{Post1866}$ is a dummy variable indicating the post-1866 period. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. See the Appendix for information on the classification of patentees by social status. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 7: Summary statistics for World's Fair exhibits per million inhabitants

	1862			1873			1876		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Prussia (old provinces)	58.38	90.37	26	110.58	125.03	26	12.15	20.28	26
Annexed territories	39.54	34.48	8	124.83	72.99	8	19.30	32.22	8

Note: This table presents summary statistics for the number of World's Fair exhibits per million inhabitants, excluding unprocessed commodities (e.g., minerals) and all cultural exhibits (e.g., artworks). We distinguish between Prussia (old provinces) and annexed territories. Data is on the district level.

Table 8: Effect of patent-regime change on world's fair exhibits

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	Poisson	Poisson	Poisson
	ln(ExPC)	ln(ExPC)	ln(ExPC)	Exhibits	Exhibits	Exhibits
Annexed x T_{1873}	0.8105***	1.4358***	1.3040***	0.4401*	0.7864***	0.6724***
	(0.2908)	(0.2891)	(0.3312)	(0.2386)	(0.1319)	(0.1511)
Annexed x T_{1876}	0.3303	1.0655***	0.9819**	0.9863**	1.3047***	1.0879***
	(0.5592)	(0.3031)	(0.4021)	(0.4729)	(0.3024)	(0.3323)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Population Control	No	No	No	Yes	Yes	Yes
Additional Controls	No	Yes	Yes	No	Yes	Yes
Clustering	Yes	Yes	Yes	Yes	Yes	Yes
N	102	102	66	102	102	66
Sample	Full	Full	Excluding East Elbia	Full	Full	Excluding East Elbia
Within R^2	0.82	0.82	0.81	.	.	.

Note: This table presents estimates for the effect of the patent-regime change on the number of World's Fair exhibits. We use a linear fixed-effects regression model with ln(ExPC) as the dependent variable in columns (1) to (3) and a conditional fixed-effects Poisson model with Exhibits as the dependent variable in columns (4) to (6). ln(ExPC) is the natural logarithm of (1 + number of World's Fair exhibits per million inhabitants), and Exhibits is the number of World's Fair exhibits. The coefficients of the interactions Annexed x T_{1873} and Annexed x T_{1876} indicate the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. In columns (4) to (6), we also add Population (number of inhabitants) as control. In column (2) and (5), we add five additional control variables: Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade). In columns (3) and (6), we use the specifications as in columns (2) and (5), but we exclude the eastern provinces of Prussia (East Prussia, West Prussia, Pomerania, Posen, and Silesia). We report the standard errors in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 9: Effect of patent-regime change on the composition of exhibits by technology group

	(1)	(2)	(3)	(4)	(5)	(6)
	Metals & Mining in %	Chemicals in %	Foodstuff & Kindred Products in %	Machine-building & Transport in %	Instruments in %	Textiles in %
Annexed x $T_{Post1873}$	-6.6356**	1.9905	32.9492***	5.1418*	-8.5080**	8.0941
	(3.0551)	(4.3573)	(8.4832)	(2.4447)	(3.5267)	(6.3910)
Annexed x $T_{Post1876}$	-13.0662***	-3.1537	40.2022***	6.3078*	-8.7195*	0.7397
	(3.8482)	(4.1752)	(10.5954)	(3.0598)	(4.4210)	(6.1420)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes	Yes	Yes	Yes
Clustering	District	District	District	District	District	District
N	102	102	102	102	102	102
Within R^2	0.13	0.5	0.12	0.16	0.17	0.18

Note: This table shows results for the effect of the patent-regime change on the composition of world's fair exhibits by technology groups. We use a fixed-effects OLS regression in all columns. In all columns, the share of world's fair exhibits of a specific technology group (in %) is the dependent variable (e.g., in column (1), we test the effect of patent-regime change on the share of exhibits related of the group Metals & Mining). The interactions Annexed x T_{1873} and Annexed x T_{1876} estimates the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the years 1873 and 1876. In all columns, we include district-fixed effects, year-fixed effects, and five additional controls (Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade)). We use robust standard errors adjusted for clustering at the district level. See the Appendix for information on the classification of technology groups. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 10: Effect of patent-regime change on the composition of exhibits by product groups

	(1) Investment goods in %	(2) Intermediate goods in %	(3) Consumer goods in %
Annexed x $T_{Post1873}$	2.1656 (3.8030)	-11.2188 (8.2637)	33.6003*** (7.5101)
Annexed x $T_{Post1876}$	8.4790* (4.5498)	-23.0414*** (7.3622)	16.9512 (12.0213)
District FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes
Clustering	District	District	District
N	102	102	102
Within R^2	0.29	0.24	0.08

Note: This table shows results for the effect of the patent-regime change on the composition of world's fair exhibits by product groups. We use a fixed-effects OLS regression in all columns. In all columns, the share of world's fair exhibits of a specific technology group (in %) is the dependent variable (e.g., in column (1), we test the effect of patent-regime change on the share of exhibits related of the group Metals & Mining). The interactions Annexed x T_{1873} and Annexed x T_{1876} estimates the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the years 1873 and 1876. In all columns, we include district-fixed effects, year-fixed effects, and five additional controls (Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade)). We use robust standard errors adjusted for clustering at the district level. See the Appendix for information on the classification of technology groups. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 11: Alternative explanations: market integration and economic liberalization

	Dependent variable: ln(ExPC)				
	(1)	(2)	(3)	(4)	(5)
Annexed x T_{1873}	1.5899*** (0.2921)	1.2291*** (0.4516)	1.4582*** (0.4991)	1.5516*** (0.4088)	1.9041*** (0.6458)
Annexed x T_{1876}	1.0585*** (0.3003)	0.9871** (0.6114)	1.0914* (0.6266)	1.3442** (0.5232)	1.5309*** (0.5311)
Border Prussia x T_{1873}	0.3749 (0.2874)				
Border Prussia x T_{1876}	-0.1046 (0.4463)				
Border State x T_{1873}			0.3261 (0.2825)		
Border State x T_{1876}			0.0138 (0.4306)		
Guilds State x T_{1873}					0.6921 (0.4694)
Guilds State x T_{1876}					-0.879 (0.5724)
District FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes	Yes	Yes
Clustering	Yes	Yes	Yes	Yes	Yes
N	102	138	138	114	114
Sample	Full	Full + Control	Full + Control	Full + Control	Full + Control
Within R^2	0.83	0.81	0.81	0.83	0.84

Note: This table presents estimates for the effect of market integration and economic liberalization on World's Fair exhibits. We use a linear fixed-effects regression model with ln(ExPC) as the dependent variable in all columns. ln(ExPC) is the natural logarithm of (1 + number of World's Fair exhibits per million inhabitants). The coefficients of the interactions Annexed x T_{1873} and Annexed x T_{1876} indicate the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In all columns, we include district-fixed effects and year-fixed effects, we use robust standard errors adjusted for clustering on the district level, and we add five additional control variables: Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade). We include the two additional interaction terms,Border Prussia x T_{1873} and Border Prussia x T_{1876} in column (1), Border State x T_{1873} and Border State x T_{1876} in columns (2) and (3), and Guilds State x T_{1873} and Guilds State x T_{1876} in columns (4) and (5) to perform Placebo-control tests. Border Prussia is a dummy variable indicating an old Prussian district that bordered with one of the annexed districts, border State is a dummy variable indicating a district that was in one of Prussia's bordering states that was not annexed, and Guilds State is a dummy variable indicating a district that was in one of Prussia's bordering states that was not annexed and where freedom of trade was introduced after 1862, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In columns (2) and (3), we add data for a group of control states that border with Prussia (Brunswick, Bremen, Hamburg, Hesse-Darmstadt, Lübeck, Mecklenburg-Schwerin, and Saxony), and we add data for a group of control states where freedom of trade was introduced after 1862 (Brunswick, Hamburg, Lübeck, Mecklenburg-Schwerin) in columns (4) to (5). Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 12: The Effect of Patenting on World's Fair Exhibits by Technology Groups

	Dependent variable: Δln(Exhibits)			
	(1) Hanover	(2) Hesse-Kassel	(3) Prussia (old)	(4) All territories
Δln(PatentStock)	-0.3548* (0.1853)	-0.3114 (0.2205)	-1.2352** (0.5535)	-0.3998*** (0.1413)
State dummies	No	No	No	Yes
N	14	10	14	38
R^2	0.26	0.14	0.35	0.21

Note: This table presents estimates for the effect of patenting on world's fair exhibits. We use a linear regression model with Δln(Exhibits) as the dependent variable in all columns. Exhibits are aggregated by technology group and states for the world's fairs of 1862 and 1873. Δln(Exhibits) is the first difference of the natural logarithm of (1 + number of world's fair exhibits), which measures the change in the number of exhibits between 1862 and 1873. To compute the stock of patents related to each technology group, we aggregated all patents granted in the patent-granting state five years before 1862 and 1873, respectively. Δln(PatentStock) is the first difference of the natural logarithm of (1 + the patent stock), which measures the change of the patent stock between 1862 and 1873. Column (1) shows the results for Hanover, (2) for Hesse-Kassel, (3) for Prussia (old provinces), and (4) for all three territories combined. In column (4), we add state dummies. In all columns, we include a regression constant, we weight the observations by the mean patent stocks, and we use robust standard errors. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Table 13: Patenting and Innovation in the Chemical Industries of Hanover and Prussia

	1862		1873		ΔExhibits in %
	Patents (1857-61)	Exhibits	Patents (1868-72)	Exhibits	
Hanover	16	10	9	25	150
Prussia (old provinces)	9	68		130	91

Note: This table shows the stocks of valid chemical-related patents granted in the five-years periods before the 1862 and 1873 world's fair for Hanover and Prussia, respectively (note that there are no differences in the patent stocks for1873, given that there was only one patent system after 1866). The table also shows the number of chemical-industry exhibits. ΔExhibits is the change in the number of exhibits between 1862 and 1873 in %.

Appendix

A1 Additional Statistics and Results

A1.1 Additional Summary Statistics

Number of Domestic Patents

In Table A1, we report additional summary statistics for the number of domestic patents per year and district. As in the main text, we distinguish between the two periods before and after the patent-regime change (1855-65 and 1867-77) and between Prussia (old provinces) and annexed territories. The figures show that there was an increase in patenting in old Prussian provinces over time. By contrast, we find a massive drop in the number of domestic patents in annexed territories. This observation underlines that the drop in the mean number of patents per million inhabitants, which we discuss in the main text, is driven by the decline of patents but not by population changes (e.g., due to migration).

Table A1: Summary Statistics: Number of Domestic Patents

	1855-65			1867-77		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Prussia (old provinces)	1.89	3.77	286	3.58	10.05	286
Annexed territories	2.10	2.64	88	1.11	1.93	88

Note: This table presents summary statistics for the number of domestic patents granted by a group of territories and for the periods 1855-65 and 1867-77, respectively. The observations are yearly and on the district level.

Population

In Table A2, we report additional summary statistics for the population in million per year and district. As in the main text, we distinguish between the two periods before and after the patent-regime change (1855-65 and 1867-77) and between Prussia (old provinces) and annexed territories. The figures show that the number of inhabitants was smaller in districts that Prussia annexed in 1866 when compared with Prussia's old provinces. However, when comparing the change in the mean number of inhabitants between the two periods, we find similar growth rates, suggesting similar population-growth patterns. We interpret this as evidence that there was no migration wave from annexed territories to Prussia's old provinces.

Table A2: Summary Statistics: Population in Million Inhabitants

	1855-65			1867-77		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Prussia (old provinces)	0.70	0.26	286	0.79	0.31	286
Annexed territories	0.39	0.17	88	0.43	0.18	88

Note: This table presents summary statistics for the population in million by a group of territories and for the periods 1855-65 and 1867-77, respectively. The observations are yearly and on the district level.

World's Fair exhibits

In Table A3, we report additional summary statistics for the number of World's Fair exhibits per million inhabitants per year and district. In the paper, we exclude unprocessed commodities such as minerals and cultural goods such as artworks. Table A3 shows the descriptive statistics for all exhibits (including commodities and cultural goods). The table distinguishes between two periods before and after the patent-regime change (1855-65 and 1867-77) and between Prussia (old provinces) and annexed territories. The comparison between World's Fair exhibits from Prussia (old provinces) and annexed territories reveals a similar picture as in Table 6, in which we exclude commodities and cultural goods.

Table A3: Summary statistics for World's Fair exhibits per million inhabitants (all exhibits, including commodities and cultural goods)

	1862			1873			1876		
	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Prussia (old provinces)	68.59	93.29	26	122.96	129.37	26	16.18	34.88	26
Annexed territories	41.92	35.31	8	143.97	80.66	8	19.89	32.01	8

Note: This table presents summary statistics for the number of World's Fair exhibits per million inhabitants (all exhibits, including unprocessed commodities such as minerals and all cultural goods such as artworks. We distinguish between Prussia (old provinces) and annexed territories. Data is on the district level.

A1.2 Additional Regression Results

Effect of Patent-Regime Change on Patenting

In columns (1) to (3) of Table 4 of the paper, we use the log-specification *ln(PPC)*, which makes it easier to interpret the estimated coefficients. However, since there are many zero observations–a typical characteristic of disaggregated patent data–, we add one to the actual number of patents per million inhabitants to compute the natural logarithm. This transformation could lead to a bias so that we have to rule out that the log-transformation drives the observed effect. For this reason, we show estimates for the model without log-transformation in columns (1) to (3) of Table A4. We use the same specifications as in columns (1) to (3) of Table 4 but we take *PPC* (patents per million inhabitants) as endogenous variable. In all three columns, the estimated coefficient of *Annexed State x* $T_{Post1866}$ is significantly negative. These results strengthen the argument that, in annexed territories, the number of domestic patents per million inhabitants decreased significantly after 1866.

Table A4: Effect of patent-regime change on patents per million inhabitants

	(4)	(5)	(6)
	OLS	OLS	OLS
	PPC	PPC	PPC
Annexed x $T_{Post1866}$	-4.6942** (1.7355)	-4.4791* (2.4121)	-4.8965* (2.5691)
District FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Population Control	No	No	No
Additional Controls	No	Yes	Yes
Clustering	Yes	Yes	Yes
N	748	748	484
Sample	Full	Full	Excluding East Elbia
Within R^2	0.22	0.24	0.28

Note: This table shows additional results for the effect of the patent-regime change on domestic patenting. In columns (1) to (3), we use a fixed-effects OLS regression with patents per million inhabitants (PPC) as the dependent variable. The interaction Annexed x $T_{Post1866}$ estimates the effect of patent-law change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and $T_{Post1866}$ is a dummy variable indicating the post-1866 period. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. In columns (2) and (3), we include the following additional control variables: Population Density (=inhabitants (in 1,000) per km²), Steel Production (=steel production per capita), and Coal Mining (= coal mining per capita), and Economic Liberalization (= years since the liberalization of trade). In column (3), we exclude the eastern Prussian provinces. Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Effect of Patent-Regime Change on World's Fair exhibits (including all exhibits)

In the paper, we exclude all commodities and cultural goods when analyzing the effect of the patent-regime change on World's Fair exhibits. To show that excluding these types of exhibits does not drive the results, we also run regressions for all exhibits (including commodities and cultural goods). Table A4 shows the results. The structure of the table resembles the structure of Table 7 in the paper. We show the results for the fixed-effects OLS model with *ln(ExPC)* as the endogenous variable in columns (1) to (3) and the results for the conditional fixed-effects Poisson model with *Exhibits* as endogenous variable and *Population* as a control in columns (4) to (6). In column (1), we find a significantly positive effect of *Annexed x* T_{1873} and no significant effect of *Annexed x* T_{1876}. However, when including additional controls, we find a significantly positive effect for both interaction terms in column (2), and the estimated coefficients change only slightly when we exclude East Elbia in column (3). In columns (4) to (6), the effects of *Annexed x* T_{1873} and *Annexed x* T_{1876} are also positive and highly significant. We conclude that including commodities and cultural goods (which we exclude in the paper) provides similar results.

Table A5: Effect of patent-regime change on World's Fair exhibits (all exhibits)

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	Poisson	Poisson	Poisson
	ln(ExPC)	ln(ExPC)	ln(ExPC)	Exhibits	Exhibits	Exhibits
Annexed x T_{1873}	0.9407***	1.6195***	1.5409***	0.6632***	0.9170***	0.8188***
	(0.2754)	(0.2980)	(0.3228)	(0.2210)	(0.1459)	(0.1673)
Annexed x T_{1876}	0.4463	1.1961***	1.1431**	0.9008**	1.1010***	0.8706**
	(0.5609)	(0.3064)	(0.4173)	(0.4586)	(0.3393)	(0.3568)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Population Control	No	No	No	Yes	Yes	Yes
Additional Controls	No	Yes	Yes	No	Yes	Yes
Clustering	Yes	Yes	Yes	Yes	Yes	Yes
N	102	102	66	102	102	66
Sample	Full	Full	Excluding East Elbia	Full	Full	Excluding East Elbia
Within R^2	0.83	0.83	0.81	.	.	.

Note: This table presents estimates for the effect of the patent-regime change on the number of all World's Fair exhibits (including commodities and cultural goods). We use a linear fixed-effects regression model with ln(ExPC) as the dependent variable in columns (1) to (3) and a conditional fixed-effects Poisson model with Exhibits as the dependent variable in columns (4) to (6). ln(ExPC) is the natural logarithm of (1 + number of World's Fair exhibits per million inhabitants), and Exhibits is the number of World's Fair exhibits. The coefficients of the interactions Annexed x T_{1873} and Annexed x T_{1876} indicate the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In all columns, we include district-fixed effects and year-fixed effects, and we use robust standard errors adjusted for clustering on the district level. In columns (4) to (6), we also add Population (number of inhabitants) as control. In column (2) and (5), we add five additional control variables: Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade). In columns (3) and (6), we use the specifications as in columns (2) and (5), but we exclude the eastern provinces of Prussia (East Prussia, West Prussia, Pomerania, Posen, and Silesia). We report the standard errors in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

Effects of market integration and economic liberalization on World's Fair exhibits

In Table 10 of the paper, we have presented additional results for the fixed-effects OLS model to rule out market integration and economic liberalization as alternative explanations for the observed increase in World's Fair exhibits. To show that these results are robust to different model specifications, we replicated the regressions of Table 10 by using a conditional fixed-effects Poisson model with *Exhibits* (number of exhibits) as endogenous variable and *Population* (inhabitants) as an additional control. In Table A5, we present the results. In column (1), we show that the interactions *Border Prussia x* T_{1873} and *Border Prussia x* T_{1873} (which we use to test for market integration within Prussia) are not significant. In column (2) and (3), we show results for the sample with additional control states. In column (3), the coefficients of *Border State x* T_{1873} and *Border State x* T_{1876} (which we use to test for market integration in the Northern German Federation and the German Empire) are also not significant.

Finally, we show the results for the sample with additional control states that introduced freedom of trade after 1862 in columns (4) and (5). In column (5), the coefficient of *Guilds State x* T_{1873} is not significant, and the coefficient of *Guilds State x* T_{1876} is significantly negative. Thus, the results presented in Table A5 mirror the results in Table 10, suggesting that market integration and other institutional reforms can not explain the observed increase in World's Fair exhibits in annexed territories.

Table A6: Alternative explanations: market integration and economic liberalization – Results for the Poisson-regression models

	(1) Poisson Exhibits	(2) Poisson Exhibits	(3) Poisson Exhibits	(4) Poisson Exhibits	(5) Poisson Exhibits
Annexed x T_{1873}	0.8711*** (0.1136)	0.6633*** (0.2125)	0.7950*** (0.2471)	0.8367*** (0.2001)	0.9654*** (0.2698)
Annexed x T_{1876}	1.3159*** (0.2900)	1.1286*** (0.4035)	1.3345*** (0.3674)	1.4611*** (0.3528)	1.4775*** (0.2650)
Border Prussia x T_{1873}	0.4529 0.2859				
Border Prussia x T_{1876}	-0.1132 (0.4401)				
Border State x T_{1873}			0.1324 (0.1799)		
Border State x T_{1876}			0.3154 (0.4099)		
Guilds State x T_{1873}					0.2178 (0.2413)
Guilds State x T_{1876}					-0.7231** (0.3100)
District FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Population Control	Yes	Yes	Yes	Yes	Yes
Additional Controls	Yes	Yes	Yes	Yes	Yes
Clustering	Yes	Yes	Yes	Yes	Yes
N	102	138	138	114	114
Sample	Full	Full + Control	Full + Control	Full + Control	Full + Control

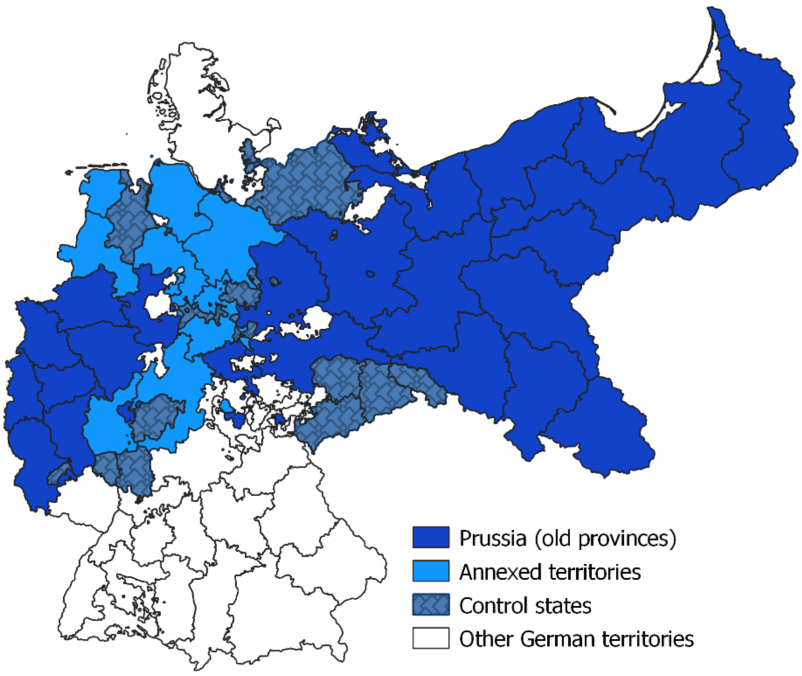
Note: This table presents estimates for the effect of market integration and economic liberalization on World's Fair exhibits. We use a conditional fixed-effects Poisson model with Exhibits as the dependent variable in all columns. Exhibits is the number of World's Fair exhibits. The coefficients of the interactions Annexed x T_{1873} and Annexed x T_{1876} indicate the effect of patent-regime change. Annexed is a dummy variable indicating whether Prussia annexed the district in 1866, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In all columns, we include district-fixed effects and year-fixed effects, we use robust standard errors adjusted for clustering on the district level, and we include Population (number of inhabitants) as well as five additional control variables: Population Density (= number of inhabitants (in 1,000) per km²), Steel Production (= steel production in tons per capita), Coal Mining (= coal production in tons per capita), Distance (=the great-circle distance between the district capital and the location of the World's Fair in km), and Economic Liberalization (= years since the liberalization of trade). We include the two additional interaction terms,Border Prussia x T_{1873} and Border Prussia x T_{1876} in column (1), Border State x T_{1873} and Border State x T_{1876} in columns (2) and (3), and Guilds State x T_{1873} and Guilds State x T_{1876} in columns (4) and (5) to perform Placebo-control tests. Border Prussia is a dummy variable indicating an old Prussian district that bordered with one of the annexed districts, border State is a dummy variable indicating a district that was in one of Prussia's bordering states that was not annexed, and Guilds State is a dummy variable indicating a district that was in one of Prussia's bordering states that was not annexed and where freedom of trade was introduced after 1862, and T_{1873} and T_{1876} are dummy variables indicating the respective year. In columns (2) and (3), we add data for a group of control states that border with Prussia (Brunswick, Bremen, Hamburg, Hesse-Darmstadt, Lübeck, Mecklenburg-Schwerin, and Saxony), and we add data for a group of control states where freedom of trade was introduced after 1862 (Brunswick, Hamburg, Lübeck, Mecklenburg-Schwerin) in columns (4) to (5). Standard errors are in parentheses. ***, **, and * denotes significance at the 1%, 5%, and 10% levels, respectively.

A2 Data Set and Variable Description

A2.1 Description of the Data Set

In the paper, we use data on the level of administrative districts (*Regierungsbezirke*). We distinguish between Prussia (old provinces) and annexed territories (see Figure A1). Prussia (old provinces) includes the Rhine Province, Westphalia, Brandenburg, Berlin, Pomerania, Silesia, Posen, West Prussia, East Prussia, and the Prussian province of Saxony (note that the latter is different from the independent Kingdom of Saxony). Every province consists of several districts (except for Berlin). Annexed territories include the Kingdom of Hanover, the Electorate of Hesse (Hesse-Kassel), the Duchy of Nassau, and the Free City of Frankfurt am Main. In 1866, Hanover became a Prussian province that constitutes of six districts, while Hesse-Kassel, Nassau, and Frankfurt am Main formed the new Prussian province Hesse-Nassau with districts Kassel and Wiesbaden (including the former territories of Nassau and Frankfurt am Main). Note that the data set does not contain data for Schleswig-Holstein because there was no independent patent system in the Duchies of Schleswig and Holstein before 1866. It also does not include data for the (small) southern Prussian exclave Hohenzollern.

Figure A1: Territories included in the empirical analysis



Note: This map illustrates the territories included in our empirical analysis. Black lines indicate borders of states and administrative districts.

To rule out alternative explanations, we use additional data on other German states (see Table 10 in the paper). In Figure A1, we show the geographic location of these control states that border Prussia. Control states include the following territories: the Kingdom of Saxony, Grand Duchy of Hesse (Hesse-

Darmstadt), Grand Duchy of Mecklenburg-Schwerin, Duchy of Brunswick, Free Hanseatic City of Bremen, Free Hanseatic City of Hamburg, and the Free Hanseatic City of Lübeck.

A2.2 Patent Data

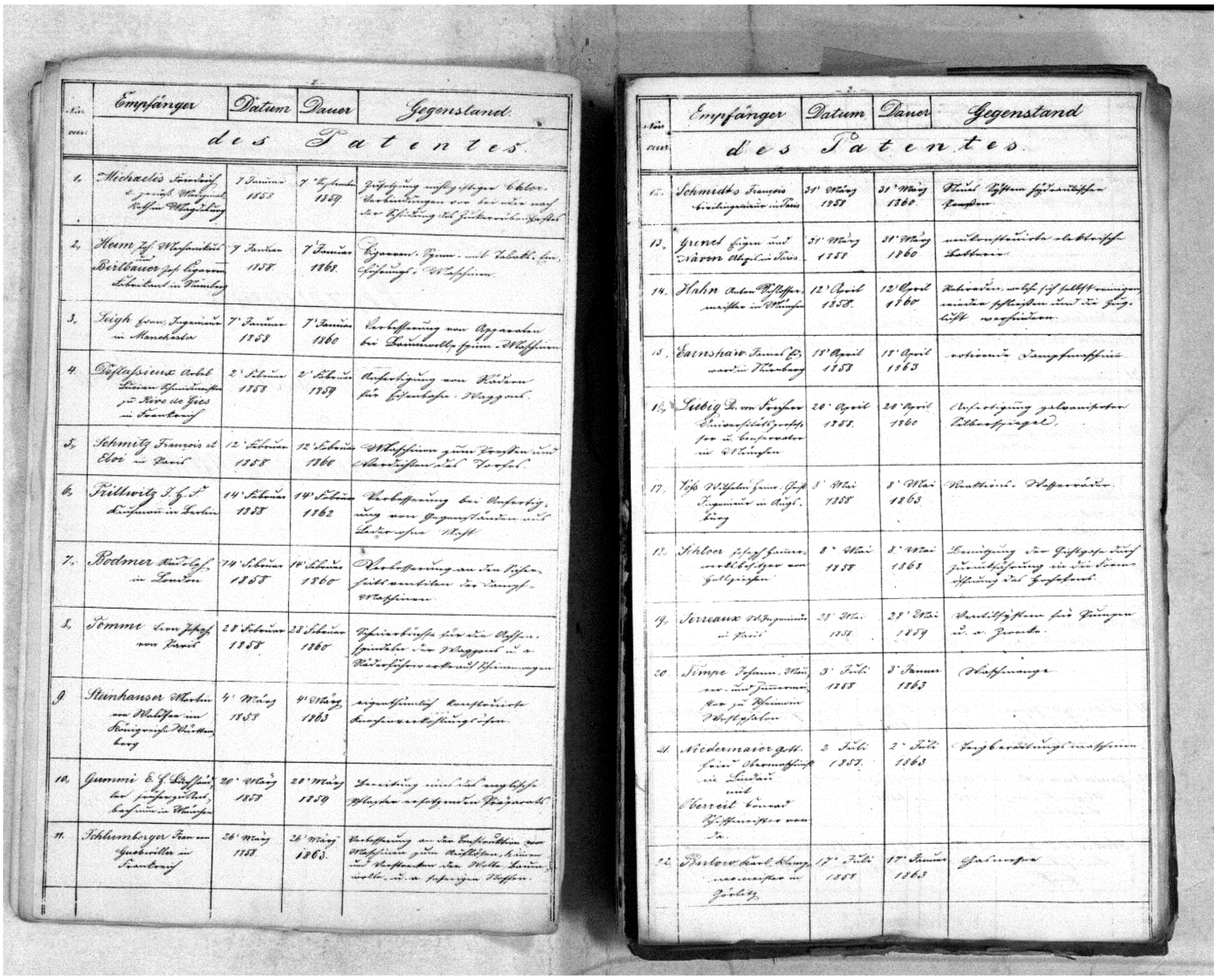
We hand-collected patent data from mostly hand-written patent lists that are kept in the files of the Ministry of Finance of the Grand Duchy of Baden. The files are available in the General State Archive in Karlsruhe (file numbers: Generallandesarchiv (GLA) 237/5210-14 and 12127). The German patent authorities used these yearly lists for the mutual exchange in the Zollverein based on an agreement signed in 1842 (Donges and Selgert, 2019a). The lists include information about the name of the patentee, the occupational background, the place of residence, the date of issue, and a brief description of the patented object (for an example, see Figure A2). For a small number of years and states, where the patent lists are missing in the General State Archive, we used additional sources to complete the missing information.

In the paper, we only include *domestic* patentees and drop all foreign patentees. Domestic patents are patens filed by citizens of the respective states. For example, when collecting the data for Hanover in the period 1855-65, we only include patents filed by Hanoverians. However, we drop all patents filed by inventors or companies from other German states (e.g., Prussia) and non-German states (e.g., the United Kingdom). In doing so, we get a measure of local patenting activity. For Prussia, we also drop all patents owned by "patent agents" (*Patent-Agenten*). These agents acted as intermediaries for non-German inventors and companies since foreigners were officially not allowed to file and own patents in Prussia before 1877 (though, there were some exceptions, for example, for inventors from countries with which Prussia had signed trade agreements; Donges and Selgert, 2019b).

We aggregated all patents by year and district, based on the place of residence of the patentee to create the panel data set. To compute patents per million inhabitants, we use the information on the yearly district population that is available on HGIS-Germany.[1] We use the following variables: ***ln(PPC)*** is the natural logarithm of (one + number of patents per million inhabitants), ***PPC*** is the number of patents per million inhabitants), and ***Patents*** is the absolute number of patents.

[1] Link: http://www.ekomp.digihist.de/Dokumentation_Datensaetze/Zeitreihen/Bevoelkerung/.

Figure A2: Example for a patent list used in the Zollverein



Empfänger	Datum	Dauer	Gegenstand
des	Patentes		

Source: Picture of an original patent list recorded in GLA 237/5210-14 and 12127.

In Table 5, we show regression results for patents of specific technology groups. Note that the original patent records only list the patents by the date of issue but not ordered by technology class, as was the case after the introduction of national patent law in the German Empire in 1877. Therefore, we first assigned technology classes for each patent, following the classification scheme as the Imperial Patent Office. This classification scheme distinguishes between 89 classes, ranging from "1. Processing of ores and fuels" to "89. Sugar and starch production". For our study, we then aggregated these technology classes to get 15 different groups in total. In the paper, we provide results for the following groups (the technology classes of the Imperial Patent Office in parentheses):

"Machine-building" (13 (steam boilers), 14 (steam engines), 20 (railway operations), 21 (electrical engineering), 24 (firing installations), 27 (blower), 35 (hoists), 36 (heating installations), 46 (internal combustion engines), 47 (machine parts), 58 (squeezing machines), 59 (pumps), 65 (shipbuilding), 74 (signals), 81 (conveyors packaging machines), 88 (wind and water power)), **"Metals & Mining"** (1 (processing of ores), 4 (lighting with gas), 5 (mining), 7 (metal sheet, metal tubes, wire, rolling of metal), 10 (solid fuels), 18 (iron metallurgy), 19 (railway superstructure), 26 (gas generation), 31 (metal casting), 40 (non-ferrous metals and alloys), 48 (chemical metal-working), 49 (mechanical metal-working), 87 (machine tools)), **"Food, drinks & tobacco"** (2 (bakery), 6 (beer, wine, and alcohol), 17 (ice machines), 45 (agricultural machinery), 50 (flour mills), 53 (foodstuff in general), 64 (bar equipment), 66 (meat processing), 79 (tobacco), 82 (drying and kilning), 89 (sugar and starch)), **"Chemicals"** (12 (chemical processes), 16 (fertilizers), 23 (mineral oil and lipids), 22 (dyestuffs), 78 (explosives and matches)), and **"Textiles"** (3 (clothing), 8 (textile-processing), 25 (lace), 41 (hats), 52 (sewing), 73 (ropes), 76 (spinning), 86 (weaving)).

A2.3 Data on World's Fair Exhibits

We hand-collected data on World's Fair exhibits from the official exhibition catalogs. We use *International Exhibition. 1862. Official Catalogue of the Industrial Department. Third Edition* (printed for Her Majesty's Commissioners by Truscott, Son & Simmons, London) for the 1862 World's Fair in London, *Officieller General-Catalog. Zweite Vermehrte Auflage* (published by Verlag der General-Direction, Vienna) for the 1873 World's Fair in Vienna, and *Official Catalogue of the U.S. International Exhibition 1876. Revised Edition* (published for the Centennial Catalogue Company by John R. Nagle and Company, Philadelphia) for the 1876 World's Fair in Philadelphia. The catalogs include information about the name of the exhibitor, the place of residence, and a brief description of the exhibited product or products (for an extract of the 1862 exhibition catalog, see Figure A3).

We use the description of the exhibited product to identify commodities (e.g., minerals or unprocessed agricultural products) and cultural goods (e.g., artworks such as paintings), which we exclude in the paper. We then aggregated the number of exhibits by district and year. To compute the number of exhibits per million inhabitants, we use district-level population data from HGIS-Germany.[2] We use the following variables: ***ln(ExPC)*** is the natural logarithm of (one + exhibits per million inhabitants), and ***Exhibits*** is the absolute number of exhibits.

The exhibits are grouped and listed by industries. However, there is no systematic classification so that industry definitions and the level of aggregation varies over time. Thus, we harmonized the classification. Moreover, we find that some smaller industries are not represented continuously. In 1876, for example, there are no exhibits related to civil engineering, in contrast to 1862 and 1873. There are also cases for which the overall number of exhibits is relatively small in one year. For this reason, when analyzing the effects for exhibits of specific technology groups separately, we only focus only on four technology groups that we can well identify and that are relevant in quantitative terms: **"Machine-**

[2] Link: http://www.ekomp.digihist.de/Dokumentation_Datensaetze/Zeitreihen/ Bevoelkerung/.

building" (including also transportation, in particular, railways), **"Chemicals"**, **"Food, drinks & tobacco"** (including agriculture), and **"Textiles"**.

Moreover, we use the description of the exhibits to identify and categorize **"investment goods"** (all kinds of machines), **"intermediate goods"** (e.g., crude steel or basic chemicals), **"consumer goods"** (including non-durables such as beer or textiles and durables such as furniture), and "other goods" (the remainder, including, e.g., architectural models or building-construction plans).

Figure A3: Extract from the 1862 exhibition catalogue

[GERMANY]—HANOVER. 257

S.W. Transept and S.W. Transept Gallery.

CLASS 30.

328 BÖHLER, F.—Household furniture of hart's horn, objects of ivory.

329 JACQUET, H. SON.—Fancy furniture of carved wood.

CLASS 31.

330 LAUSBERG, C.—Metal caps for corks.

CLASS 33.

331 GOLDSCHMIDT, M. SON.—Jewellery.

332 FRIEDMANN, J. — Gold and silver-smith's ware.

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HANOVER.

CLASS 1.

341 GEORGE MARIA SMELTING WORKS, *near Osnabrück.*—Iron ores and pig-iron.

342 EGESTORFF, G. *Linden, near Hanover.* —Salt.

343 IN DER STROTH, H. *Bentheim.*—Jet coal.

344 MUNICIPALITY, *Osnabrück.* — Coal (Anthracite) from the Piesberg.

345 MOSQUA, *Hildesheim.*—Mill stones.

360 GUMMI-KAMM-CO. *Harburg.*—Combs of vulcanized caoutchouc.

361 HENNECKE, JAC. *Goslar.*—Oil and oil-cakes.

362 HURTZIG, BROS. *Linden, near Hanover.* —Manufactures of bleached and hardened caoutchouc.

363 TIEDGE, C. *Hanover.* — Pitch for chasing.

364 WILHARM & MÜLLER, *Melle.*—Machine-made corks.

CLASS 7.

365 KNÖVENAGEL, A. *Linden, near Hanover.*—Wood-sawing machine.

366 VOIGTLÄNDER, F. *Schladen.* — Tobacco spinning machine.

CLASS 8.

367 EGESTORFF, G. *Linden, near Hanover.* —Loco mobil steam-engine, iron casts.

CLASS 10.

368 EGESTORFF, A. *Linden, near Hanover.* —Asphalt.

369 HENNING, D. H. *Limmer, near Hanover.*—Asphalt and mineral tar.

370 HEYN, C. F. *Lüneburg.*—Statue of cement. Blocks united by cement.

371 MOSQUA, *Hildesheim.*—Cement.

Source: *International Exhibition. 1862. Official Catalogue of the Industrial Department. Third Edition* (printed for Her Majesty's Commissioners by Truscott, Son & Simmons, London)

A2.4 Control Variables

We use the following control variables *Population Density*, *Steel Production*, *Coal Mining*, *Economic Liberalization*, and *Distance to Exhibition*, which we describe in the following:

Population Density is the number of inhabitants (in 1,000) per square meter. We use information on the population of each district that is available on HGIS-Germany.[3]

[3] Link: http://www.ekomp.digihist.de/Dokumentation_Datensaetze/Zeitreihen/Bevoelkerung/.

Steel Production is the district-level steel production (in tons) per capita. We computed this figure based on yearly steel-production data that is available on HGIS-Germany.[4]

Coal Mining is the district-level coal production (hard coal and lignite, in tons) per capita. We computed this figure based on the yearly coal mining data that is available on HGIS-Germany.[5]

Economic Liberalization measures the years since the introduction of freedom of trade (*Gewerbefreiheit*) in each district. Data on the introduction of freedom of trade is from Donges et al. (2019) (see the information on the dissolution of guilds in section 2.1 of the online appendix).

Distance to Exhibition measures the great-circle distance between the location of the World's Fair (1862: London, 1873: Vienna, 1876: Philadelphia) and each district. We use the geo-codes of the main city of each district to compute the distances.

[4] Link: http://www.ekomp.digihist.de/Dokumentation_Datensaetze/Zeitreihen/Huettenindustrie/.
[5] Link: http://www.ekomp.digihist.de/Dokumentation_Datensaetze/Zeitreihen/Bergbau/.