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Shades of a Socialist Legacy? Innovation Activity in East and West Germany 1877-2014

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Abstract

The unification of the East and West German states in 1990 initiated the integration of two distinct innovation systems. In this process, the poorly functioning socialist system of East Germany adopted the formal institutions and organization of West Germany, a western-style market economy. We investigate the effect of this integration on patenting activity by applying a difference-in-difference approach. While patenting activity increased in both parts of the country until recently, the gap between East and West Germany widened considerably over time. This divergence in innovation activity suggests that current East-West differences may be indirectly rooted in this socialist legacy and the sudden shock transformation that occurred upon reunification. We also find that the similarity of the technology profile of the East and West German innovation systems is crucial to understand the divergence. So, East German innovation activity fell behind especially in technologies where both East and West Germany were specialized in before re-unification. The same applies to technologies where only West Germany was specialized in. Our findings indicate that integrating the two innovation systems mainly benefitted the West.

Keywords: Innovation, Socialism, Transformation, Germany

JEL-classification: O31, O52, P27

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1. Socialism, capitalism, and innovation[1]

After World War II (WWII), Germany was divided into two states. While the western part of the country, the Federal Republic of Germany (FRG), became a modern market economy, the eastern part turned into a soviet-style socialist planned economy, the German Democratic Republic (GDR). This separation and the sudden reunification more than 40 years later make Germany a fascinating laboratory for analyzing the effects of drastic institutional and political change.

This paper investigates the development of innovation activities in Germany before the German separation, as well as during and after German reunification. We try to answer two main questions. The first concerns the effect of forty years of socialism on innovation performance in East Germany compared to West Germany. The second concerns innovation performance in East and West Germany after reunification and the subsequent integration of their innovation systems. How was East German innovation performance affected by the reunification and radical transformation of various societal areas? In what ways did reunification benefit innovation performance in East and West Germany? And does the lingering socialist legacy and radical transition experienced continue to have consequences even today?

By answering these questions, we contribute to the discourse on how economic outcomes are affected by communism in the context of the "natural experiment" born of Germany's history of division and reunification (e.g., Becker et al. 2020; Wyrwich 2022; Fritsch et al. 2022). We highlight the impact of socialism on innovation activity (e.g., Mayntz 1998; Radosevic 2022; Kotz et al. 2002; Augustine 2007) and the long-run organization of economic activity.[2] We also strive to understand the historical roots of innovation activities, specifically how institutional legacies of the past impact economic outcomes (Nunn 2020).[3]

[1] We are thankful for the helpful comments from Holger Graf, Ann Hipp, Slavo Radosevic, and Mirko Titze on an earlier version of this paper.

[2] Becker et al. (2020), Cantoni and Yuchtman (2021), Fritsch and Wyrwich (2018), Fritsch, Greve and Wyrwich (2022), Wyrwich (2020).

[3] Del Monte, Moccia and Pennachio (2020); Ferrucci (2020); Fiszbein (2022); Moser, Voena and Waldinger (2014).

Moreover, our analysis is an interesting case study on what can happen when two distinctly organized innovation systems integrate.

In the context of transition, Germany's history allows for a clean assessment of the impact of socialism and transition policies for at least two reasons. First, during German unification, the ready-made institutional framework of the West German market economic system was transferred to the East virtually overnight. This economic shock treatment meant that the East German economy did not have to cope with incomplete institutional adjustments, as was the case in other countries of the former Soviet Bloc (Johnson 2001). Hence, we can assess the impact of socialist legacy on innovation activity in the setting of a unique natural experiment where a fully-fledged market economy was exogenously introduced. East and West Germany faced identical institutional framework conditions before and after the German separation. The key difference between the two parts of the country is that for four decades, only the East was exposed to a communist regime that included a Soviet-type socialist innovation system, followed by a shock transformation. Because of this distinction, we can use West Germany as a benchmark for measuring the impact of the socialist legacy on the East.

We find a considerably lower level of patenting in East Germany directly following the regime switch – an effect of the inefficient socialist innovation system. In the first years of the transformation process, East German innovation activities were subject to considerable structural adjustment processes and consolidation in technological fields where both parts of the country were specialized. These adjustments occurred because the more advanced West outperformed the East. After the unification, patenting levels increased substantially in both parts of the country. However, this increase accelerated in the West while plateauing in the East. After 2007, patenting activity in East Germany began decreasing, even in technological fields where East and West Germany had both been strongly specialized directly preceding the German reunification.

Our findings demonstrate that the combination of socialism, a drastic transition shock, and the process of integrating East Germany into the dominant West German system had a long-term negative treatment effect on the level of innovation activity in East Germany. The German example indicates that the

socialist system, as also seen in Eastern Europe, has not only failed as an economic and societal model but that its innovation-related heritage can only make limited contributions in the framework of a market economy. These results highlight the importance of regions developing specific profiles of their innovation activities so that they may continue to be competitive in the face of national or global integration processes.

The remainder of the paper is as follows: Section 2 provides a brief overview of innovative activity in Germany over the last 140 years, and Section 3 describes the potential effects of reunification on innovation in East and West Germany. We then examine the East-West distribution of inventive activity before and after the separation in Section 4 and provide an overview of the data and the results of a difference-in-difference analysis in Section 5. In Section 6, we explore the role of technological specialization in how German unification affected patenting activity. Finally, in Section 7, we conclude our results and discuss policy implications and limitations, along with avenues for further research.

2. A short history of innovation activity in Germany

2.1 Before and during separation

By the turn of the 20th century, Germany became one of the world's leading industrial powers advancing in technological fields such as chemical, pharmaceutical, automobile, and electricity that were characteristic of the "second industrial revolution" (Grupp, Dominguez-Lacasa and Friedrich-Nishio 2002; Naudé and Nagler 2022). Mroczkowski (2014) traces this success back to the country's well-functioning innovation system. This system was characterized by novel research universities that combined teaching with basic and applied research, successful collaboration between public and private sectors, consistent state policies that supported innovation activities, and the availability of financial resources. The emergence of corporate laboratories for Research and Development (R&D) in the 1870s and 1880s and the enactment of German patent law in 1877 contributed significantly to this process (Burhop 2010). The country lost its leading position during the Nazi era with the expulsion of Jewish scientists (e.g., Waldinger 2012) and the devastating WWII that led to its separation into East and West states.

The FRG became an innovative western-style market economy (Fritsch and Wyrwich 2021), but it lost much of its former capability for breakthrough innovations (Naudé and Nagler 2018). The GDR was occupied by the Soviet Union which installed a socialist state with a centrally planned economic system. In contrast to West Germany, the GDR faced substantial dismantling of industrial and innovative structures during the first years of the Soviet occupation (Ritschl and Vonyó 2014; Steiner 2010).[4] During this time, the GDR's innovative potential declined as many innovative firms relocated to the West to escape the communist regime. East Germany also experienced a considerable exodus of well-qualified and entrepreneurial-minded people up until the border closure of 1961 (Ritschl 2010; Falck et al. 2013; Ritschl and Vonyó 2014; Becker et al. 2020).[5]

The Soviet-style innovation system installed in the GDR proved relatively inefficient (Mayntz 1998; Radosevic 1998; Kotz et al. 2002; Augustine 2007). Research and development followed a linear model of innovation that practically ignored any feedback loops (for a schematic overview of actors and linkages, see Meske 1993). As a result of this rigid organization, the GDR innovation system failed to adapt its industrial and innovative capacities to global developments such as the oil crises of the 1970s (Blum and Dudley 1999; 2000). Another obstacle to innovation activities that the GDR faced was the closed border to the technologically more advanced West which hindered connections to global knowledge flows (Grupp et al. 2002). Moreover, the Western countries introduced an embargo on the Eastern Block for the export of innovative goods that hampered access to technology.

Compared to the FRG, the former GDR devoted a slightly higher share of expenditures and personnel to R&D (Meske 1993; Sleifer 2006; Guenther, Hipp,

[4] Although West Germany experienced more damage from the war, the ruination of the industrial stock and reparations to the occupying forces hit East Germany much more heavily (Sleifer 2006). By 1948, the Soviets had dismantled capital assets, such as relocating machinery from around 3,400 factories to the Soviet Union. Shortly after the war, the reparations amounted to almost half of the gross national product, and as of 1953, they still comprised 13% (Steiner 2010). According to Ritschl and Vonyó (2014), the Soviet reparations reduced the East German capital-labor ratio in industry by about one-third.

[5] Prominent examples include car manufacturers *Audi* and *BMW*, and *Siemens*, the leading German electrical engineering firm at that time. Some firms split into an Eastern and a Western part; prominent examples are the *Carl Zeiss* company—a world market leader in optical instruments and the glass-making firm, *Schott*.

and Ludwig 2020). The government also followed policies that resulted in a higher share of patented inventions as compared, for example, to West Germany. However, the link between patenting and productivity remained weak (Frieling 2021), suggesting severe inefficiencies in the innovation system. One example of such inefficiency is that industrial firms rarely applied inventions patented by the public research institutes of the *Academy of Sciences,* the main organizer of extra-university public research. This pattern demonstrated a distinct lack of absorptive capacity and is quite remarkable as many of the patents filed by these institutes emerged from a collaboration with industry. This incongruity suggests that the link between public research and industry, frequently enforced by central planners, often proved costly and inefficient (Mayntz 1998). In conclusion, at the advent of economic transition, the GDR innovation system, as compared to the FRG, was plagued by several inefficiencies within its innovation system.

2.2 Reunification and transformation

The communist East German regime collapsed unexpectedly and quickly after the fall of the Berlin Wall in 1989. In July 1990, the two German states introduced a currency union, followed by a formal reunification in early October. This sudden shock transition in East Germany involved a massive decline in the industrial sector. Many formerly state-owned enterprises could not compete effectively and were shut down (for details, see Brezinski and Fritsch 1995; Burda and Hunt 2001). Only a few viable firms survived (Mergele, Hennicke and Lubczyk 2020), sometimes as extended workbenches of West German and international companies, without any significant individual innovation activities. Most large state-owned enterprises were dismantled and transformed into unrelated small and medium-sized firms (e.g., Radosevic 2022).

The East German education sector and public research became restructured according to the West German model. This restructuring involved substantial changes to universities and academic education. The *Academy of Sciences* shut down, and several of its institutional components became integrated into West German public research organizations such as the *Max Planck,* the *Leibniz,* and the *Fraunhofer Society*. Estimates show that only 40% of the GDR's scientific employees remained in research after the reunification (Kocka 1994; Meske 1993). After 1990, almost 25% of inventors involved in patenting adopted

research positions in West Germany (Dorner et al. 2016). The intensive restructuring of the East German innovation system destroyed many relationships and hampered cooperative R&D activities (Meske 2000).

There is a persistent East-West gap in innovation activities apparent since the beginning of the transformation process in 1990. Despite massive subsidies for private sector R&D activity and considerable investment in universities and public research institutes, the average level of innovation activity in East Germany is consistently lower and less productive than in West Germany (Fritsch and Slavtchev 2011; Rammer, Gottschalk and Trunschke 2020). East Germany has only a few highly innovative places, particularly Berlin, Dresden, and Jena, but these represent largely isolated "pockets of excellence," or "cathedrals in the desert," poorly connected to their hinterland (Fritsch and Graf 2011).

While the East-West innovation gap is well-documented, the reasons for this gap remain uncertain. The common wisdom in the respective literature tends to regard the East-West innovation gap mainly as a long-term consequence of the socialist period. It is, however, unclear to what extent the observable differences result from the rapid integration of the two innovation systems initiated by a shock transition. There is also hardly anything known about how German reunification affected innovation activities in West Germany. Is it possible that the West was able to harvest most of the benefits of integrating the two innovation systems? The following section attempts to disentangle the effects of integrating these innovation systems.

3. The effect of reunification on innovation activity in East and West

The effects of reunification and transformation on innovation activities in East and West Germany are diverse and complex. A general expectation is that integrating two formerly separate innovation systems should have positive scale effects such as increased richness and diversity in the knowledge base, more opportunities for cooperation, and a beneficial division of innovative labor. Resource mobility, particularly the mobility of R&D personnel, should also improve, resulting in a better allocation of resources. Moreover, the increased complexity of the system may lead to intensified competition among researchers and, therefore, greater efficiency.

In East Germany, the radical reorganization of the innovation system should have had short-run negative consequences while producing positive effects in the long-run. Long-run innovation activities would have benefitted from scale effects, better organization, and unrestricted access to technologies and global knowledge. One factor that shaped the integration process was the similarity of technological specializations between each innovation system. During the German reunification, the technological profiles of the East and West German innovation systems were highly similar for two reasons. First, East and West Germany constituted an integrated innovation system in the pre-separation period. Second, GDR leadership pushed scientists and engineers to catch up with technological developments in western countries, particularly in West Germany. This benchmark was crucial in demonstrating socialist superiority (Steiner 2010).[6] A prime example of this is the case of *Carl Zeiss*, a world-leading producer of optical instruments since the 19th century. After WWII, this company split into an East German and West German firm. After 40 years of separation into a socialist and a market-oriented environment, Kogut and Zander (2000) show that the technological profiles of both firms remained very similar.

Because West German research was generally more advanced than that in East Germany (see section 2), the similarity between their respective technological fields implies that West German projects outcompeted their East German counterparts in a consolidation effect (Grupp et al. 2002). This consolidation process is unlikely to explain the East-West gap in the first transition years. This process may have initiated divergent long-run developments in the respective technological fields for several reasons.

First, innovation activity in West Germany in these technologies might have been particularly efficient compared to East Germany due to specialization and scaling advantages. Such advantages could make it difficult for East German actors to catch up. Second, the migration of East German scientists and engineers

[6] This focus was pursued despite the official policy of sharing R&D results within the COMECON. Such cooperation often did not work in practice (Augustine 2014). Catching up with the West was achieved in the early years of separation via still-existing personal contacts between West and East German scientists. Starting in the mid-1960s, the GDR enormously increased direct imports, as well as licensing of Western technology for integration into its production processes; the illegal importation of Western technologies also escalated during this time (Glitz and Meyersson 2020).

during the consolidation process in the first few years after reunification may have reinforced specialization and scaling advantages (Dorner et al. 2016). Third, the extensive restructuring of the GDR innovation system destroyed many established links among actors, and damaged networks. The high turbulence during the first few years of the transition caused many firms and organizations to radically reorganize or shut down; this hampered the establishment of trustful relationships necessary for the effective division of innovative labor.

While implementing institutional change and establishing smooth interaction may require considerable time under *normal* circumstances, the transition process may have increased the effort and the time necessary for adjustments. An analysis by Ruhrmann, Fritsch and Leydesdorff (2022) supports this conjecture as they find that more than twenty years after the transition, regional innovation systems in East Germany were still far less integrated with low levels of local synergy to foster innovation. In other words, there were lower levels of "systemness", where "systemness" refers to the relational embeddedness and the mutual interplay of the political, economic, technological, and cultural systems within a geographical area. Altogether, based on these different effects, one may expect convergence in the quantity and productivity of innovation activities in East and West Germany in the long run only. In the short run, one should observe few tendencies for convergence.

4. Empirical approach

4.1 Data

Our empirical analysis uses patents as an indicator of innovation activity. Patents are advantageous because they contain vital information across various regions over time. This information includes the name(s) and address(es) of the applicant(s) and the inventors, the technological field of the invention, and the date of application (for an overview, see Griliches 1990, and Nagaoka, Motohashi and Goto 2010).

A disadvantage of patents is that they represent only the first stage of the innovation process. Therefore, one does not know if, when, or how an invention is applied in a new process or product (Feldman and Kogler 2010). Another critical issue is that not all inventors and firms use patents to protect their intellectual

property (Cohen, Nelson and Walsh 2000; Blind et al. 2006). Hence, not all inventions are patented. Moreover, some inventors obtain multiple related patents for basically the same invention to block follow-up patents from rivals. There is also a clear indication that the economic value of patents significantly varies, indicating that their economic impact is unpredictable.[7]

To assess how the German separation impacted patenting activity, we sought data from before and after the introduction of socialism in 1945. Data before 1945 comes from the PatentCity project which provides location information for all patents granted in Germany since the introduction of patent protection legislation in 1877 (Bergeaud and Verluise 2022).[8] In our econometric assessment of the impact of German separation, we use information from 1877 to 1939 so that we may test whether there were parallel development trends in East and West Germany pre-separation. The onset of WWII in 1939 is used as a reference point because patenting activity toward the end of WWII might be biased. To calculate the number of regional patents per capita, we extra- and interpolated population figures based on census data and the German Local Population Database for the years: 1871, 1910, 1925, and 1939 (Statistik des Deutschen Reichs 1927; Roesel 2022).

Patenting data for West Germany from 1980 onward are provided by Rassenfosse, Kozak and Seliger (2019). Data on East German (GDR) patents are available from 1949 to 1990, but only patent applications between 1989 and 1990 contain meaningful location information (for details, see Hipp et al. 2022). The technical quality standards that an invention had to meet to be eligible for filing a patent were comparable in the GDR and the FRG.[9] However, the differences of the patenting procedures in the FRG and GDR make a comparison of patents levels during the separation from 1945-1990 rather difficult. The differences

[7] The distribution of the economic value of patents appears to be highly skewed. While a few patents are extremely valuable, most are not (Harhoff et al. 1999; Harhoff, Scherer and Vopel 2003).

[8] The pre-1945 data have the drawback that the location information usually corresponds to the applicant. This implies a bias in the regional assignment because multi-establishment firms or research organizations with multiple locations typically file all their patents under the location of their headquarters, independent of where the research was conducted. Another limitation of the pro-1945 data provided by PatentCity is that it only includes granted patents and not all applications.

[9] This is stated in Federal German patent law (e.g., BPatG in GRUR 1993, p. 733, 735).

imply that inventions were more likely to be filed as a patent in the GDR (Grupp et al. 2002; Wießner 2015; Hipp et al. 2022; for details, see Appendix B).

Patent data are again comparable between the East and West from 1991 onward when the same patent law applied to both parts of the country.[10] In the analysis, we use the data provided by Rassenfosse, Kozak and Seliger (2019) for this period.[11] A drawback of these data is that they do not include information on the technological field (IPC class) of a patent which is crucial in understanding the mechanisms behind East-West differences. Therefore, we rely on the OECD RegPat data (version July 2021) to analyze the differences between technological fields.[12] We also run our analysis with RegPat data as a robustness check to rule out that the choice of datasets affects the results.

In our econometric assessment, every patent is assigned to a planning region (*Raumordnungsregionen*) in East or West Germany[13]. In the analysis, we do not consider Berlin because it is not possible to distinguish patents from the Eastern and the Western part of the city neither for the pre- nor post-separation periods.[14]

[10] The Patent Law Amendment Act came into force on June 29, 1990. However, the first complete year with patents registered under the new jurisdiction is 1991.

[11] These data include geocoded information on the residence(s) of the inventor(s) in all countries worldwide from 1980-2014, including internationally registered and purely national patents (i.e., those only registered in their country of origin). PatentCity does not include internationally registered patents but using this source for pre-1945 patents is not problematic because no international patent organization existed yet. The European Patent Office and the World Intellectual Property Organization were founded almost a century later, in 1977 and 1967, respectively.

[12] A drawback of RegPat is that it includes only internationally registered patents (Maraut et al. 2008).

[13] Planning regions represent functionally integrated spatial units compared to labor market areas in the US. Planning regions consist of at least one city and its surrounding area. We employ planning regions as spatial units of analysis to account for the common practice of regionalizing patents by assigning them to the region where the inventor resides (for details, see Maraut et al. 2008). Since an inventor often resides some distance from her/his workplace, restricting the region size to the narrowly defined district or city would lead to underestimating the respective city's level of inventive activity. Moreover, functional regions are more appropriate because they account for spillovers between cities and their surroundings.

[14] We also omit the Saarland region because it was not in the data from 1920-1935 when the League of Nations managed the area.

4.2 Patenting in East and West Germany 1877-2014

Figure 1 shows patent intensity in East and West Germany as number of patents per 10 thousand population before the separation from 1877 to 1945, from 1980-1990, and post-unification, from 1991 to 2014.[15] The data suggest that patent intensity during the pre-separation years was very similar in the two parts of the country; differences between East and West Germany in this period were small and not statistically significant (see Table A1 in Appendix A).

As mentioned in 4.1, the East German patenting system was marked by peculiarities hampering a direct comparison of patent data with the FRG. One effect of this was that the number of internationally registered patents was very low in absolute terms but also relative to the number of patents only registered within the GDR. So, the share of internationally registered patents over all patents was only 0.032 in the GDR while it was 0.295 in the FRG. We calculate an adjusted number of the GDR patents and assume that the adjusted number is close to the number that would have emerged if the patenting procedures in the GDR had been like that in the FRG, yielding a similar ratio between international and national-only patents.[16] Had the share in the GDR mimicked that seen in the FRG, the average number of patent applications per 10 thousand population in the GDR would have been 0.60 in 1989, much lower than the respective value of 2.75 for the FRG. Simultaneously, the original (non-adjusted) number of patents registered at the GDR patent office was about 4 patents per 10 thousand population (see Figure 1).

In 1991, the first year for which directly comparable data exist, we find that patenting activity in East Germany was only 14.5% compared to West Germany, with 0.31 patents per 10 thousand population versus 2.14 patents, respectively. Given that there was no significant East-West difference in patenting activity before the German separation, this difference indicates a considerably negative impact of socialism.

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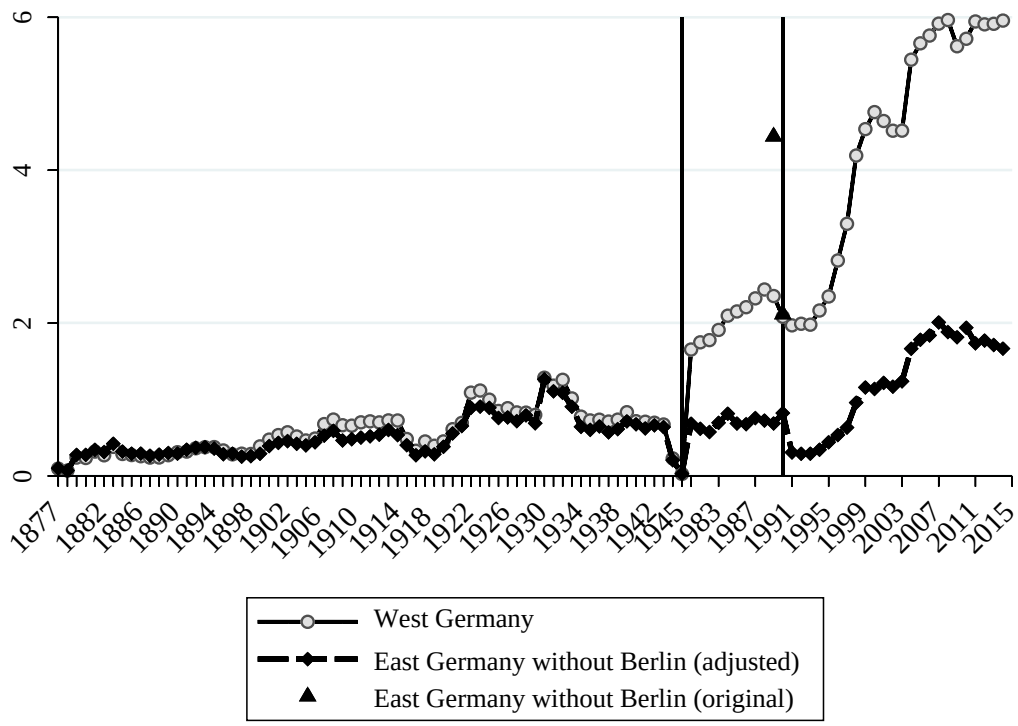
[15] A graph including Berlin is shown in the Appendix (Figure A1).

[16] We can show both the non-adjusted and the adjusted numbers of GDR patents for 1989 and 1990 (see Figure 1). We have no location information for GDR patents before 1989. Therefore, we cannot remove international patents and those patents from East Berlin like in the other years. This means that we show only the adjusted numbers for the years 1980 to 1988 because the adjustment procedure does not require a location information.



Notes: The data for the pre-WWII period (1877-1945) are from PatentCity. Vertical lines indicate the period of separation (1945-90). Data for East Germany between 1980 and 1990 is displayed twofold: first, an adjusted measure based on Rassenfosse, Kozak and Seliger (2019) and non-adjusted data for the years 1989 and 1990 taken from Hipp et al. (2022).

Figure 1: Average number of patent applications per 10 thousand population

In both parts of the country, patenting intensity declined directly after unification, then stagnated for some years. This development may reflect the turbulent adjustment processes during these years. In 1994, patenting intensity in East and West Germany started to increase, however, the advancing integration of the two innovation systems did not lead to convergence because the increase of patenting intensity was considerably stronger in the West, especially in the second part of the 1990s.[17] Since 2008, East German patenting intensity declined while there was a further increase in the West. At the end of our observation period in 2014, the East-West gap of patent intensity amounted to about 4.3 patents per 10 thousand population (see Table A1 in Appendix A). This is four times larger than what is seen at the end of the socialist period in 1991.[18] Overall, the strong

[17] There was a slight decrease in patenting in West Germany following the dot-com bubble bursting in 2000 and the financial crisis in 2008.

[18] The development of East German patenting activity after 1990 was similar to the development in Central Eastern European countries (CEECs) (see Figure A2 in Appendix A).

increase in patenting activity in West Germany suggests that the West was able to benefit significantly more from the integration of the two innovation systems than the East.

5. Identifying the regional effect of German separation and reunification on innovation activity

5.1 Method — Difference-in-Difference approach

To identify the regional effect of German separation and reunification on innovation activity, we apply a difference-in-difference approach (DiD). Hence, we estimate an equation of the following structure:

$$INV_{rt} = \alpha + \beta\, East_r + \gamma Year_t + \sum_{t=1877}^{1939} \sigma_t(East * Year) + \sum_{t=1991}^{2014} \sigma_t(East * Year) + \zeta X_{rt} + \varepsilon_{rt}. \quad (1)$$

In this equation, INV_{rt} denotes the patent rate in region r in year t, δ_t represents a vector of the DiD-estimators of interest, σ_t formally tests if there are common pre-separation trends, and the dummy $East_r$ indicates a location in East Germany. We also include a vector of control variables ζX_{rt} for key characteristics of the regional context that may play a role in innovative performance. Among these variables, population density (population per km^2) is supposed to control for agglomeration economies. The employment share in manufacturing accounts for the dominant role of this sector in patenting. Geographic distance to the nearest technical university founded before 1900 is supposed to control for the regional knowledge base before and after WWII.[19] The net-migration rate (number of net-migration over resident population) represents the overall development of a region.[20] We estimate the equation at the level of planning regions

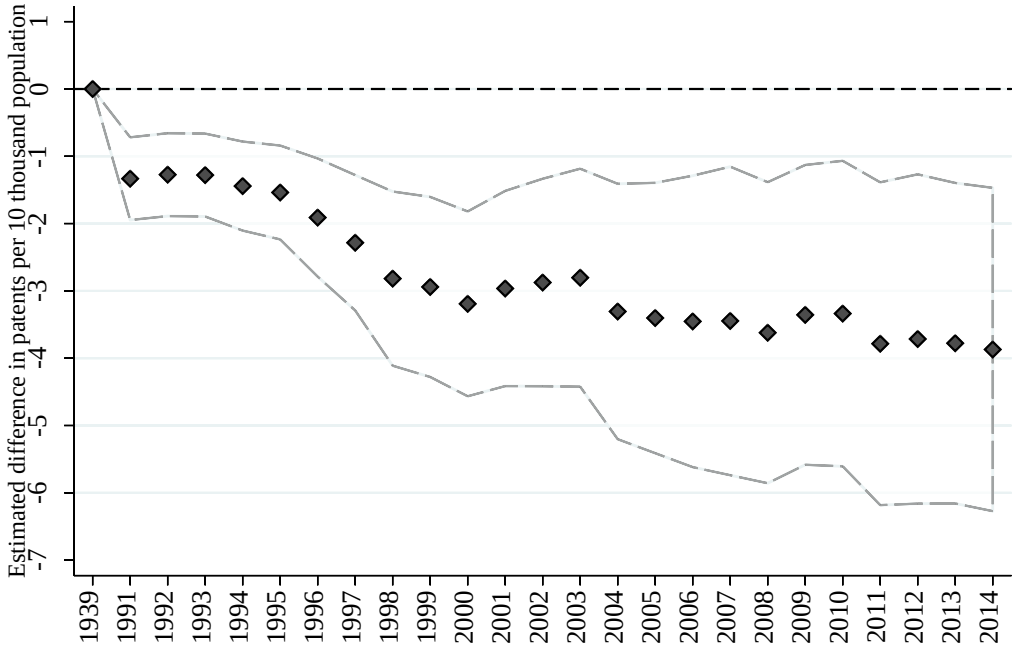
[19] Fritsch and Wyrwich (2018) showed that this variable is a good approximation of the regional knowledge base until today.

[20] The pre-separation data for the employment share in manufacturing and the net-migration rate comes from population censuses conducted in 1925 and 1939. For the remaining pre-separation years, these two variables are extrapolated. The population density in the pre-separation period is calculated based on extrapolated population figures from the German Local Population Database compiled by Roesel (2022). Post-separation figures on population come from the Federal Statistical Office, and employment data are from the Federal Employment Agency.

(*Raumordnungsregionen*) with standard errors clustered at the federal state-by-time levels to control for spatial autocorrelation.

5.2 Main findings

Figure 2 and Table A2 in Appendix A (model II) show the baseline results of our estimations of equation (1) with the data provided by Rassenfosse, Kozak and Seliger (2019). East-X-Year$_t$-interactions, which measure the DiD-coefficients of interest, capture treatment effects. Taking 1939 as a reference, the DiD-coefficients measure the effect relative to the situation before WWII and the introduction of the socialist East German state.



Notes: The figure shows coefficients for the full baseline model, including all controls (model II of Table A2 in Appendix A). Grey dashed lines represent the 95% confidence interval. Figure A3 in the Appendix exhibits all coefficients prior to the separation.

Figure 2: Difference-in-Difference (DiD) coefficients

We find statistically significant negative treatment effects for East Germany in the first years after reunification regardless of whether we control for regional economic and structural conditions (see models I-III in Table A2 in Appendix A). The effect size is between 1.1 and about 3 patents per 10 thousand population in the 1990s. As of 1994, the treatment effect steadily increases. In the 2000s, it lands between 3 and 3.6 patents per 10 thousand population, with or

without the regional controls respectively, and assumes values of more than 4 patents per 10 thousand population post 2010. Note that there were no significant East-West differences before WWII and the German separation, a crucial condition for the reliability of our DiD approach. The results are similar when using 1945 as a pre-separation reference year (see columns VI and VII of Table A2 in Appendix A). Furthermore, when considering the adjusted measure of GDR patenting activity (see Section 4.1 and Appendix B for explanations), we find that the size of the treatment effect in the last years of the GDR is very close to the size of the treatment coefficients in the final years after the reunification. It is nearly identical for 1989 and 1991 (1.5 patents per 10 thousand population) (see Figure B1 and model IV and V of Table A2).

5.3 Robustness checks and further analyses

To rule out the possibility of our results being driven by the dataset choice, we conducted several robustness checks. Hence, we ran the analysis with OECD RegPat data and data provided by PatentCity for the post-1990 period and found similar results (models I-VI in Table A3 in the Appendix). The coefficients are smaller since either only national (PatentCity) or international patents (RegPat) are included in the outcome variable.

Based on OECD RegPat data, we also distinguish different types and qualities of inventions (see Squicciarini, Dernis and Criscuolo 2013) and run the analysis for these to rule out that our results are driven by certain types of patents. In these analyses, we concentrate on quality measures that are based on backward citations, such as the measure of an invention's radicalness and originality.[21] While radicalness is measured by the number of IPC classes of the patents that are cited by the focal patent (Shane 2001), originality is measured by the breadth of the distribution across these IPC classes (for a detailed definition see Squicciarini, Dernis and Criscuolo 2013). The results for individual quality indicators show that there are no pronounced differences in the DiD-coefficients among various types of patents (see Table A5 in the Appendix).

[21] We do not include any quality measure based on forward citations because the more recent patents could hardly generate any forward citations leading to a bias in favor of older patents. The number of forward citations indicates a patent's impact on further technological developments.

To rule out the possibility that our main findings are driven by particular regions, we ran the analyses for certain parts of East Germany. The results are robust despite the size of the treatment coefficients being somewhat lower for regions with higher levels of patenting activity before the German separation (i.e., Saxony and Thuringia) (see Table A4, columns I-IV, and Figure A4 in Appendix A). We also ran an additional analysis where we assigned Berlin to East Germany (see column V of Table A4 in Appendix). The resulting treatment effect was greater than what was seen in the baseline analysis, indicating that the German separation negatively impacted innovation activity in Berlin.

6. Technological specialization and the widening gap in innovation activity

6.1 Similarities between technological profiles at the time of reunification

We argued in Section 3 that similarities between technological profiles at the time of reunification may have driven a process of consolidation where West Germany outcompeted East German innovation processes in the same technological field. We explore the relevance of such a consolidation process, and its eventual long-run consequences, by measuring the technological specialization of patenting in East and West Germany at the beginning of the transition process in 1991. To this end, we first arranged all IPC classes at the 4-digit level (N=743) according to their share of the overall number of patents. This was done separately for East and West Germany. We then added up IPC classes stepwise, beginning with the largest ones in descending order until this aggregate made up 50% of all patents in either East or West Germany (for further details of the calculations, see Appendix C).[22] Those IPC classes contained in the 50% most frequent IPC classes are regarded as fields where East or West were specialized.

We formed four categories to describe the specialization patterns of 1991.[23] The first we named *Joint Specialization*, and it includes patents in technology classes in which both East and West Germany had specialized. Patenting in technologies in this category may be prone to consolidation processes

[22] The idea is borrowed from Ferrucci (2020), who describes the approach in more detail.

[23] Table A6 in the Appendix A, provide an overview of how these IPC classes map onto broader technological fields.

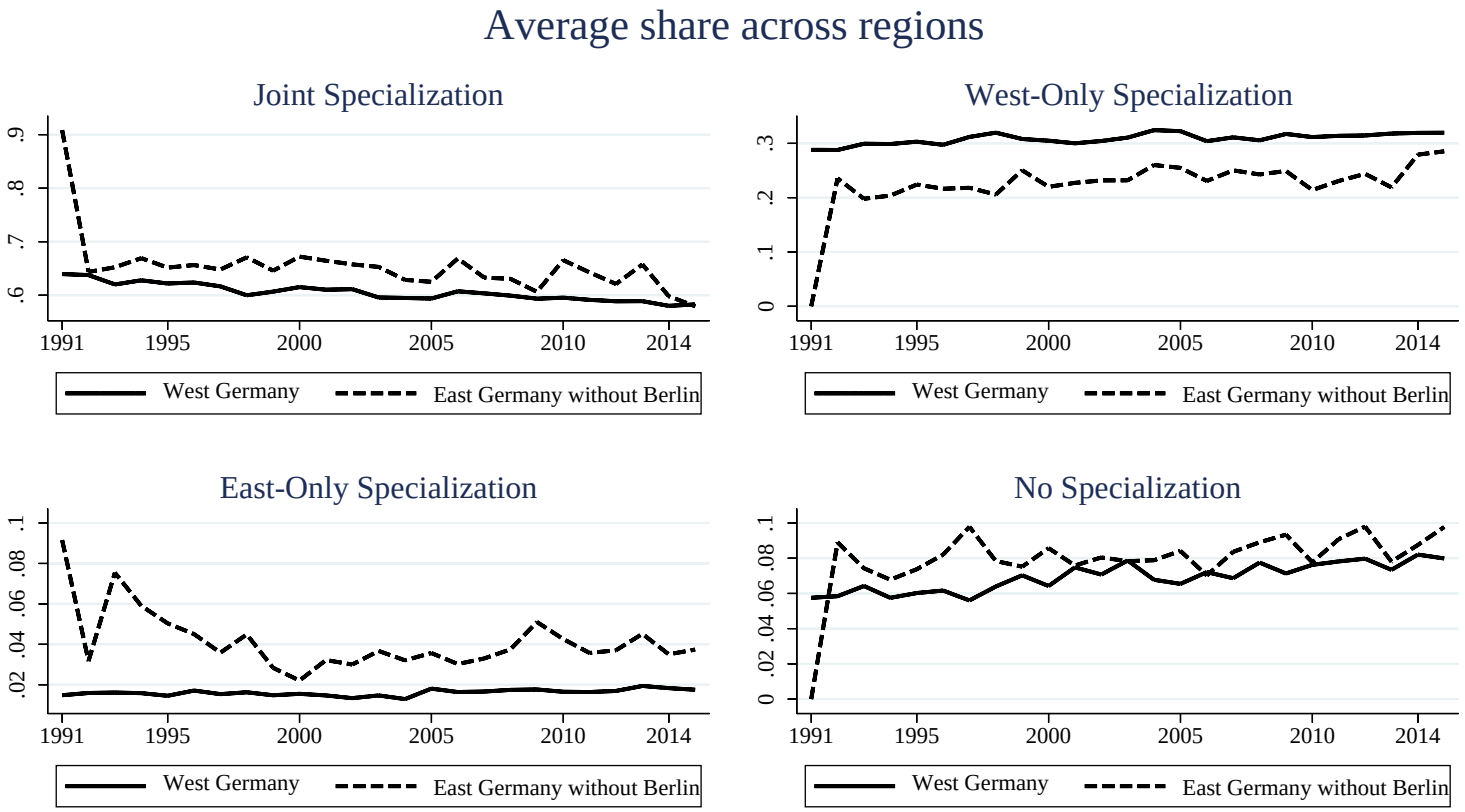


Figure 3: Specialization shares by category representing patents in technology classes in East and West Germany across time

resulting from intensive East-West competition. We named the second category *West-Only Specialization*, and it includes patents in technology classes in which only West Germany had specialized. It is plausible to assume that competition and consolidation played a less important role in these fields because there were few East German patents for these technologies. However, West German innovation activity might have been particularly successful in these technological fields thanks to specialization and scaling advantages. Hence, East German innovation activity in these technologies might struggle to catch up.

The third category, *East-Only Specialization*, includes technology classes in which only East Germany specialized. One may assume that these technologies represent niches where East German innovation activity developed relatively well after unification. For the fourth category of IPC classes, where neither East nor West Germany specialized, it is difficult to predict whether East Germany was competitive therefore, we have named this *No Specialization*.

Figure 3 exhibits the share of patents in the four groups across years and regions. In 1991, the share of patents belonging to technology classes where both East and West Germany specialized (*Joint Specialization*) was above 90% for East Germany and 64% for West Germany. In 1991, the share of patents in technology classes where West Germany, but not East Germany, specialized was close to 0% in East Germany and around 30% in West Germany (see the sub-graph in Figure 3 titled *West-Only Specialization*).

In 1991, the share of patents in technologies in which only East Germany specialized was about 8.5%, while it was 2% in West Germany (Figure 3, *East-Only Specialization*). It is remarkable that the share of patents in technologies in which neither East nor West Germany specialized made up about 6% in West Germany while it was virtually 0% in the East (Figure 3, *No Specialization*). These figures reflect a lack of diversification in East German innovation activity at the beginning of the transformation process. Altogether, the technology mix of the East German patent portfolio at the beginning of the transition process can be described as toxic, given the deficiencies of the socialist innovation system. The portfolio was strongly biased towards technologies in which West Germany was likely to outcompete the East in the coming years.

East and West Germany experienced a rapid convergence of the patent shares in all four groups of technologies in the first few years after unification. For example, the East German share of patents in technologies in which both East and West Germany specialized dropped from 90% in 1991 to 65% one year later, nearly identical to the West German value (64%). Thus, within one year, the average joint specialization shares in the East dropped to the level of the West. This sharp drop reflects the initial consolidation process described by Grupp et al. (2002). Hence, the most significant change in the East German patent portfolio occurred very early in the transition process and began to conclude toward the end of 1992 (see Figure 3).

In East Germany, the average share of patents in technologies in which West Germany specialized rose drastically from nearly 0% in 1991 to 20% in 1992. This reveals a rapid transfer of these technologies from the West to the East. Since the early 1990s, the average share of patents in technologies in which only the West specialized was about 22.5 % for East Germany and 30.9% for West Germany. For the remaining two specialization groups, the patent shares remained small and varied between 10 and 15%.

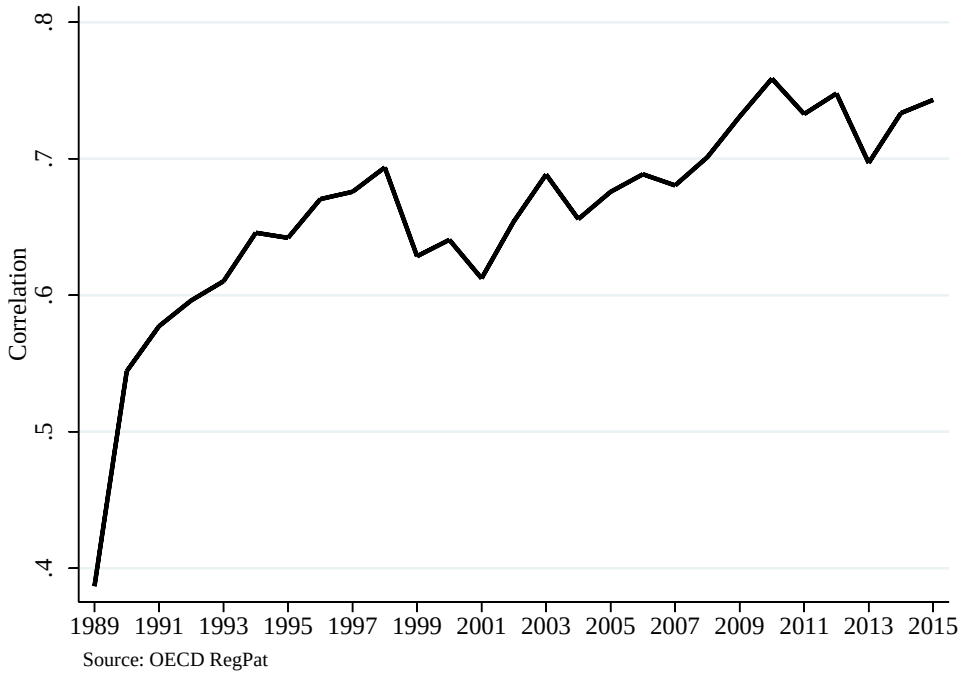


Figure 4: The relationship between technological profiles in East and West Germany after reunification

Following the relationship between the technological specializations of East and West Germany over the course of the transformation process reveals that their technological profiles became more and more similar over time (Figure 4). The correlation coefficient between the two technological profiles was around 0.4 in 1989 and continuously increased to more than 0.7 by 2015. Hence, patenting in East Germany took place more and more in technological fields where West German actors had an advantage. At the same time, the share of patents in fields with East-Only Specialization as of 1991 further decreased.

6.2 The impact of technology specialization patterns

So far, our investigation of technological specialization in East and West Germany over time has shown an increasingly large overlap between their technological profiles. We argued that the East-West gap is particularly strong for patents in areas in which both East and West Germany specialized. To test this conjecture, we apply several models at the technological level. Hence, the unit of analysis is not regions but IPC classes (N=743). The outcome variable in this analysis is the fractional count of patents per capita assigned to an IPC class, i in year t (1991-2015), in either East or West Germany (pat_{it}). We assign each IPC class to one of the four specialization groups as outlined in the previous section. In each model, we interact dummies for years, with a dummy indicating a location in East Germany.[24] The coefficients of these interaction variables indicate whether East-West differences increase over time. Formally, this can be expressed as:

$$pat_{iteast} = \beta_0 + \beta_1 year_t East + \gamma_i + \varepsilon_{it} \qquad (2)$$

where pat_{it} stands for the fractional count of patents per capita assigned to an IPC-class i in year t (1991-2015) in either East or West Germany. The main coefficients of interest are β_1. γ_i stand for time-invariant technology field fixed effects (Schmoch 2008). All models are estimated using OLS with the standard errors clustered at the level of technological field-by-year. We run a separate regression for each specialization group.

[24] We refer to the specialization in 1991. Results for the index based on 1989 are available upon request.

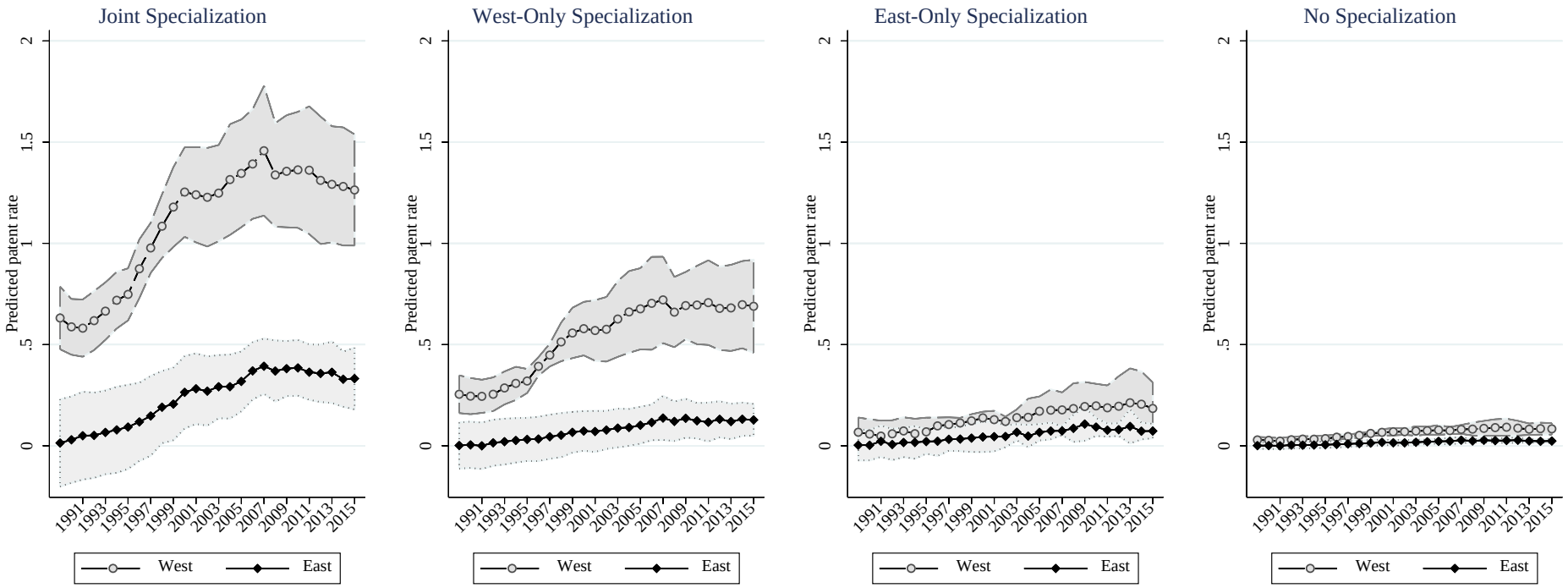


Figure 5: Initial specialization and subsequent patent intensity across years and specialization groups

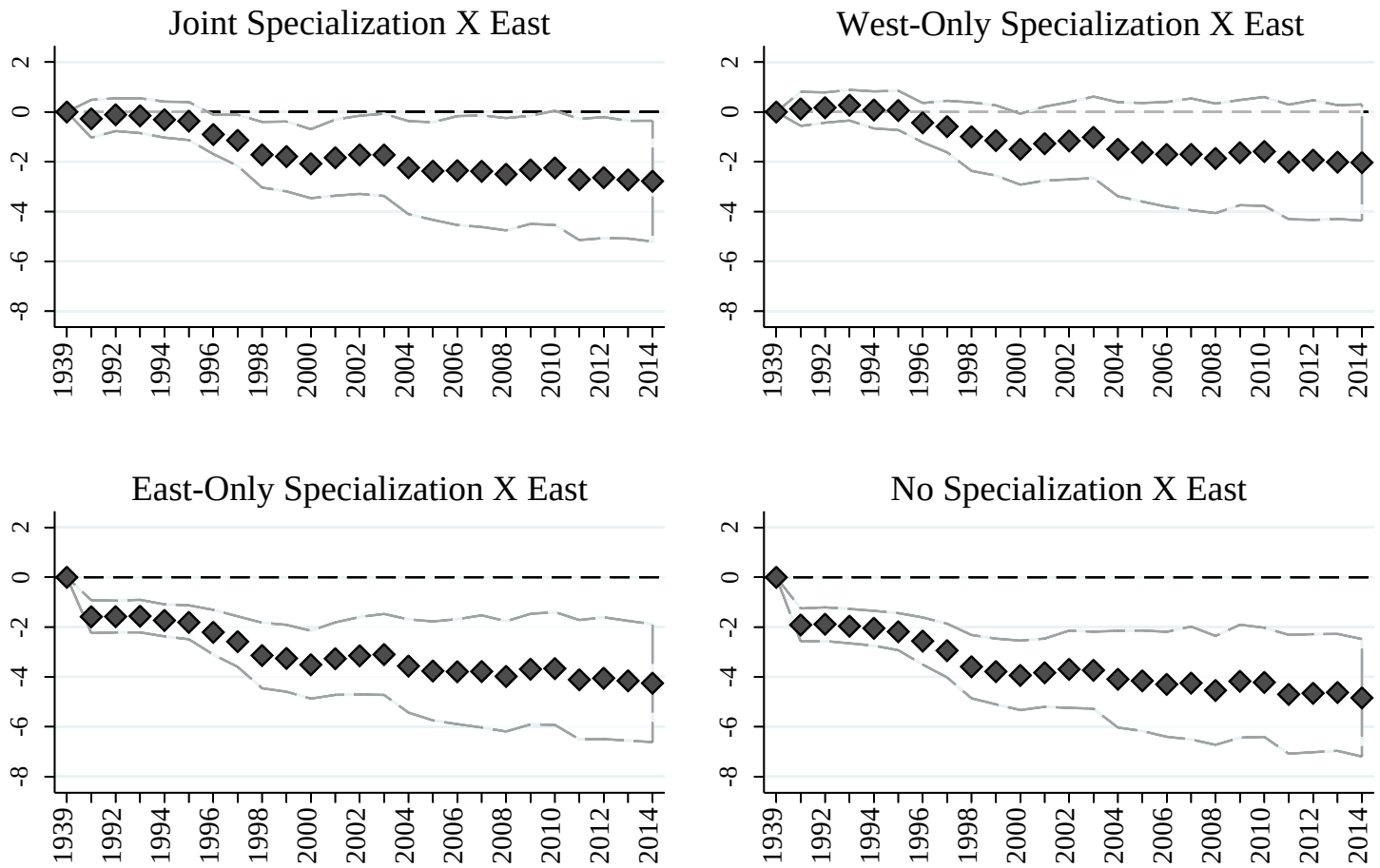


Figure 6: DiD results when controlling for specialization patterns at the beginning of the transition period

Note: in each case, the full model including all controls is estimated. Years 1877-1939 are all included in each estimation but for brevity, only the reference year 1939 is displayed. The specialization index is variable across years and regions after 1991 and equals 0 before the treatment.

Figure 5 presents the predicted patents per capita for all four specialization groups (see also Table A8 in the Appendix). We observe the greatest gap between East and West Germany throughout all years in those IPC classes in which both parts of the country had specialized (Figure 5, sub-figure Joint Specialization). The gap increases with time. Such a divergence is also prevalent in technologies where only West Germany specialized at the beginning of the transition process (Figure 5, see sub-figure West-Only Specialization). We find no statistically significant divergence pattern between the other two groups of technologies.

Finally, we analyze what happens to the treatment effects found in the regional analysis (section 5.2) when specialization patterns at the beginning of the transition period are considered in the regression. To this end, we run four additional models where we add the regional share of patents in a certain specialization group to the regional baseline models (see equation (1) in section 5.1) and interact these shares with the dummy indicating East German regions. We find that, compared to the baseline model, the estimates of the DiD treatment coefficients are much lower than they are when we control for the share of patents with joint East-West specialization (Table A9 in the Appendix). In the model West-Only Specialization, the treatment coefficients are insignificant suggesting that lagging in technologies where only West Germany specialized at the outset of the transition process is an important factor behind the long-term divergence. Controlling for the other specialization groups leaves the coefficients of the DiD estimators virtually unchanged (see Table A9 and Figure 6). In summary, the results suggest that the widening East-West gap in patenting activity is particularly driven by technologies in which only West Germany specialized at the beginning of the transformation process.

7. Summarizing discussion: What are the reasons for poor innovation performance in East Germany?

7.1 Our main results in perspective

After WWII, the integrated German innovation system was split into two parts which co-existed for about forty years: a capitalist West and a socialist East. The German reunification in 1990 initiated a re-integration of the two systems where the formal institutions of West Germany were suddenly introduced into East

Germany. Our analyses rely upon this natural experiment setting and make three main contributions. First, we are the first to quantitatively estimate the effects of forty years of a socialist system on innovation activity in East Germany. Second, we analyze the development of innovation activities in East and West Germany during the shock transition. Third, we investigate the reasons for the patterns that we find.

Our assessment reveals that the German separation, the introduction of a socialist innovation system, and the reunification all had a significant negative treatment effect on the level of innovation activity in East Germany. We find a significant East-West gap and that post-reunification, the East falls far behind the West, especially in those technological fields where both East and West Germany had specialized at the beginning of the transition process.

Our findings suggest that the integration of East and West Germany implied a consolidation of innovation activities in the early 1990s. This consolidation seems to have caused a long-term divergence of innovation activities—particularly in technologies where both the East and West had specialized—for at least three reasons. First, West German innovation activity in these technological fields was, on average, advanced and efficient relative to East Germany. This pattern might have been even more pronounced in technologies in which West Germany specialized due to scaling advantages. Second, the West likely benefited considerably from the migration of East German scientists and engineers that occurred during the consolidation processes. Due to technological similarities between East and West inventors, the West German innovation system could easily absorb those from the East. Third, and related to the second point, the radical reorganization of the East German innovation system, combined with being outcompeted in crucial technological fields, may have significantly damaged East German innovation networks, requiring long periods to recover.

While these factors are, to a degree, rooted in the inefficiency of the socialist innovation system, the weakness of the East German innovation system since the reunification is also a long-lasting result of the ways in which the transformation process in East Germany was organized. One important negative factor in this respect was the destruction of the institutional structures due to the sudden exposure of East German firms to global competition, radical privatization

of state-owned enterprises, and a complete re-organization of public research and higher education.

We also observe an increasingly large East-West gap over time in technologies where only West Germany specialized. This finding is interesting because innovation activities in these technologies hardly existed in East Germany at the beginning of the transition process, yet patenting activity sharply rose in these areas by the early 1990s. It is an open question since the lack of historical roots and tradition of these new activities explains the divergence over time.

The outperformance of East German innovation activities in certain fields corresponds to the discouragement hypothesis of Aghion et al. (2004, 2009) who speculate that the reaction to a highly efficient competitor's threat depends on an actor's distance from the technological frontier. Accordingly, the entry of technologically advanced firms into an economy can encourage innovation and improved productivity of those incumbents that operate close to the technological frontier, whereas it may discourage those who lag far behind.

Another reason for the lag in East German innovation activity, frequently cited in the political debate, claims that the economy in this part of the country mainly consists of small and medium-sized companies, with only a few large companies as an exception. This argument has some justification in that large companies often perform important functions in innovation systems as gatekeepers and brokers (Agrawal and Cockburn 2003; Graf 2011). However, it can also be argued that the small-firm structure of the East German economy is a symptom of low economic performance, ultimately due to the insufficient success of innovation efforts. A further argument against the dominance of small-scale firms as an explanation for the lag in East German patenting is the tendency of smaller firms to file a greater number of patents per unit of R&D input (Cohen and Klepper 1996).

Altogether, there were several factors that negatively affected innovation activity in East Germany after 1990. This notwithstanding, as the overall level of innovation activity increased until the mid-2000s, the integration of both systems also had positive effects that could be due to a more efficient division of innovative labor via the integration of the two systems.

7.2 Policy implications

In considering the importance of a well-working innovation system for regional development, our analyses provide some important implications for policymakers. First, our findings shed light on the problems related to a disruptive and radical shock transformation of a socialist innovation system to a market-based system. The German example demonstrates that sudden exposure to global competition, combined with a radical reconstruction of institutional structures, may result in long-term low innovation performance. Remarkably, massive policy support with high subsidies for innovation activities could not prevent the increasingly large East-West gap regarding innovation activities. This failure casts doubt on hopes for a quick recovery from radical transformation processes. Other former socialist transformation countries implemented strategies that led to much more gradual changes. We are, however, not aware of great improvements in innovation performance in any of these cases (Meske 2004; Radosevic 1998; 2022).

A further important policy implication of our analysis that holds independent of the actual transformation strategy applied concerns the technological profile. The example of East Germany makes it very clear that a country and region need to develop specific technological competencies to avoid being outcompeted. This is particularly relevant in the context of the increasing globalization and interaction of different types of innovation systems. Hence, policy should aim to develop specific knowledge and capabilities to remain competitive and successfully participate in the international division of labor.

7.3 Limitations and avenues for further research

There are several limitations to our analyses which provide avenues for further research. Despite finding that technological similarity between East and West Germany explains the development of East-West differences in patenting after 1990, there is room for investigating an underlying mechanism of this process in greater detail. We suspect that the out-migration of inventors, R&D employees, and generally well-educated personnel is only one of several reasons for the erosion of the East German knowledge base. Hence, it unclear to what extent former R&D employees switched to occupations in less patent-intensive fields such as innovative services. Moreover, we do not know to what extent the

consolidation of the two innovation systems at the expense of the East can be explained by discouragement (Aghion et al. 2004, 2009). If discouragement was relevant, what differentiates those who were discouraged from those who decided to compete? At what stages of the transformation process did discouragement occur?

Another limitation of our analysis follows from the well-known weaknesses of patents as indicators of innovation activity (Griliches 1990; Nagaoka, Motohashi and Goto 2010). Hence, we do not know if our results hold for innovation processes unrelated to patenting. This includes innovation processes in the service sector, where patenting plays only a minor role. We also did not analyze other aspects of innovation processes, such as the adoption and implementation of new technology. Moreover, we did not account for the geographic distribution of innovation activities within East Germany and the innovation performance in individual regions over time. It would be interesting to investigate the possible long-run impact of socialist policies on regional innovation systems. We also did not attempt to make a detailed account of the systemness of innovation processes. Methods to assess the systemness of an innovation system and identify ways to improve systemic weaknesses are important avenues for further research.[25]

Another open question concerns the effects of the knowledge transfer from the West to the East and the rather generous financial support of East German innovation activities since unification. What was the impact of the public promotion policies, and why could this policy not prevent East-West divergence?

An important arena for future research is to broaden our evidence by investigating how we can apply our analysis at the European level to understand the impact of communism on innovation performance (Radosevic 2022). Another area to explore is the role of inventor mobility on regional differences seen in innovation activity. This may also be helpful in understanding regional disparities in countries beyond the transition context. Lastly, research should focus on the evolution of regional disparities in different technology fields. Given that the GDR massively subsidized innovation activity in microelectronics, it may be

[25] See Leydesdorff (2021) and Ruhrmann, Fritsch and Leydesdorff (2022) for examples.

interesting to investigate the long-term development of this particular technological field.

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Appendix A: Tables and Figures

Table A1: Mean comparison tests of patent rates in different years

	Mean (West)	Mean (East)	Difference	Standard error
Pre-separation period				
1877	0.1002	0.1089	-0.0086	0.0242
1880	0.2198	0.2758	-0.0560	0.0414
1890	0.2953	0.2953	0.0001	0.0540
1900	0.4585	0.4185	0.0400	0.0711
1910	0.6374	0.5956	0.0418	0.1013
1920	0.5523	0.5887	-0.0364	0.0942
1930	1.1368	1.2707	-0.1339	0.1867
1939	0.7490	0.7723	-0.0233	0.1222
1940	0.6509	0.7089	-0.0580	0.1154
1945	0.0233	0.0342	-0.0109	0.0076
Post-reunification period				
1991	2.1375	0.3091	1.8284***	0.1992
1992	2.1483	0.3188	1.8295***	0.2086
1993	2.1027	0.3189	1.7837***	0.2021
1994	2.3239	0.3869	1.9370***	0.2372
1995	2.5200	0.4951	2.0248***	0.2558
1996	3.0123	0.5860	2.4263***	0.2975
1997	3.4774	0.6907	2.7868***	0.3219
1998	4.4262	1.0535	3.3727***	0.4153
1999	4.7496	1.2314	3.5183***	0.4437
2000	5.0074	1.2176	3.7899***	0.4604
2001	4.8370	1.3076	3.5294***	0.4803
2002	4.6583	1.2477	3.4106***	0.4510
2003	4.6204	1.3381	3.2823***	0.4596
2004	5.6094	1.8074	3.8020***	0.5414
2005	5.8558	1.8803	3.9755***	0.5834
2006	5.9332	1.9607	3.9725***	0.5878
2007	6.0475	2.1444	3.9031***	0.6095
2008	6.0546	2.0029	4.0516***	0.6302
2009	5.6459	1.9600	3.6859***	0.5658
2010	5.7800	2.0740	3.7060***	0.5933
2011	5.9832	1.8708	4.1124***	0.6798
2012	5.9685	1.8957	4.0728***	0.6776
2013	5.9457	1.7960	4.1497***	0.6750
2014	6.0476	1.7736	4.2740***	0.7384

Notes: Berlin and Saarland are excluded from the sample. The number of observations is 394 in all cases and corresponds to the number of counties. **significant at the 5% level; ***significant at the 1% level. Values for the years 1878 to 1938 omitted in order to economize on space.

Table A2: The treatment effect of the separation and reunification on innovation activity over time

	I	II	III	IV	V	VI	VII
East X Year1877	0.125	0.110	0.066	0.125	0.110	0.125	0.003
	(0.70)	(0.42)	(0.20)	(0.70)	(0.42)	(0.70)	(0.07)
East X Year1880	0.161	0.147	0.103	0.161	0.147	0.161	0.039
	(0.84)	(0.62)	(0.32)	(0.84)	(0.61)	(0.84)	(0.49)
East X Year1890	0.102	0.089	0.049	0.102	0.089	0.102	-0.021
	(0.53)	(0.37)	(0.16)	(0.53)	(0.37)	(0.53)	(-0.27)
East X Year1900	0.036	0.025	-0.012	0.036	0.025	0.036	-0.087
	(0.18)	(0.11)	(-0.04)	(0.18)	(0.10)	(0.18)	(-0.95)
East X Year1910	-0.079	-0.090	-0.127	-0.079	-0.090	-0.079	-0.202
	(-0.35)	(-0.38)	(-0.43)	(-0.35)	(-0.38)	(-0.35)	(-1.37)
East X Year1920	0.065	0.061	0.040	0.065	0.061	0.065	-0.058
	(0.30)	(0.25)	(0.13)	(0.30)	(0.25)	(0.30)	(-0.46)
East X Year1930	0.100	0.100	0.088	0.100	0.101	0.100	-0.023
	(0.28)	(0.57)	(0.25)	(0.28)	(0.57)	(0.28)	(-0.07)
East X Year1939	Reference	Reference	Reference	Reference	Reference	Reference	-0.122
							(-0.69)
East X Year1945						0.122	Reference
						(0.69)	
East X Year1989				-1.547***	-1.542***		
				(-3.96)	(-3.79)		
East X Year1991	-1.543***	-1.333***	-1.143***	-1.543***	-1.333***	-1.543***	-1.665***
	(-4.64)	(-4.26)	(-4.77)	(-4.64)	(-4.25)	(-4.64)	(-5.89)
East X Year1992	-1.580***	-1.273***	-1.083***	-1.580***	-1.273***	-1.580***	-1.702***
	(-4.53)	(-4.06)	(-4.71)	(-4.53)	(-4.05)	(-4.53)	(-5.64)
East X Year1993	-1.567***	-1.279***	-1.085***	-1.567***	-1.279***	-1.567***	-1.690***
	(-4.42)	(-4.08)	(-4.74)	(-4.42)	(-4.07)	(-4.42)	(-5.48)
East X Year1994	-1.701***	-1.443***	-1.246***	-1.701***	-1.443***	-1.701***	-1.823***
	(-4.38)	(-4.28)	(-5.14)	(-4.38)	(-4.27)	(-4.38)	(-5.26)
East X Year1995	-1.786***	-1.538***	-1.338***	-1.786***	-1.538***	-1.786***	-1.909***
	(-4.38)	(-4.33)	(-5.33)	(-4.38)	(-4.32)	(-4.38)	(-5.18)
East X Year1996	-2.163***	-1.910***	-1.718***	-2.163***	-1.910***	-2.163***	-2.285***
	(-4.29)	(-4.27)	(-5.58)	(-4.29)	(-4.27)	(-4.29)	(-4.83)
East X Year1997	-2.545***	-2.284***	-2.093***	-2.545***	-2.284***	-2.545***	-2.668***
	(-4.46)	(-4.46)	(-5.83)	(-4.46)	(-4.45)	(-4.46)	(-4.92)
East X Year1998	-3.113***	-2.817***	-2.623***	-3.113***	-2.817***	-3.113***	-3.235***
	(-4.32)	(-4.27)	(-5.35)	(-4.32)	(-4.27)	(-4.32)	(-4.63)
East X Year1999	-3.259***	-2.941***	-2.739***	-3.259***	-2.941***	-3.259***	-3.381***
	(-4.41)	(-4.31)	(-5.41)	(-4.41)	(-4.31)	(-4.41)	(-4.70)
East X Year2000	-3.501***	-3.192***	-2.979***	-3.501***	-3.192***	-3.501***	-3.624***
	(-4.60)	(-4.56)	(-5.70)	(-4.60)	(-4.56)	(-4.60)	(-4.89)
East X Year2001	-3.305***	-2.964***	-2.739***	-3.305***	-2.965***	-3.305***	-3.428***
	(-4.09)	(-4.01)	(-4.89)	(-4.09)	(-4.01)	(-4.09)	(-4.35)
East X Year2002	-3.228***	-2.875***	-2.653***	-3.228***	-2.875***	-3.228***	-3.350***
	(-3.78)	(-3.66)	(-4.35)	(-3.78)	(-3.66)	(-3.78)	(-4.01)
East X Year2003	-3.159***	-2.804***	-2.590***	-3.159***	-2.804***	-3.159***	-3.281***
	(-3.55)	(-3.40)	(-4.01)	(-3.55)	(-3.40)	(-3.55)	(-3.76)
East X Year2004	-3.661***	-3.306***	-3.092***	-3.661***	-3.306***	-3.661***	-3.783***
	(-3.55)	(-3.42)	(-3.97)	(-3.55)	(-3.42)	(-3.55)	(-3.72)
East X Year2005	-3.757***	-3.403***	-3.190***	-3.757***	-3.403***	-3.757***	-3.880***
	(-3.43)	(-3.32)	(-3.80)	(-3.43)	(-3.32)	(-3.43)	(-3.59)
East X Year2006	-3.802**	-3.453**	-3.240***	-3.802**	-3.453**	-3.802**	-3.925***
	(-3.22)	(-3.13)	(-3.49)	(-3.22)	(-3.13)	(-3.22)	(-3.36)
East X Year2007	-3.788**	-3.446**	-3.229**	-3.788**	-3.446**	-3.788**	-3.910**
	(-3.04)	(-2.95)	(-3.26)	(-3.04)	(-2.95)	(-3.04)	(-3.17)
East X Year2008	-3.961**	-3.621**	-3.407***	-3.961**	-3.621**	-3.961**	-4.083***
	(-3.24)	(-3.18)	(-3.54)	(-3.24)	(-3.18)	(-3.24)	(-3.38)

East X Year2009	-3.686**	-3.356**	-3.144**	-3.686**	-3.356**	-3.686**	-3.808**
	(-3.03)	(-2.96)	(-3.28)	(-3.03)	(-2.96)	(-3.03)	(-3.16)
East X Year2010	-3.659**	-3.337**	-3.125**	-3.659**	-3.337**	-3.659**	-3.782**
	(-2.95)	(-2.88)	(-3.19)	(-2.95)	(-2.88)	(-2.95)	(-3.08)
East X Year2011	-4.089**	-3.785**	-3.571***	-4.089**	-3.785**	-4.089**	-4.212**
	(-3.16)	(-3.10)	(-3.46)	(-3.16)	(-3.10)	(-3.16)	(-3.28)
East X Year2012	-4.016**	-3.715**	-3.500***	-4.016**	-3.714**	-4.016**	-4.138**
	(-3.05)	(-2.98)	(-3.33)	(-3.05)	(-2.98)	(-3.05)	(-3.18)
East X Year2013	-4.081**	-3.777**	-3.564***	-4.081**	-3.777**	-4.081**	-4.203***
	(-3.17)	(-3.11)	(-3.48)	(-3.17)	(-3.11)	(-3.17)	(-3.30)
East X Year2014	-4.171**	-3.871**	-3.659***	-4.171**	-3.870**	-4.171**	-4.293***
	(-3.22)	(-3.16)	(-3.55)	(-3.22)	(-3.16)	(-3.22)	(-3.35)
Manufacturing share		3.170***	3.018***		3.167***		
		(12.59)	(11.87)		(12.75)		
Population density		0.970**	4.137***		0.933**		
		(2.50)	(10.02)		(2.42)		
Distance to nearest technical university		0.001*	0.002***		0.001**		
		(1.95)	(5.20)		(2.03)		
Migration rate		-0.006***	-0.006***		-0.006***		
		(-11.64)	(-13.40)		(-11.83)		
Federal State fixed effects			Yes				
Number of observations	7917	7917	7917	8827	8008	8463	8463
R-squared	0.57	0.62	0.67	0.56	0.62	0.58	0.58

Notes: Results in all columns are based on Patentcity before WWII and Rassenfosse, Kozak and Seliger (2019) data for more recent periods. Berlin and Saarland are excluded from the sample because only certain parts of Berlin came under socialist rule, and the data for this city cannot be subdivided into treated and non-treated areas. In the case of Saarland, the data for 1925 is not available. Robust standard errors are in parentheses. All models include an East dummy and year-fixed effects. The clustering is on a state-by-time level. The number of planning regions is 91. The number of Federal States is 14. ***statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level.

Table A3: Robustness checks with different data sources

	I	II	III	IV	V	VI
East X Year1877	0.125	0.098	0.071	0.125	0.108	0.095
	(0.70)	(0.53)	(0.34)	(0.70)	(0.81)	(0.71)
East X Year1880	0.161	0.135	0.108	0.161	0.145	0.132
	(0.84)	(0.85)	(0.53)	(0.84)	(1.31)	(1.04)
East X Year1890	0.102	0.078	0.053	0.102	0.087	0.074
	(0.53)	(0.47)	(0.28)	(0.53)	(0.74)	(0.60)
East X Year1900	0.036	0.015	-0.008	0.036	0.022	0.010
	(0.18)	(0.09)	(-0.05)	(0.18)	(0.19)	(0.10)
East X Year1910	-0.079	-0.100	-0.123	-0.079	-0.093	-0.105
	(-0.35)	(-0.58)	(-0.67)	(-0.35)	(-0.75)	(-0.88)
East X Year1920	0.065	0.055	0.040	0.065	0.056	0.048
	(0.30)	(0.32)	(0.22)	(0.30)	(0.47)	(0.41)
East X Year1930	0.100	0.096	0.087	0.100	0.093	0.088
	(0.28)	(0.61)	(0.34)	(0.28)	(0.53)	(0.39)
East X Year1939	Reference	Reference	Reference	Reference	Reference	Reference
East X Year1991	-1.175***	-0.952***	-0.834***	-0.577**	-0.368**	-0.303**
	(-4.61)	(-4.63)	(-5.75)	(-2.82)	(-2.92)	(-2.56)
East X Year1992	-1.253***	-0.958***	-0.844***	-0.586**	-0.304**	-0.239**
	(-4.52)	(-4.34)	(-5.71)	(-2.77)	(-2.51)	(-2.15)
East X Year1993	-1.394***	-1.111***	-0.994***	-0.601**	-0.333**	-0.267**
	(-4.55)	(-4.41)	(-6.06)	(-2.77)	(-2.69)	(-2.37)
East X Year1994	-1.433***	-1.171***	-1.051***	-0.641**	-0.396**	-0.330**
	(-4.50)	(-4.59)	(-6.15)	(-2.74)	(-2.73)	(-2.71)
East X Year1995	-1.502***	-1.247***	-1.125***	-0.593**	-0.356**	-0.289**
	(-4.47)	(-4.53)	(-6.11)	(-2.49)	(-2.40)	(-2.39)
East X Year1996	-1.829***	-1.573***	-1.456***	-0.621**	-0.386**	-0.322**
	(-4.48)	(-4.55)	(-5.90)	(-2.48)	(-2.43)	(-2.45)
East X Year1997	-2.008***	-1.746***	-1.631***	-0.715**	-0.476**	-0.413**
	(-4.58)	(-4.62)	(-5.89)	(-2.78)	(-2.75)	(-3.05)
East X Year1998	-2.148***	-1.860***	-1.744***	-0.848**	-0.580**	-0.516**
	(-4.68)	(-4.69)	(-5.89)	(-3.01)	(-2.90)	(-3.26)
East X Year1999	-2.341***	-2.034***	-1.913***	-0.943**	-0.654**	-0.586**
	(-5.22)	(-5.38)	(-6.84)	(-3.06)	(-2.81)	(-3.15)
East X Year2000	-2.378***	-2.073***	-1.944***	-0.986**	-0.698**	-0.625**
	(-4.69)	(-4.72)	(-5.85)	(-3.08)	(-2.89)	(-3.10)
East X Year2001	-2.322***	-1.989***	-1.851***	-0.955**	-0.634**	-0.557**
	(-4.21)	(-4.14)	(-4.94)	(-3.07)	(-2.71)	(-2.92)
East X Year2002	-2.410***	-2.069***	-1.935***	-1.004**	-0.679**	-0.603**
	(-4.02)	(-3.91)	(-4.54)	(-3.13)	(-2.73)	(-2.92)
East X Year2003	-2.447***	-2.108***	-1.980***	-0.960**	-0.639**	-0.567**
	(-4.11)	(-4.00)	(-4.68)	(-2.84)	(-2.40)	(-2.57)
East X Year2004	-2.648***	-2.308***	-2.181***	-0.933**	-0.613**	-0.541**
	(-4.03)	(-3.86)	(-4.52)	(-2.77)	(-2.33)	(-2.52)
East X Year2005	-2.677***	-2.339***	-2.212***	-0.894**	-0.576**	-0.505**
	(-3.87)	(-3.76)	(-4.28)	(-2.58)	(-2.09)	(-2.25)
East X Year2006	-2.664***	-2.329**	-2.202***	-1.005**	-0.691**	-0.619**
	(-3.49)	(-3.30)	(-3.69)	(-2.64)	(-2.21)	(-2.41)
East X Year2007	-2.701***	-2.370**	-2.240***	-0.987**	-0.677**	-0.604**
	(-3.46)	(-3.28)	(-3.66)	(-2.80)	(-2.40)	(-2.58)
East X Year2008	-2.500***	-2.172***	-2.044***	-0.900**	-0.593**	-0.522**
	(-3.76)	(-3.64)	(-4.17)	(-2.57)	(-2.10)	(-2.21)
East X Year2009	-2.421***	-2.101***	-1.975***	-0.866**	-0.569**	-0.498**
	(-3.45)	(-3.30)	(-3.76)	(-2.43)	(-1.99)	(-2.14)
East X Year2010	-2.620***	-2.305***	-2.179***	-0.754**	-0.463*	-0.393*
	(-3.64)	(-3.50)	(-3.98)	(-2.25)	(-1.77)	(-1.86)
East X Year2011	-2.700***	-2.398***	-2.269***	-0.662**	-0.383*	-0.312*

	(-3.78)	(-3.66)	(-4.20)	(-2.11)	(-1.65)	(-1.70)
East X Year2012	-2.505***	-2.205***	-2.076***	-0.683**	-0.406*	-0.335*
	(-3.66)	(-3.52)	(-4.05)	(-2.14)	(-1.67)	(-1.75)
East X Year2013	-2.501***	-2.200***	-2.072***	-0.636*	-0.359	-0.289
	(-3.72)	(-3.57)	(-4.05)	(-1.92)	(-1.38)	(-1.38)
East X Year2014	-2.560***	-2.262***	-2.135***	-0.667**	-0.395	-0.325
	(-3.95)	(-3.82)	(-4.43)	(-2.03)	(-1.53)	(-1.57)
Manufacturing share		2.307***	2.104***		2.373***	2.343***
		(13.69)	(13.21)		(26.24)	(22.73)
Population density		1.784***	4.084***		2.950***	4.328***
		(6.25)	(12.79)		(12.25)	(16.61)
Distance to nearest		0.001***	0.001***		0.000***	0.001***
technical university		(5.20)	(8.25)		(4.19)	(6.64)
Migration rate		-0.004***	-0.004***		-0.001***	-0.002***
		(-12.80)	(-12.92)		(-9.68)	(-13.83)
Federal State fixed effects			Yes			Yes
R-squared	0.57	0.64	0.68	0.33	0.50	0.55

Notes: Results in columns 1-3 are based on RegPat data for the post-reunification period; results in columns 4-6 are based on Patentcity data. Berlin and Saarland are excluded from the sample because only certain parts of Berlin came under socialist rule, and the data for this city cannot be subdivided into treated and non-treated areas. In the case of Saarland, the data for 1925 is not available. All models include an East dummy and year-fixed effects. The number of observations is 7,917 in all models. Robust standard errors are in parentheses. The clustering is on a state-by-time level. The number of planning regions is 91. The number of Federal States is 14. ***statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level.

Table A4: Robustness checks: Comparison between selected East German regions and West Germany

	Thuringia and Saxony		Mecklenburg-Western Pommerania, Brandenburg and Saxony Anhalt		Berlin included
	I	II	III	IV	V
East X Year1877	-0.033	-0.095	0.222	0.242	-0.147
	(-0.22)	(-0.24)	(1.10)	(0.78)	(-0.39)
East X Year1880	0.054	-0.010	0.227	0.249	-0.080
	(0.30)	(-0.03)	(1.07)	(0.89)	(-0.21)
East X Year1890	-0.010	-0.079	0.171	0.199	-0.142
	(-0.05)	(-0.23)	(0.82)	(0.69)	(-0.37)
East X Year1900	0.033	-0.041	0.037	0.072	-0.178
	(0.21)	(-0.10)	(0.18)	(0.26)	(-0.45)
East X Year1910	0.062	-0.011	-0.166	-0.131	-0.198
	(0.39)	(-0.02)	(-0.76)	(-0.48)	(-0.44)
East X Year1920	0.126	0.059	0.027	0.069	-0.082
	(0.75)	(0.12)	(0.12)	(0.28)	(-0.19)
East X Year1930	0.435	0.371	-0.107	-0.059	0.197
	(1.37)	(1.24)	(-0.29)	(-0.33)	(0.31)
East X Year1939	Reference	Reference	Reference	Reference	Reference
East X Year1991	-1.701***	-1.348**	-1.445***	-1.339***	-1.825***
	(-5.36)	(-3.17)	(-4.17)	(-3.84)	(-3.92)
East X Year1992	-1.678***	-1.129**	-1.519***	-1.350***	-1.858***
	(-5.05)	(-2.62)	(-4.22)	(-3.93)	(-3.89)
East X Year1993	-1.647***	-1.105**	-1.518***	-1.380***	-1.841***
	(-4.91)	(-2.58)	(-4.14)	(-4.09)	(-3.82)
East X Year1994	-1.767***	-1.245**	-1.660***	-1.567***	-1.969***
	(-4.78)	(-2.76)	(-4.15)	(-4.49)	(-3.88)
East X Year1995	-1.817***	-1.295**	-1.767***	-1.692***	-2.054***
	(-4.68)	(-2.83)	(-4.22)	(-4.58)	(-3.93)
East X Year1996	-2.159***	-1.628**	-2.166***	-2.084***	-2.432***
	(-4.43)	(-3.06)	(-4.23)	(-4.59)	(-4.05)
East X Year1997	-2.554***	-2.023***	-2.540***	-2.441***	-2.801***
	(-4.59)	(-3.39)	(-4.40)	(-4.75)	(-4.26)
East X Year1998	-3.018***	-2.457***	-3.171***	-3.028***	-3.355***
	(-4.26)	(-3.35)	(-4.37)	(-4.61)	(-4.23)
East X Year1999	-3.190***	-2.606***	-3.301***	-3.134***	-3.494***
	(-4.37)	(-3.45)	(-4.41)	(-4.54)	(-4.31)
East X Year2000	-3.343***	-2.781***	-3.599***	-3.440***	-3.734***
	(-4.49)	(-3.67)	(-4.71)	(-4.90)	(-4.50)
East X Year2001	-2.997***	-2.414**	-3.495***	-3.296***	-3.542***
	(-3.76)	(-2.95)	(-4.37)	(-4.55)	(-4.06)
East X Year2002	-2.957***	-2.363**	-3.394***	-3.178***	-3.461***
	(-3.46)	(-2.68)	(-3.97)	(-4.13)	(-3.78)
East X Year2003	-2.783**	-2.198**	-3.390***	-3.158***	-3.400***
	(-3.00)	(-2.27)	(-3.90)	(-3.96)	(-3.59)
East X Year2004	-3.105**	-2.524**	-4.002***	-3.770***	-3.898***
	(-3.07)	(-2.47)	(-3.97)	(-3.98)	(-3.60)
East X Year2005	-3.170**	-2.586**	-4.119***	-3.886***	-3.988***
	(-2.99)	(-2.46)	(-3.82)	(-3.85)	(-3.49)
East X Year2006	-3.233**	-2.653**	-4.152***	-3.928***	-4.030**
	(-2.84)	(-2.44)	(-3.53)	(-3.58)	(-3.29)
East X Year2007	-3.062**	-2.489**	-4.235***	-4.021***	-4.020**
	(-2.57)	(-2.18)	(-3.45)	(-3.50)	(-3.13)
East X Year2008	-3.205**	-2.642**	-4.426***	-4.209***	-4.185***
	(-2.74)	(-2.37)	(-3.72)	(-3.78)	(-3.31)
East X Year2009	-2.905**	-2.349**	-4.166***	-3.962***	-3.924**

	(-2.50)	(-2.10)	(-3.52)	(-3.59)	(-3.12)
East X Year2010	-2.826**	-2.275**	-4.172***	-3.978***	-3.907**
	(-2.40)	(-2.01)	(-3.48)	(-3.56)	(-3.06)
East X Year2011	-3.292**	-2.758**	-4.580***	-4.411***	-4.321**
	(-2.60)	(-2.20)	(-3.64)	(-3.73)	(-3.24)
East X Year2012	-3.267**	-2.736**	-4.477***	-4.312***	-4.245**
	(-2.49)	(-2.09)	(-3.51)	(-3.57)	(-3.14)
East X Year2013	-3.503**	-2.975**	-4.437***	-4.264***	-4.307**
	(-2.79)	(-2.41)	(-3.47)	(-3.54)	(-3.25)
East X Year2014	-3.592**	-3.071**	-4.527***	-4.355***	-4.405***
	(-2.81)	(-2.42)	(-3.55)	(-3.63)	(-3.30)
Manufacturing share		3.743***		3.702***	
		(12.05)		(12.18)	
Population density		0.813		-0.329	
		(1.59)		(-0.63)	
Distance to nearest		0.000*		0.001**	
technical university		(1.69)		(1.99)	
Migration rate		-0.007***		-0.006***	
		(-11.65)		(-11.31)	
Number of observations	6786	6786	7221	7221	8004
R-squared	0.57	0.62	0.58	0.63	0.56

Notes: All results are based on PatentCity data for the pre-treatment period and Rassenfosse, Kozak and Seliger (2019) data for the post-reunification period. Saarland is completely excluded from the sample and Berlin is included only in the last column where it is assigned to East Germany throughout the entire observation period. All models include an East dummy and year-fixed effects. The clustering is on a state-by-time level. The number of planning regions is 91. The number of Federal States is 14 and 15 for the last column. Constants are omitted for brevity. ***statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level.

Table A5: Further analysis for different patent quality indicators

	Original		Non-original		Radical		Non-radical	
	I	II	III	IV	V	VI	VII	VIII
East X Year1877	0.125	0.098	0.125	0.105	0.125	0.100	0.125	0.102
	(0.70)	(0.76)	(0.70)	(0.78)	(0.70)	(0.76)	(0.70)	(0.77)
East X Year1880	0.161	0.135	0.161	0.141	0.161	0.137	0.161	0.139
	(0.84)	(1.25)	(0.84)	(1.27)	(0.84)	(1.24)	(0.84)	(1.26)
East X Year1890	0.102	0.078	0.102	0.084	0.102	0.079	0.102	0.081
	(0.53)	(0.68)	(0.53)	(0.71)	(0.53)	(0.68)	(0.53)	(0.70)
East X Year1900	0.036	0.014	0.036	0.019	0.036	0.015	0.036	0.017
	(0.18)	(0.12)	(0.18)	(0.16)	(0.18)	(0.13)	(0.18)	(0.15)
East X Year1910	-0.079	-0.101	-0.079	-0.096	-0.079	-0.100	-0.079	-0.098
	(-0.35)	(-0.76)	(-0.35)	(-0.75)	(-0.35)	(-0.75)	(-0.35)	(-0.76)
East X Year1920	0.065	0.052	0.065	0.055	0.065	0.053	0.065	0.054
	(0.30)	(0.41)	(0.30)	(0.45)	(0.30)	(0.42)	(0.30)	(0.43)
East X Year1930	0.100	0.092	0.100	0.093	0.100	0.093	0.100	0.093
	(0.28)	(0.50)	(0.28)	(0.54)	(0.28)	(0.51)	(0.28)	(0.53)
East X Year1939	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference
East X Year1991	-0.322*	-0.106	-0.638**	-0.424***	-0.376**	-0.160	-0.605**	-0.390**
	(-1.72)	(-0.85)	(-3.10)	(-3.33)	(-1.98)	(-1.29)	(-2.97)	(-3.03)
East X Year1992	-0.354*	-0.080	-0.684**	-0.401**	-0.398**	-0.123	-0.665**	-0.384**
	(-1.88)	(-0.67)	(-3.14)	(-2.96)	(-2.09)	(-1.02)	(-3.09)	(-2.87)
East X Year1993	-0.412**	-0.148	-0.752**	-0.482**	-0.452**	-0.186	-0.735**	-0.466**
	(-2.13)	(-1.21)	(-3.23)	(-3.12)	(-2.28)	(-1.48)	(-3.25)	(-3.13)
East X Year1994	-0.458**	-0.210*	-0.730**	-0.482**	-0.478**	-0.231*	-0.734**	-0.485**
	(-2.29)	(-1.70)	(-3.13)	(-3.26)	(-2.39)	(-1.93)	(-3.17)	(-3.21)
East X Year1995	-0.479**	-0.237*	-0.757**	-0.516**	-0.529**	-0.288**	-0.731**	-0.488**
	(-2.38)	(-1.91)	(-3.13)	(-3.18)	(-2.54)	(-2.22)	(-3.15)	(-3.18)
East X Year1996	-0.615**	-0.375**	-0.918***	-0.679***	-0.671**	-0.432**	-0.890***	-0.650***
	(-2.83)	(-2.70)	(-3.33)	(-3.45)	(-2.92)	(-2.83)	(-3.38)	(-3.52)
East X Year1997	-0.719**	-0.476**	-0.971***	-0.727***	-0.786***	-0.543***	-0.936***	-0.691***
	(-3.11)	(-2.98)	(-3.45)	(-3.58)	(-3.30)	(-3.31)	(-3.39)	(-3.46)
East X Year1998	-0.750**	-0.484**	-1.047***	-0.776***	-0.838***	-0.572***	-0.997***	-0.727***
	(-3.28)	(-3.14)	(-3.56)	(-3.61)	(-3.41)	(-3.33)	(-3.60)	(-3.65)
East X Year1999	-0.859***	-0.575***	-1.089***	-0.798***	-0.897***	-0.611***	-1.099***	-0.809***

	(-3.69)	(-3.77)	(-3.95)	(-4.16)	(-3.74)	(-3.91)	(-4.05)	(-4.25)
East X Year2000	-0.839***	-0.553**	-1.124***	-0.832***	-0.922***	-0.635***	-1.086***	-0.795***
	(-3.38)	(-3.23)	(-3.65)	(-3.69)	(-3.49)	(-3.37)	(-3.72)	(-3.76)
East X Year2001	-0.858***	-0.544**	-1.032**	-0.710**	-0.915***	-0.600**	-1.015***	-0.695**
	(-3.35)	(-3.09)	(-3.25)	(-3.02)	(-3.38)	(-3.18)	(-3.30)	(-3.06)
East X Year2002	-0.948***	-0.631**	-1.015**	-0.688**	-0.955***	-0.636**	-1.055**	-0.730**
	(-3.31)	(-2.95)	(-3.13)	(-2.81)	(-3.34)	(-3.01)	(-3.20)	(-2.89)
East X Year2003	-0.911**	-0.599**	-1.010***	-0.687**	-0.944**	-0.630**	-1.022***	-0.702**
	(-3.29)	(-2.93)	(-3.30)	(-3.10)	(-3.29)	(-2.98)	(-3.38)	(-3.16)
East X Year2004	-1.021***	-0.709**	-1.086***	-0.763**	-1.093***	-0.779**	-1.056**	-0.736**
	(-3.36)	(-3.04)	(-3.34)	(-3.05)	(-3.46)	(-3.19)	(-3.28)	(-2.94)
East X Year2005	-1.021***	-0.710**	-1.112**	-0.792**	-1.150***	-0.838**	-1.023**	-0.705**
	(-3.31)	(-3.04)	(-3.18)	(-2.90)	(-3.41)	(-3.19)	(-3.11)	(-2.78)
East X Year2006	-0.981**	-0.674**	-1.054**	-0.738**	-1.150**	-0.840**	-0.936**	-0.621**
	(-2.98)	(-2.53)	(-2.99)	(-2.64)	(-3.14)	(-2.76)	(-2.87)	(-2.45)
East X Year2007	-0.996**	-0.690**	-1.035**	-0.722**	-1.158**	-0.851**	-0.898**	-0.586**
	(-3.03)	(-2.62)	(-3.08)	(-2.74)	(-3.19)	(-2.83)	(-2.90)	(-2.49)
East X Year2008	-0.944**	-0.641**	-0.970**	-0.661**	-1.092**	-0.789**	-0.862**	-0.554**
	(-3.20)	(-2.94)	(-3.08)	(-2.82)	(-3.25)	(-3.02)	(-3.06)	(-2.75)
East X Year2009	-0.970**	-0.676**	-0.895**	-0.595**	-1.072**	-0.777**	-0.825**	-0.526**
	(-3.11)	(-2.78)	(-2.70)	(-2.36)	(-3.11)	(-2.84)	(-2.68)	(-2.29)
East X Year2010	-1.023***	-0.733**	-0.922**	-0.627**	-1.112**	-0.821**	-0.863**	-0.569**
	(-3.36)	(-3.14)	(-2.90)	(-2.63)	(-3.24)	(-2.98)	(-3.01)	(-2.77)
East X Year2011	-1.039***	-0.758***	-0.963**	-0.679**	-1.189***	-0.909***	-0.842**	-0.558**
	(-3.47)	(-3.34)	(-3.11)	(-2.94)	(-3.56)	(-3.44)	(-2.97)	(-2.73)
East X Year2012	-0.942**	-0.663**	-0.884**	-0.603**	-1.013**	-0.734**	-0.837**	-0.556**
	(-3.28)	(-3.07)	(-2.91)	(-2.69)	(-3.16)	(-2.94)	(-3.04)	(-2.82)
East X Year2013	-0.875**	-0.595**	-0.891**	-0.609**	-1.002**	-0.723**	-0.789**	-0.507**
	(-3.07)	(-2.75)	(-3.17)	(-3.04)	(-3.26)	(-3.03)	(-2.99)	(-2.73)
East X Year2014	-0.911**	-0.636**	-0.862**	-0.585**	-0.992***	-0.717**	-0.807**	-0.530**
	(-3.29)	(-3.07)	(-3.19)	(-3.21)	(-3.31)	(-3.15)	(-3.21)	(-3.15)
Manufacturing share	1.844***		2.264***		1.953***		2.125***	1.844***
	(22.14)		(22.29)		(22.42)		(21.76)	(22.14)
Population density	0.001***		0.000***		0.001***		0.001***	0.001***
	(8.88)		(5.95)		(7.53)		(7.22)	(8.88)
Distance to nearest	-0.002***		-0.002***		-0.002***		-0.002***	-0.002***
technical university	(-12.06)		(-10.82)		(-11.85)		(-11.26)	(-12.06)
Migration rate	2.765***		2.796***		2.764***		2.759***	2.765***

	(11.50)		(11.63)		(11.44)		(11.49)	(11.50)
Number of observations	7917	7917	7917	7917	7917	7917	7917	7917
R-squared	0.35	0.53	0.36	0.54	0.39	0.55	0.34	0.52

Notes: All results are based on PatentCity data for the pre-treatment period and RegPat data for the post-reunification period. Saarland is completely excluded from the sample and Berlin is included only in the last column where it is assigned to East Germany throughout the entire observation period. All models include an East dummy and year-fixed effects. The clustering is on a state-by-time level. The number of planning regions is 91. The number of Federal States is 14 and 15 for the last column. Constants are omitted for brevity. ***statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level.

Table A6: Distribution of IPC classes across specializations and technological fields as of 1991[26]

Technological fields	(1) East-Only Specialization	(2) West-Only Specialization	(3) Joint Specialization	(4) No Specialization
Analysis of biological materials	0	0	1	0
Audio-visual technology	1	2	5	8
Basic communication processes	0	6	1	3
Basic materials chemistry	4	4	9	15
Biotechnology	2	1	5	0
Chemical engineering	4	10	13	26
Civil engineering	0	13	10	14
Computer technology	0	2	3	10
Control	0	7	1	5
Digital communication	0	2	0	1
Electrical machinery, apparatus, energy	1	10	8	9
Engines, pumps, turbines	2	9	4	18
Environmental technology	0	4	7	6
Food chemistry	2	2	1	18
Furniture, games	0	8	1	8
Handling	0	5	7	1
IT methods for management	0	0	0	1
Machine tools	0	13	11	19
Macromolecular chemistry, polymers	1	0	5	1
Materials, metallurgy	2	5	6	3
Measurement	7	5	11	21
Mechanical elements	1	5	7	8
Medical technology	0	2	7	3
Micro-structural and nano-technology	0	0	0	4
Optics	0	4	4	2
Organic fine chemistry	1	2	5	1
Other consumer goods	1	12	3	32
Other special machines	2	8	12	19
Pharmaceuticals	2	2	7	5
Semiconductors	0	0	1	0
Surface technology, coating	0	4	5	3
Telecommunications	1	5	3	1
Textile and paper machines	1	11	6	31
Thermal processes and apparatus	4	6	7	13
Transport	1	21	5	18
Total	40	190	181	327

Note: The numbers are the counts of IPC classes in the respective category.

[26] To assign IPC classes to a technological field, we adopt the classification by Schmoch (2008).

Table A8: The treatment effect for different specialization types (analysis at technology-level)

	(1) East-Only Specialization	(2) West-Only Specialization	(3) Joint Specialization	(4) No Specialization
East X Year1992	-0.027***	0.005	-0.035	-0.003
	(0.008)	(0.023)	(0.082)	(0.003)
East X Year1993	-0.031***	-0.021	-0.068	-0.006**
	(0.011)	(0.024)	(0.083)	(0.003)
East X Year1994	-0.017**	-0.037	-0.109	-0.005*
	(0.009)	(0.028)	(0.090)	(0.003)
East X Year1995	-0.022**	-0.044	-0.124	-0.007**
	(0.011)	(0.028)	(0.092)	(0.003)
East X Year1996	-0.050***	-0.114***	-0.225**	-0.012***
	(0.014)	(0.038)	(0.101)	(0.003)
East X Year1997	-0.047***	-0.159***	-0.299***	-0.013***
	(0.014)	(0.046)	(0.103)	(0.003)
East X Year1998	-0.053***	-0.216***	-0.363***	-0.017***
	(0.015)	(0.059)	(0.110)	(0.004)
East X Year1999	-0.059***	-0.246***	-0.442***	-0.024***
	(0.018)	(0.066)	(0.122)	(0.006)
East X Year2000	-0.069***	-0.261***	-0.458***	-0.026***
	(0.025)	(0.065)	(0.121)	(0.007)
East X Year2001	-0.058***	-0.254***	-0.427***	-0.031***
	(0.020)	(0.074)	(0.126)	(0.009)
East X Year2002	-0.048***	-0.253***	-0.426***	-0.032***
	(0.018)	(0.076)	(0.127)	(0.008)
East X Year2003	-0.046**	-0.294***	-0.425***	-0.032***
	(0.021)	(0.084)	(0.125)	(0.010)
East X Year2004	-0.067	-0.326***	-0.492***	-0.032***
	(0.044)	(0.088)	(0.137)	(0.008)
East X Year2005	-0.078***	-0.331***	-0.496***	-0.033***
	(0.030)	(0.088)	(0.131)	(0.009)
East X Year2006	-0.077**	-0.344***	-0.491***	-0.029***
	(0.035)	(0.094)	(0.131)	(0.009)
East X Year2007	-0.078***	-0.339***	-0.533***	-0.030***
	(0.028)	(0.094)	(0.140)	(0.009)
East X Year2008	-0.072**	-0.295***	-0.437***	-0.035***
	(0.036)	(0.081)	(0.126)	(0.011)
East X Year2009	-0.061***	-0.312***	-0.444***	-0.036***
	(0.022)	(0.076)	(0.123)	(0.011)
East X Year2010	-0.079***	-0.327***	-0.447***	-0.041***
	(0.026)	(0.082)	(0.126)	(0.012)
East X Year2011	-0.085***	-0.346***	-0.466***	-0.042***
	(0.030)	(0.088)	(0.129)	(0.011)
East X Year2012	-0.090**	-0.303***	-0.422***	-0.036***
	(0.044)	(0.087)	(0.134)	(0.012)
East X Year2013	-0.091***	-0.317***	-0.397***	-0.035***
	(0.032)	(0.089)	(0.134)	(0.009)
East X Year2014	-0.107**	-0.321***	-0.421***	-0.039***
	(0.043)	(0.088)	(0.131)	(0.010)
East X Year2015	-0.086**	-0.317***	-0.400***	-0.037***
	(0.034)	(0.092)	(0.126)	(0.010)
Constant	-0.024	0.130***	1.473***	0.044***
	(0.026)	(0.034)	(0.118)	(0.006)
Number of observations	2,000	9,500	9,050	16,350
R-squared	0.293	0.389	0.408	0.265

Notes: All models include an East dummy and fixed effects for years and technological fields.

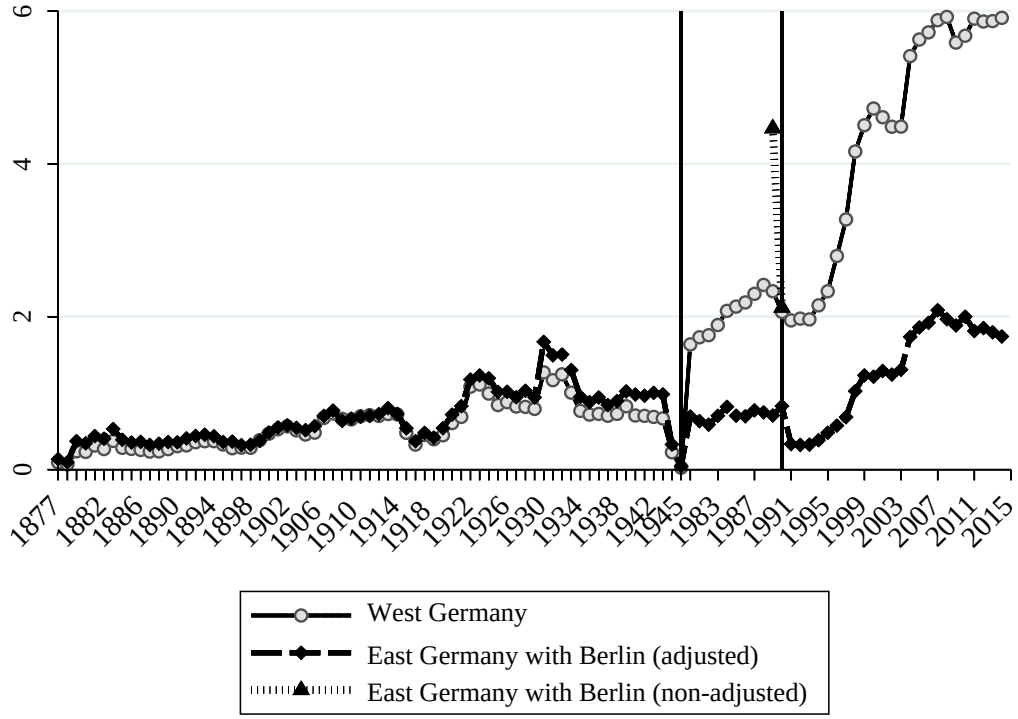
Table A9: The treatment effect when considering the regional share of patents from different specialization types

	East-Only Specialization	West-Only Specialization	Joint Specialization	No specialization
East X Year1991	-1.584***	0.123	-0.275	-1.913***
	(-4.72)	(0.35)	(-0.71)	(-5.69)
East X Year1992	-1.579***	0.175	-0.112	-1.884***
	(-4.86)	(0.57)	(-0.33)	(-5.47)
East X Year1993	-1.560***	0.271	-0.152	-1.961***
	(-4.68)	(0.86)	(-0.43)	(-5.57)
East X Year1994	-1.731***	0.081	-0.311	-2.046***
	(-5.28)	(0.21)	(-0.84)	(-5.74)
East X Year1995	-1.810***	0.062	-0.367	-2.183***
	(-5.21)	(0.15)	(-0.94)	(-5.75)
East X Year1996	-2.207***	-0.432	-0.905**	-2.559***
	(-4.82)	(-1.07)	(-2.26)	(-5.31)
East X Year1997	-2.583***	-0.586	-1.139**	-2.943***
	(-5.00)	(-1.11)	(-2.18)	(-5.35)
East X Year1998	-3.140***	-0.992	-1.720**	-3.589***
	(-4.68)	(-1.41)	(-2.56)	(-5.54)
East X Year1999	-3.255***	-1.145	-1.788**	-3.783***
	(-4.76)	(-1.59)	(-2.50)	(-5.62)
East X Year2000	-3.510***	-1.497**	-2.079**	-3.937***
	(-5.05)	(-2.06)	(-2.94)	(-5.54)
East X Year2001	-3.268***	-1.269*	-1.837**	-3.831***
	(-4.41)	(-1.68)	(-2.36)	(-5.48)
East X Year2002	-3.149***	-1.158	-1.722**	-3.693***
	(-3.97)	(-1.47)	(-2.15)	(-4.67)
East X Year2003	-3.099***	-1.018	-1.724**	-3.731***
	(-3.74)	(-1.22)	(-2.05)	(-4.74)
East X Year2004	-3.563***	-1.498	-2.237**	-4.092***
	(-3.73)	(-1.56)	(-2.35)	(-4.13)
East X Year2005	-3.761***	-1.621	-2.375**	-4.155***
	(-3.72)	(-1.61)	(-2.38)	(-4.04)
East X Year2006	-3.791***	-1.703	-2.354**	-4.297***
	(-3.53)	(-1.59)	(-2.11)	(-4.00)
East X Year2007	-3.781**	-1.701	-2.380**	-4.246***
	(-3.29)	(-1.49)	(-2.08)	(-3.68)
East X Year2008	-3.979***	-1.863*	-2.502**	-4.541***
	(-3.53)	(-1.66)	(-2.18)	(-4.08)
East X Year2009	-3.689**	-1.631	-2.325**	-4.173***
	(-3.26)	(-1.52)	(-2.10)	(-3.61)
East X Year2010	-3.663**	-1.585	-2.247*	-4.218***
	(-3.17)	(-1.42)	(-1.92)	(-3.77)
East X Year2011	-4.113***	-2.008*	-2.713**	-4.698***
	(-3.37)	(-1.71)	(-2.19)	(-3.86)
East X Year2012	-4.054**	-1.932	-2.637**	-4.654***
	(-3.25)	(-1.58)	(-2.13)	(-3.85)
East X Year2013	-4.154***	-2.012*	-2.722**	-4.622***
	(-3.39)	(-1.73)	(-2.26)	(-3.86)
East X Year2014	-4.251***	-2.030*	-2.780**	-4.839***
	(-3.52)	(-1.71)	(-2.25)	(-4.03)
Manufacturing share	2.949***	2.971***	3.248***	3.165***
	(13.37)	(12.47)	(13.08)	(12.45)
Population density	0.001**	0.001**	0.000	0.000*
	(3.16)	(2.07)	(1.37)	(1.74)
Distance to nearest technical university	-0.006***	-0.006***	-0.006***	-0.006***
	(-11.71)	(-11.78)	(-10.77)	(-11.06)
Migration rate	0.884**	1.240***	1.235**	1.209**

	(2.30)	(3.45)	(3.18)	(3.18)
East-Only Specialization	-23.617***			
	(-5.49)			
East-Only Specialization X East	22.747***			
	(5.26)			
West-Only Specialization		5.607***		
		(8.10)		
West-Only Specialization X East		-5.932***		
		(-7.79)		
Joint Specialization			2.519***	
			(7.92)	
Joint Specialization X East			-1.888***	
			(-5.53)	
No Specialization				-11.042***
				(-7.87)
No Specialization X East				11.988***
				(7.45)
R-squared	0.63	0.64	0.63	0.63

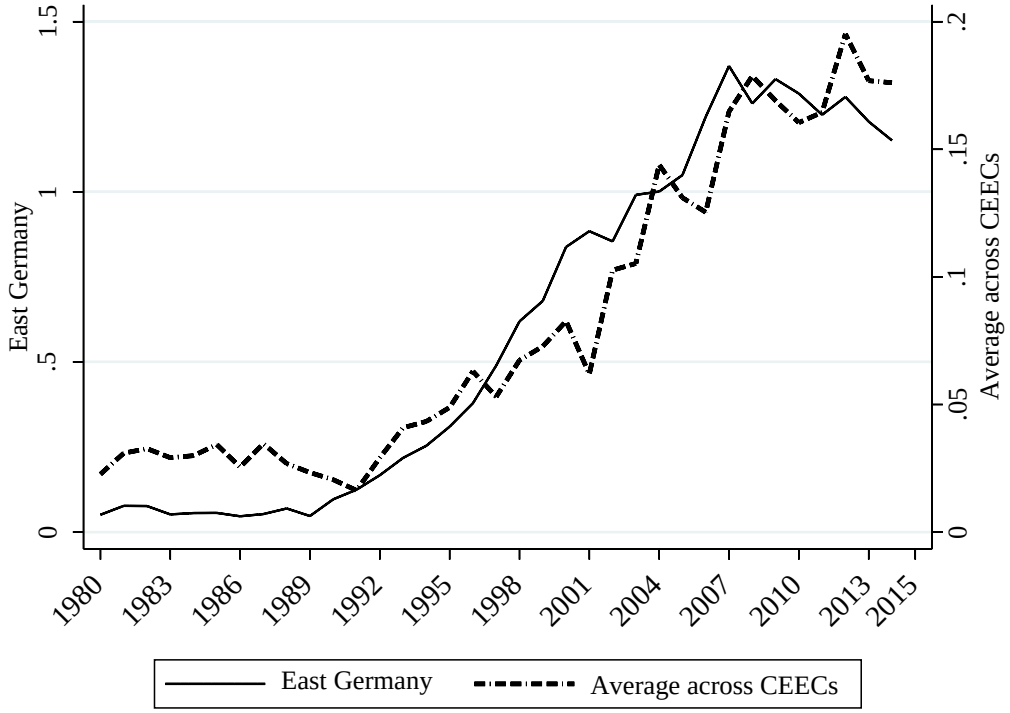
Notes: All pre-WWII years 1877-1939 are included, but coefficients are omitted for brevity. Coefficients for pre-WWII treatment effects are all insignificant. All models include an East dummy and year-fixed effects. The number of observations is 7,917 in all models. Berlin and Saarland are excluded from the sample because only certain parts of Berlin came under socialist rule, and the data for this city cannot be subdivided into treated and non-treated areas. In the case of Saarland, the data for 1925 is not available. Robust standard errors are in parentheses. The clustering is on a state-by-time level. The number of planning regions is 91. The number of Federal States is 14. Constants are omitted for brevity. The East dummy cannot be interpreted because of multicollinearity with the Federal State dummies. Year dummies and interactions between year dummies and regional characteristics are not shown for brevity. ***statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level.

Figures



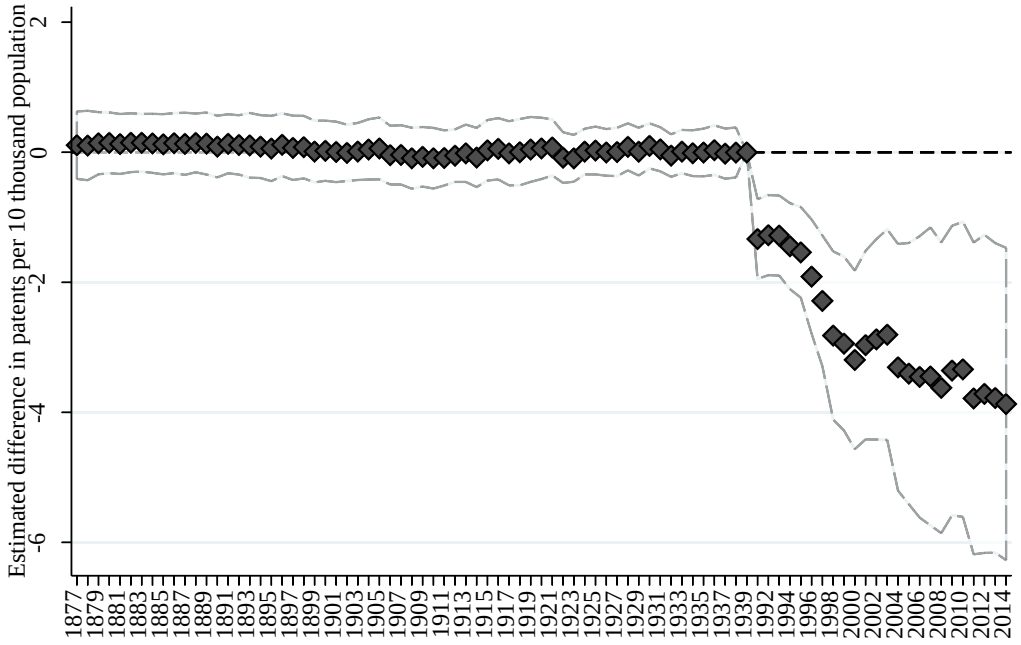
Notes: Before WWII, there were many major innovators such as AEG, one of the largest electrical engineering firms worldwide at that time, and Siemens, a prominent manufacturing firm that initially had headquarters in Berlin but relocated to West Germany after East Germany was occupied by the Soviet Army in 1945. Due to Berlin's high innovativeness (over 9.4 patents per capita in 1925), East German patent intensity in 1925 was far above the West German level (3.24 vs. 1.90 patents per 20 thousand population).

Figure A1: Number of patent applications per 10 thousand population in East and West Germany - Berlin assigned to East Germany



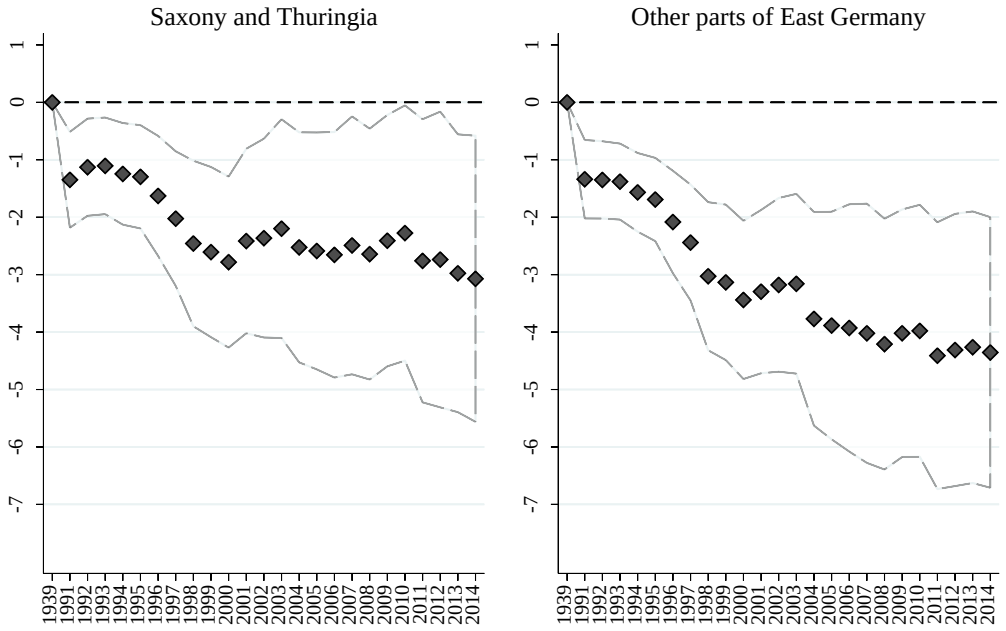
Note: Patents per 10.000 population. CEECs include Soviet satellite states: Poland, Romania, Czechoslovakia, Hungary, Bulgaria, East Germany, Yugoslavia, and Albania. Source: RegPat.

Figure A2: Patents per 10.000 population in East Germany and in CEECs



Notes: The figure shows all coefficients for the full baseline model including all controls (model II of Table A2 in Appendix A). Grey dashed lines represent the 95% confidence interval.

Figure A3: Difference-in-Difference (DiD) coefficients for the entire period of observation



Notes: The Figure shows coefficients for the full baseline model including all controls for Saxony and Thuringia (model 6 of Table A2) and the other parts of East Germany (model 7 of Table A2). Grey dashed lines represent the 95% confidence interval. In the pre-separation period, years 1877-1939 are included, but omitted in the Figure for brevity.

Figure A4: DiD coefficients for different parts of East Germany

Appendix B: GDR patents

Notes: Figure on the left-hand side shows coefficients for the baseline model without any controls for the post-separation period after 1980 (model 4 of Table A2). Figure on the right-hand side shows coefficients for the full baseline model including all controls for the post-separation period after 1989 (model 5 of Table A2). Grey dashed lines represent the 95% confidence interval. The years 1877-1939 are included in the estimations but omitted in the Figure for brevity.

Figure B1: DiD coefficients including GDR-adjusted data

The peculiarities of the GDR patent system

The GDR Patent law was introduced on September 6, 1950, and remained in force until the end of the GDR in 1990. The GDR patenting system was rather different from the West German system. These differences imply that *patents* had a different meaning in the GDR. The three main differences are grounded in (1) the intellectual property rights emerging from filing a patent, (2) the incentives and costs of filing a patent, and (3) the patent examination procedure.

The GDR patenting system distinguished between economic patents (*Wirtschaftspatente*) and the so-called exclusive patents (*Ausschließungspatente*) that were like patents in market economies. For economic patents, the applicant had no exclusive intellectual property rights. There was enormous and effective political pressure to apply for economic patents. For example, in 1985, there were

11,760 economic patent grants, but only 30 exclusive patents were registered (Grupp et al. 2002). The pronounced preference for economic patents reflected the ideological view of the socialist state that inventions should be freely available to everyone. To incentivize patenting activity, inventors who filed a patent received compensation. This incentive was fostered by relatively low application costs for economic patents, which were also completely covered by the inventor's employer.

Finally, the patenting examination system in the GDR allowed granting patents before the application had been examined for the substantive requirements for patent protection such as novelty, technical progress, prior intellectual property (IP) rights, etc. An extensive examination in line with these criteria followed only in case of invention exploitation, i.e. when it went into production. This measure aimed to reduce red tape formalities and the backlog of unprocessed patent applications, thus fueling inventor activity (Wießner 2015). Even though East and West Germany were members of international organizations that regulated IP protection and were, therefore, subject to the same legal provisions, the implementation of these provisions looked very different in West Germany, where only exclusive patents existed. Overall, the differences in IP rights between the FRG and the GDR, as well as the incentives and costs for filing a patent, and the patent examination procedure, make a meaningful comparison of patenting in East and West Germany very difficult. [27]

Attempt to compare East and West German patenting activity (1980-89)

Patent intensity in the GDR was generally higher than in the FRG. Between 1980 and 1990, the average number of patents per 10 thousand population was 6.7 in the GDR, compared to 2.4 in West Germany. At the same time, the share of internationally registered patents in the GDR was only 0.032, while it was 0.295 in West Germany[28]. These figures reflect the different role of patents in the GDR

[27] To compare the level of patenting during the separation period, Grupp et al. (2002) use only those GDR patents that were also registered in West Germany. However, since the fees for patenting in West Germany had to be paid in West German currency, one can assume that East German inventions that filed for patenting in the West were highly selected and do not reflect the full extent of innovation activities in the GDR.

[28] To define the share of internationally registered patents, we used the Comprehensive Patent Database (CPDB) of the GDR to calculate the annual number of GDR patents (see Hipp et al. 2022) from 1980-1990 based on the application year. From these calculations, the approximate

system but could also simply mirror the low export intensity of GDR products and indicate a lack of foreign currency needed to register the patents abroad.

Appendix C: Measuring technological specialization

For testing the consolidation hypothesis put forward by Grupp et al. (2002), we separately measure technological specialization of patenting in East and West Germany at the beginning of the transition process by arranging all IPC classes at the 4-digit level according to their share of the overall number of patents. We sum IPC classes beginning with the largest ones in descending order until this aggregate makes 50% of all patents in either East or West Germany. We use 4-digit IPC classes. A 4-digit level in the IPC taxonomy corresponds to the third operational level, i.e., a subclass level (for the ease of wording, IPC class is used hereafter). We assign IPC classes to technology fields, adopting the classification of technological fields introduced by Schmoch (2008). In those cases where IPC classes of the fourth hierarchical level, defined as the main group in the official taxonomy, belong to different technological fields, we resort to a more disaggregated level of main groups to capture the differences across technological fields as precisely as possible.

The broad idea of measuring technological specialization comes from Ferrucci (2020). Ideally, one relies on data from 1989 to do this assessment. Unfortunately, we do not have information on the IPC class for the full scope of patent data, neither for 1989 nor later years. IPC class information is only available for internationally registered patents in RegPat. Using internationally registered patent data is advantageous because it is informative of the quality of a patent since internationally registering patents is rather costly. However, the GDR only registered 3.2% of its patents internationally during 1980-1989. For comparison, in this same period in the FRG, almost 30% of all patents were

number of foreign patents was deducted. The CPDB allows us to precisely calculate the share of foreign patents in 1989 as 12.4%. It is assumed that the share of foreign applicants is constant throughout 1980-1990. Taking this into account, 98,042 patents were granted in the GDR to non-foreign applicants from 1980-1990 (or on average, 8,913 per year). Since the data by Rassenfosse, Kozak and Seliger (2019) only contains international patents, the GDR patents from this database can all be considered international applications (of which over 64% were registered in West Germany) and can therefore be used to derive the share of GDR international patents. Note that to increase the comparability of the GDR with the CPDB, we only considered unique applications. According to Rassenfosse, Kozak and Seliger (2019), the GDR registered 3,067 patents from 1980-1990 (on average, 279 per year).

registered internationally. The first year RegPat data shows both parts of Germany operating within the same IP system is 1991. Patenting activity in 1991 may, however, be problematic as innovation processes in East Germany were already heavily affected by the shock transition. This may have also affected technological profiles. At the same time, it is safe to assume that East German patents in 1991 reflect the remnants of R&D activity in the GDR.

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