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Reversing fortunes of German regions, 1926–2019: Boon and bane of early industrialization?

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Abstract

This paper shows that nineteenth-century industrialization is an essential determinant of the pronounced changes in economic prosperity across German regions over the last 100 years. Using novel data on economic activity in 163 labor market regions in West Germany, we find that nearly half of them experienced a reversal of fortune, moving from the lower to the upper median of the income distribution or vice versa, between 1926 and 2019. Exploiting plausibly exogenous variation in access to coal, we show that early industrialization led to a massive decline in the per capita income rank after World War II, as it turned from an asset to economic development into a liability. We present evidence consistent with the view that early industrialization created a lopsided economic structure dominated by large firms, which reduced adaptive capacity and local innovation. The (time-varying) effect of industrialization explains most of the decline in regional inequality observed in Germany in the 1960s and 1970s and more than half of the current North-South gap in economic development.

Keywords Industrialization · Economic development · Regional inequality

JEL Classification N93 · N94 · O14 · R12

1 Introduction

There is growing evidence for many advanced economies that regional disparities have increased since about 1980 (e.g. Rosés and Wolf 2019a; Gaubert et al. 2021). This "return of regional inequality" (Rosés and Wolf 2019b) contributes to growing income inequality and could threaten social cohesion and political stability (Iammarino et al. 2018; Floerkemeier et al. 2021). Of particular concern are declining regions, with their lack of economic opportunity, growing social problems, and rising political tensions (Austin et al. 2018;

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Rodríguez-Pose 2018). What many of these declining regions have in common is that they had a high share of industrial jobs in the past and are now suffering from the dislocation of deindustrialization (Rosés and Wolf 2021). Against this background, this paper examines the impact of nineteenth-century industrialization on changes in West Germany's economic geography over the past 100 years.

To this end, we first construct a novel dataset on regional economic activity for 163 West German labor markets at roughly 10-year intervals from 1926 to 2019. The dataset allows us to study the rise and decline of German regions over the last 100 years, as measured by their changing position in the GDP per capita distribution. Figure 1 plots the percentile rank in the distribution in 2019 against the rank in 1926 across regional labor markets. It shows that the correlation between income ranks in 1926 and 2019 is only weakly positive at 0.11 and not statistically significantly different from zero. Nearly half of the labor markets experienced a reversal of fortune between 1926 and 2019, moving from the upper to the lower median of the income distribution (lower-right quadrant) or vice versa (upper-left quadrant).

We then test the extent to which differences in early industrialization, measured as the industrial employment share in 1882, can explain these marked changes in West Germany's economic geography. Economic historians have long hypothesized that early industrialization in Germany contributed to economic development only until the mid-twentieth century, after which it led to regional decline (Abelshauser 1984; Kiesewetter 1986; Nonn 2001). We test and quantify this hypothesis. Consistent with the hypothesis, Fig. 2 shows that early industrialization is strongly negatively associated with the change in the percentile rank of a labor market in the GDP per capita distribution over the period 1926–2019.

Of course, the observed relationship between industrialization and economic development is not necessarily causal. Unobserved institutional or geographic characteristics could jointly govern early industrialization and the development process. Moreover, the relationship may reflect reverse causality running from the development process to early industrialization (Franck and Galor 2021). To establish causality, our empirical analysis instruments a region's industrial employment share in 1882 with its weighted least-cost distance to European coal fields, while controlling for the region's connectedness to other European markets. Our strategy exploits the fact that the heavy industries, characteristic of Germany's early industrialization process, were dependent on access to coal (Ziegler 2012; Gutberlet 2014). Coal, in turn, is often found in carboniferous rock strata, formed hundreds of millions of years ago. Distance to coal fields is thus plausibly exogenous to economic development (Fernihough and O'Rourke 2020).

Our 2SLS estimates indicate that a one standard deviation increase in the employment share of industry in 1882 resulted in a 30.0 point deterioration in the percentile rank in the income distribution between 1926 and 2019. Importantly, this decline is not only the result of the fading positive impact of early coal-based industrialization but also its detrimental impact in the long run. A one standard deviation increase in industrial employment in 1882 raised the rank of a labor market by 12.2 and 15.8 percentiles in 1926 and 1957, respectively, but lowered it by 17.8 percentiles in 2019. Thus, after World War II, early industrialization went from being an asset to economic development to a liability.

What explains the decline of early industrializing labor markets in the second half of the twentieth century? Early industrializing regions in Germany were often dominated by large, capital-intensive firms, especially in heavy industries such as coal mining, iron and steel production, or shipbuilding (Abelshauser 1984; Kiesewetter 1986; Nonn 2001). These large dominant firms limited regional adaptability when the old heavy industries went into crisis after World War II (e.g. Junkernheinrich 1989; Hamm and Wienert 1990; Grabher

1993). These arguments are consistent with the view that the historical presence of large firms in heavy industry has crowded out entrepreneurial activity in U.S. cities (Chinitz 1961). The lack of entrepreneurship in cities dominated by large firms then dampened urban growth (Glaeser et al. 2015).

We provide suggestive evidence that early coal-based industrialization did indeed create a lopsided economic structure dominated by large firms, which ultimately proved detrimental to development. This lopsided structure, which we detect already in the early twentieth century, mediates the adverse influence of early industrialization on economic change after 1957. Early industrialization is also associated with a rigid political system and lower innovation today, consistent with the hypothesis that the dominance of large firms, embedded in a supportive system of corporate relationships, has reduced local innovation and thus adaptive capacity (Junkernheinrich 1989; Grabher 1993).

Finally, we examine whether regional differences in nineteenth-century industrialization underlie two trends that have received much public attention: the widening economic gap between North and South Germany, and the decline and rise of regional inequality. We quantify the contribution of early industrialization to the North-South gap by predicting the gap for a counterfactual scenario in which regions differ only in their share of industrial employment in 1882. We find that early industrialization accounts for more than half of the current North–South gap in per capita GDP. To quantify the contribution of early industrialization to regional inequality, we measure the inequality of a counterfactual GDP distribution in which all regions are assigned the mean 1882 industrial employment share. We find that the diminishing positive impact of early industrialization explains well over half of the decline in regional inequality from 1957 to 1980, but cannot explain the increase in regional inequality since 1980.[1]

Contribution to the literature

Our paper contributes to several literature strands. Firstly, we add to the nascent literature, initiated by Franck and Galor (2021),[2] on the long-run economic effects of early industrialization by providing the first empirical evidence for Germany, a country where heavy industry played a central role in the development process. Heavy industrialization created a lopsided economic structure dominated by large firms, which reduced adaptive capacity and local innovation, and ultimately depressed contemporary economic development.

Our results are consistent with those of Franck and Galor (2021), who document negative effects of early industrialization on regional prosperity in contemporary France. Franck and Galor (2021) identify negative human capital effects as the key mediating channel. For Germany, we find that early industrialization reduces vocational training and increases school dropout rates. This is likely because Germany's old industrial regions lack the extensive vocational and technical training institutions associated with the small and medium firms that dominate elsewhere in Germany (Herrigel 2000).

Secondly, we contribute to the growing literature on the long-term economic impact of natural resource abundance, showing that coal-based industrialization in Germany turned

[1] We focus on the period from 1957 to 2019 in our discussion of regional inequality, as we use firm sales as a proxy for GDP before 1957 (see Sect. 2 for details). Therefore, we cannot calculate regional inequality measures that are comparable over our entire sample period.

[2] Hitherto, the potentially detrimental long-run effects of the industrialization process in post-industrial economies have "neither been raised nor been explored in the modern economic growth literature" (Franck and Galor 2021, p. 109).

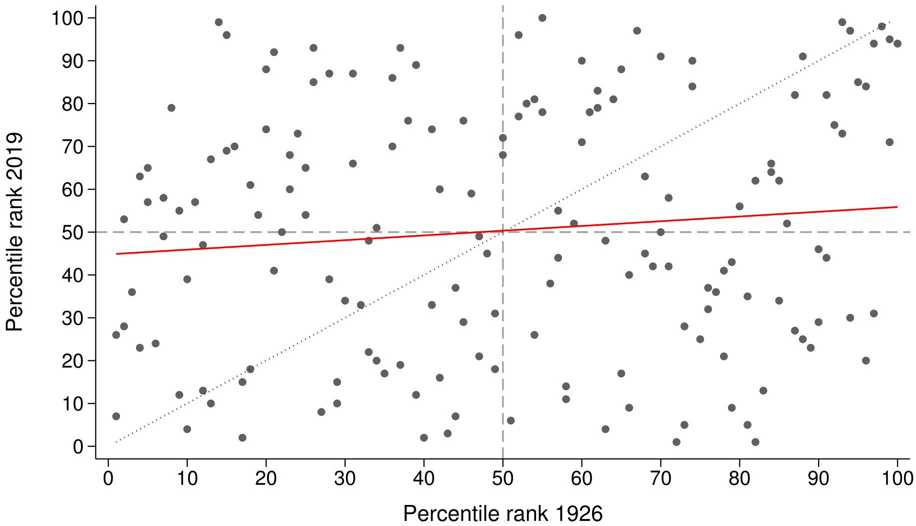

Fig. 1 Per capita income rank of West German labor markets in 1926 and 2019. *Notes* The figure plots the percentile rank in the 2019 income per capita distribution against the rank in 1926, along with the linear regression line in red. Each dot represents a labor market. Dashed horizontal and vertical lines indicate median percentile ranks. The dotted line indicates identical percentile ranks in 2019 and 1926.

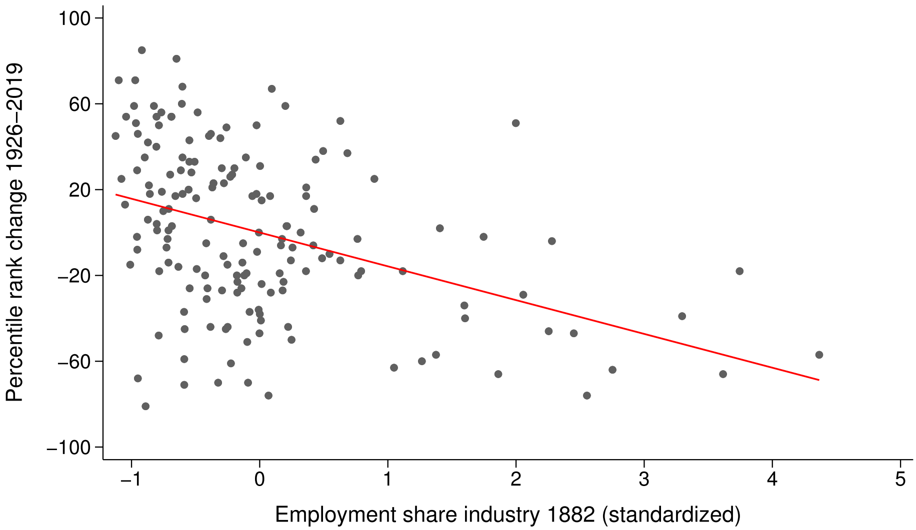

Fig. 2 Industrial employment in 1882 and per capita income rank change in 1926–2019. *Notes* The figure plots the percentile change in the per capita income rank between 1926 and 2019 on the y-axis against the standardized industrial employment share in 1882, along with the linear regression line in red. Each dot represents a labor market

from an asset to economic development into a liability over the last 100 years.[3] This finding resonates with Esposito and Abramson (2021) who show that former coal mining regions in Europe now have lower GDP per capita than regions where coal was not previously mined. Fritzsche and Wolf (2023) demonstrate that local coal abundance in Western Europe turned into a curse with the rise of cheap oil imports in the early 1960s.[4] Both papers point to negative consequences for tertiary education as the key mediating channel, with fewer universities being built in historic coal mining regions (Esposito and Abramson 2021). In contrast, we find no evidence that coal-based industrialization reduced tertiary education in West Germany, likely because new universities were established in Germany's industrial heartland in the 1960s and 1970s. Therefore, government intervention can counteract the adverse effects on tertiary education found elsewhere in Europe.

Instead, early industrialization became a constraint on economic development in Germany because of its negative impact on local entrepreneurship, innovation, and adaptability caused by the dominant position of large firms in heavy industries. This result aligns with previous findings for the U.S. and Great Britain, which have shown that the historical presence of large firms impedes entrepreneurship (Chinitz 1961; Glaeser and Kerr 2009; Glaeser et al. 2015; Stuetzer et al. 2016), and connects these earlier findings to the growing literature examining the patterns and causes of the decline of manufacturing in advanced economies.[5] In particular, our study suggests that a more diversified economic structure could help avoid the negative long-term effects of industrialization, adding to recent evidence emphasizing the importance of local human capital in adapting to deindustrialization (Fritzsche and Wolf 2023; Gagliardi et al. 2023).

Finally, we provide new descriptive insights into the evolution of regional economic activity in Germany at a much more granular level than previous studies (e.g., Kaelble and Hohls 1989; Frank 1993; Kiesewetter 2004) and quantify the contribution of early industrialization to the evolution of regional income inequality. In this respect, our work is most closely related to a recent study by Wolf (2019), which describes the evolution of regional GDP for German NUTS-2 regions over the period 1900–2010. We complement Wolf (2019) by presenting evidence for 163 labor markets within West Germany instead

[3] A large literature, reviewed for example by Van der Ploeg (2011) and Venables (2016), examines the impact of natural resource abundance on development, focusing mainly on the impact of oil in the post-World War II period. A common theme in this literature is the "resource curse", which describes the underperformance of resource-rich economies.

[4] Moreover, Matheis (2016) documents the negative long-term effects of coal production on the population of US counties. In Europe, proximity to coal boosts urban growth between 1750 and 1900 (Fernihough and O'Rourke 2020), but becomes a liability after the late 1970s (Rosés and Wolf 2021). Prior work for Germany provided case studies for single regions and sectors, notably mining in the Ruhr region (Abelshauser 1984; Nonn 2001).

[5] An older literature strand documents the poor industrial performance of the U.K. in the 1960s and 1970s and explores potential causes for the country's relative decline (e.g., Kitson and Michie 1996; Broadberry and Crafts 2003). In contrast to our study, this literature focuses on the national level. At the regional level, Rice and Venables (2021) show that the decline in manufacturing employment in the 1970s still predicts low employment today. Similarly, Austin et al. (2018) links U.S. deindustrialization to current non-employment rates. Recent evidence suggests that trade with China has contributed to U.S. manufacturing decline since the 1990s (Autor et al. 2016) but has stabilized manufacturing employment in Germany (Dauth et al. 2017). The decline of the Rust Belt, the heavy manufacturing region bordering the Great Lakes, has been linked to prolonged labor market conflict in the region's key industries (Alder et al. 2023).

of 29 regions.[6] In addition, we focus on changes in the position in the income distribution (rather than on regional convergence as Wolf 2019, does).

2 Data

This section describes our data. More details on the sources and the definition of all variables can be found in Section A.1 in the Appendix.

2.1 Unit of analysis

Our unit of analysis is the 163 West German labor markets defined in Institut für Weltwirtschaft (1974) based on commuting flows.[7] We aggregate our source data, collected at the level of counties (*Kreise*), to the level of labor markets using Geographical Information System (GIS) software.[8] The fact that we focus on local labor markets rather than counties has two advantages. First, where people live and work often differs at the county level, which poses problems in ranking counties based on their per capita income. In contrast, most people live and work within the same local labor market. Second, territorial reforms led to a sharp decrease in the number of West German counties, especially in the 1970s, making the conversion of data in historical to current county boundaries prone to error. A common reform was to merge urban counties (*Stadtkreise*) with their surrounding rural counties (*Landkreise*). Such reforms do not pose problems at the level of local labor markets, as the latter encompass interconnected rural and urban counties.

2.2 GDP per capita, 1926–2019

Our main outcome variable, ranging from 1 to 100, is the percentile rank of a labor market in the income distribution of West German labor markets. We have two main reasons for focusing on income ranks rather than levels. First, levels for 1926–1955 are not directly comparable to levels for 1957–2019. This is because we proxy regional GDP prior to 1957 with firm sales, as discussed below. More generally, the recurring revisions to the national accounts and the need to adjust for inflation make it difficult to compare income levels over time. Second, we consider percentile ranks a more intuitive measure for documenting reversals (or changes in position in the income per capita distribution more generally).

[6] Local labor markets are economic units defined by commuting patterns, so residents typically live and work in the same labor market. Nevertheless, the smaller spatial unit in our study may exacerbate potential regional spillovers, complicating our empirical analysis of the long-run effects of coal-based industrialization. However, we show in Sect. 3 that our main results hold at a higher level of aggregation, similar to that of Wolf (2019).

[7] To the best of our knowledge, the definition in Institut für Weltwirtschaft (1974) is the earliest available for West Germany. We exclude the Saarland from our sample, as it did not become part of postwar West Germany until 1957.

[8] The definition of local labor markets is based on county boundaries in 1966. For other years, we overlay maps of historical county boundaries with the base map of local labor markets. We then use the proportion of each historical county's area that belongs to a particular local labor market to aggregate the county-level data.

Nevertheless, we also present estimates using income levels as the dependent variable, which shed additional light on the economic significance of our results.[9]

West Germany's federal statistical office began publishing disaggregated GDP per capita data at the county level in 1957. We digitized the data for 1957–1992 from printed sources. Data are available for eleven years in this period, namely for 1957, 1961, 1964, 1966, 1968, 1970, 1972, 1974, 1978, 1980, and 1992. GDP data for 1992–2019 are available at an annual frequency in electronic form (Arbeitskreis VGR der Länder 2021). As in, e.g., Vonyó (2012) or Peters (2022), we proxy regional GDP before 1957 by firm sales, which we collected for 1926, 1935, 1950, and 1955. Although firm sales are not a direct measure of the production value, they correlate strongly with local GDP and deliver similar income rankings.[10]

In total, our dataset contains regional income statistics for 41 years between 1926 and 2019. Since we are interested in long-term changes rather than short-term fluctuations, our analysis focuses on data points at roughly 10-year intervals, namely 1926, 1935, 1950, 1957, 1961, 1970, 1980, 1992, 2000, 2010, and 2019 (where we include 1957 as the first year for which GDP per capita data are available). The years chosen are broadly comparable to those in Wolf (2019).[11]

The maps in Fig. 3 illustrate how the economic weights within West Germany have shifted over time. For each West German labor market, the maps show its quartile rank in the income distribution in 1926, 1957, and 2019. In 1926, the economic powerhouses are scattered across the country. They are mainly concentrated in the metropolitan areas in the west (Rhineland, Ruhr region) and north (Bremen, Hamburg). But there are also clusters of rich labor markets in the south, e.g., around Munich or Stuttgart. Poorer labor markets are concentrated in the southeast of West Germany. Despite the potentially asymmetric effects of World War II and the rise of the Iron Curtain, West Germany's economic geography changed little between 1926 and 1957.[12]

In 2019, the regional distribution of incomes has changed significantly. Labor markets in the Ruhr area in particular have slipped in the income ranking. The same applies to some of the historically rich regions in northern Germany, such as Bremerhaven or Itzehoe. By contrast, only a few of today's poorest labor markets are still to be found in the southeast. Instead, the poorest regions are now concentrated in the far west and northwest of West Germany. Several major centers of the automotive industry (Ingolstadt, Munich, Sindelfingen, Stuttgart, and Wolfsburg) top the ranking, accompanied by large cities such as Cologne, Düsseldorf, and Frankfurt.

[9] Appendix Figure A-1 shows the distribution of (log) GDP per capita in 1957, 1980, and 2019. The distribution became less unequal between 1957 and 1980, making a labor market's position in the distribution less consequential for relative GDP per capita. In contrast, the distribution became more unequal again between 1980 and 2019. We return to the issue of regional inequality in Sect. 5.

[10] The correlation between a labor market's percentile rank in the 1955 sales per capita and the 1957 GDP per capita distribution is 0.870. The corresponding scatterplot in Appendix Figure A-2 confirms the close correspondence between GDP per capita and sales across labor markets. Additional comparisons between sales and GDP are possible for the nine West German states in 1950, when the correlation coefficient is 0.99. In data from before World War II, the correlation between per capita sales in 1935 and per capita national income in 1936 is 0.92 across 19 German regions (Braun and Kvasnicka 2014).

[11] Wolf (2019) reports GDP per capita data at the NUTS-2 level for 1900, 1910, 1925, 1938, 1950, 1960, 1970, 1980, 1990, 2000, and 2010. We do not interpolate to obtain data for years ending with 0 in case they are not readily available. For instance, we do not interpolate our data for 1957 and 1961 to obtain a value for 1960, but rather stick to 1961.

[12] The correlation between the position in the 1957 GDP per capita distribution and the 1926 sales per capita distribution is 0.712, despite the change in measurement. Correlating the ranks in the 1926 and 1955 sales per capita distributions even yields a coefficient of 0.797.

2.3 Industrial employment share 1882

Our main explanatory variable of interest is the share of the local workforce working in industrial occupations in 1882. We thus measure industrialization after Germany's take-off phase, typically dated to 1840–1870s, but before the rise of new industries during Germany's *Hochindustrialisierung* (Ziegler 2012; Tilly and Kopsidis 2020). Our measure comes from the first German-wide occupation census that contains results at the county level (Kaiserliches Statistisches Amt 1884) and is standardized to have a mean of zero and a standard deviation of one.

2.4 Distance to European coal fields

Our empirical analysis uses an instrumental variable strategy to identify the causal effect of early industrialization on development. We use the weighted least-cost distance to European coal fields as an instrument for the 1882 employment share in industrial occupations. Access to coal is widely acknowledged as a key factor behind the success of Germany's early industrializing regions, which relied mainly on heavy industries (Fremdling 1977; Ziegler 2012). Fernihough and O'Rourke (2020) have recently demonstrated the importance of coal for the European Industrial Revolution in general.

Previous studies have used the proximity to the nearest coal-bearing rock strata as an instrument for the historical use of steam engines (de Pleijt et al. 2020) and coal mining (Esposito and Abramson 2021). In contrast to these papers, we use the sum of least-cost distances to all European coalfields, weighted by their area, to account for the fact that the closest coalfield is not necessarily the one that can be reached with the lowest transportation costs. This modification is important for the German context. In particular, regions in northern and northeastern Germany initially relied primarily on British coal, rather than coal from closer German mines, because of the low cost of river and sea transportation (Fremdling 1979).[13] By accounting for the size of a coalfield, our measure also distinguishes between smaller and larger coal fields with potentially very different yields.

To calculate the instrumental variable, we first divide Europe in a one-by-one kilometer grid. Based on the local geography, we assign each cell a specific pre-industrial (1790) transportation cost, which we take from Daudin (2010).[14] We normalize the cost to one for cells that have access to the sea. Cells with access to a major river are assigned a cost value of 1.018, all other cells are assigned Daudin's value for road transport of 2.963.[15] We then calculate the least-cost distance from each labor market to all European coalfields, using Dijkstra's algorithm and the grid as cost surface. The algorithm finds the least-cost path from a region to a coalfield, adding cell-specific costs along the way. The instrument for a

[13] The relatively low price of English coal in northern Germany was also due to lower production costs in English mines, but this is not accounted for by our instrument.

[14] By relying on a pre-industrial cost vector that does not include transportation via paved roads, canals, or railroads, we avoid that our instrumental variable captures the fact that early industrialized regions are better connected to the transportation network for endogenous reasons. Since mode-specific transport cost vectors are not available for Germany, we adopt a cost vector for France, which has a similar topography.

[15] We take shape files of major European rivers from Fernihough and O'Rourke (2020). The value for rivers is the average of upstream and downstream river transport. We also probe the robustness of our results to alternative costs vectors. In particular, we use squared transport costs and assign higher costs of 2.476 to river and 9.75 to road transport, respectively, following Bairoch (1910). Moreover, we restrict the set of rivers to those that are at least 20 meters wide and two meters deep in an additional robustness check.

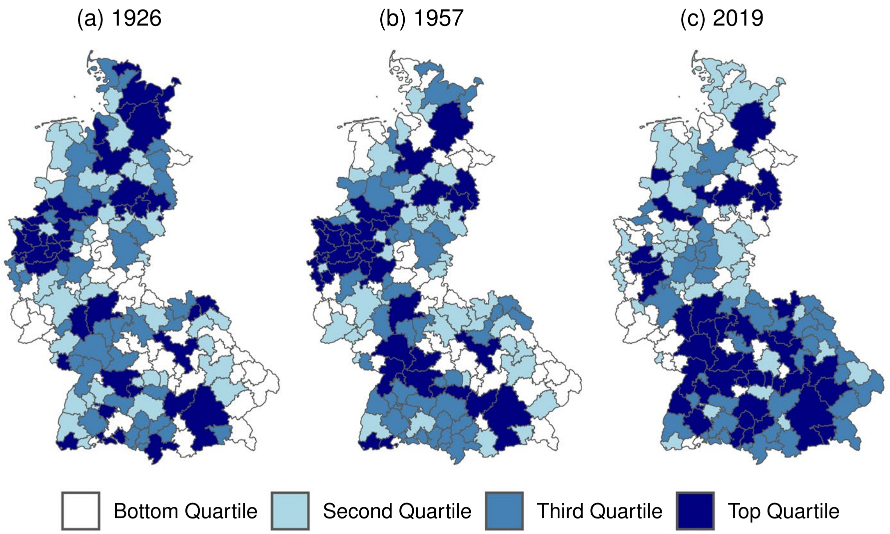

Fig. 3 Per capita income rank of West German labor markets, 1926–2019 (quartiles). *Notes* Each map shows the quartile rank in the per capita income distribution of West German labor markets in 1926 (**a**), 1957 (**b**), and 2019 (**c**)

given labor market i, C_i, is the logarithm of the weighted sum of the least-cost distances to all coalfields:

$$C_i = \log\left(\sum_{k=1}^{K} \frac{area_k}{cost_{ik}}\right), \tag{1}$$

where $cost_{ik}$ is the least cumulative costs from labor market i to coalfield k and $area_k$ is the area of the coalfield polygon in square kilometers. We take the location and extent of European coalfields from Fernihough and O'Rourke (2020).

Figure 4 illustrates the regional variation in the instrument as well as the location of the most important coalfields, coast lines, and major rivers. Higher values indicate more favorable access to coal. Not surprisingly, access is most favorable in the Ruhr region and in regions connected to the Ruhr by rivers. Regions in northern Germany also have relatively favorable access to coal because they can obtain British coal via the North Sea.[16] To ensure that the instrument does not just pick up the connectedness of a labor market within Europe, our empirical analysis controls for a labor market's sum of least-cost distances to all European grid cells on land using the same cost vector as in Eq. (1).

[16] Unfortunately, we lack nineteenth-century coal prices for regional labor markets, which are arguably a more direct measure of access to coal. However, using data on coal prices for 45 German cities in 1906/7, we find that our instrument predicts the cross-city variation in coal prices well (the correlation coefficient is – 0.722).

2.5 Economic structure in 1907

To test whether early industrialization led to a lopsided economic structure, we digitized the 1907 Census of Manufactures (*Gewerberbliche Betriebsstatistik*) (Kaiserliches Statistisches Amt 1909a, b). The data provide county-level information on the number of establishments and their total employment, disaggregated by 3-digit industries. We use the data to calculate the average firm size in industry and mining, the employment share in industries dominated by large firms, and sectoral employment concentration. We define industries dominated by large firms as those with a Germany-wide employment share of at least 50% in firms with at least 501 or 1000 employees. These industries include, for example, coal mining, arms foundries, and shipbuilding (see Appendix Table A-2 for a complete list). We measure concentration using the Herfindahl–Hirschman Index (HHI).[17]

3 Early industrialization and economic development, 1926–2019

This section tests the hypothesis that early industrialization was initially beneficial and later detrimental to economic development, leading to a relative deterioration in the position in the income distribution over the period 1926–2019.

3.1 Empirical specification

We estimate the effect of early industrialization on subsequent development using 2SLS. The second stage regression quantifies the effect of the standardized industrial employment share in 1882, $I_{i,1882}$, on a labor market's percentile rank in the income per capita distribution, $y_{i,t}$ (or changes thereof):

$$y_{i,t} = \alpha + \beta_t \hat{I}_{i,1882} + \mathbf{X}_i^{'} \gamma_t + \epsilon_{i,t}, \tag{2}$$

where $\mathbf{X}_i$ is a set of control variables, which in our baseline regression includes land accessibility and the number of towns per area in 1700 (see next paragraph for details), and $\epsilon_{i,t}$ is an error term.[18] We obtain the predicted values of $I_{i,1882}$, $\hat{I}_{i,1882}$, from a first stage regression using the (log) weighted least-cost distance to European coal fields, C_i, as an instrument for early industrialization (see Sect. 2.4 for details on the construction of the instrument):

$$I_{i,1882} = \delta + \zeta C_i + \mathbf{X}_i^{'} \eta + u_i, \tag{3}$$

where $\mathbf{X}_i$ contains the same control variables as in Eq. (2). Along with 2SLS estimates, we also report the results from conditional OLS regressions (relating $y_{i,t}$ to $I_{i,1882}$) and

[17] The index is calculated as $HHI_i = \sum_{l=1}^{L} (b_{il})^2$, where b_{il} is the employment share of labor market i in (3-digit) industry l in total industrial employment. The HHI ranges from $1/L$ (when all sectors have equal employment) to 1 (when all employment is concentrated in one sector). We use data for $L = 300$ sectors.

[18] Our regression model is similar in spirit to Franck and Galor (2021), who also regress indicators of regional development at different points in time on a measure of early industrialization (total horsepower of steam engines in 1860–65), exploiting the diffusion of steam engines in their IV strategy.

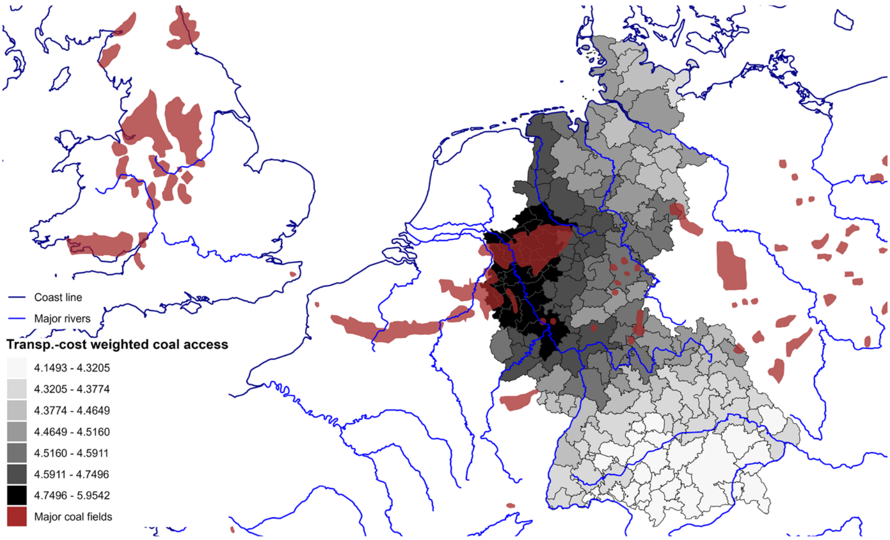

Fig. 4 Weighted least-cost distance to European coalfields. *Note* See the main text for details on the construction of the weighted least-cost distance. The transport cost vector is taken from Daudin (2010)

reduced-form regressions (relating $y_{i,t}$ to C_i).[19] To account for spatial correlation, we always report Conley (1999) standard errors and standard errors clustered at the level of 36 districts (*Regierungsbezirke*).

The key identifying assumption for the 2SLS regression to yield a consistent estimate of our coefficients of interest, β_t, is $Cov(C_i, \epsilon_{i,t}) = 0$. The assumption states that (i) there is no unobserved factor that drives economic development and is correlated with C_i and that (ii) C_i affects economic development only through its effect on early industrialization. An obvious challenge to the identifying assumption is that coal access might capture favorable location and thus better market access in general, as, e.g., regions along rivers tend to have better access to coal. To address this concern, we include the weighted least-cost distance to all European land cells as control variable. Intuitively, the control measures a region's geographic isolation within Europe.[20] We thus exploit only the residual variation in coal access, which is not driven by a region's favorable location in general. Furthermore, we control for the number of towns per square kilometer in 1700, reported in Cantoni et al. (2020), to capture differences in pre-industrial development (and locational fundamentals that lead to these differences).

Another challenge to the identifying assumption is shocks during our sample period that exhibit spatial patterns, which the instrument picks up. Several shocks come to mind. First, the German division in 1945 and re-unification in 1990 led to an asymmetric loss and gain

[19] In addition, we estimate an ordered probit model in which the explanatory variable of interest, the industrial employment share in 1882, is treated as endogenous. This allows us to account for the fact that $y_{i,t}$ is a limited dependent variable. The results of the ordered probit model, which are available from the authors upon request, confirm the pattern found in our linear model.

[20] Ashraf et al. (2010) establish that, in contrast to conventional wisdom, prehistoric geographical isolation has positive long-run effects on cross-country differences in economic development.

of market access for regions at the former inner-German border (Redding and Sturm 2008). These regions, in turn, are predominately located in northern Germany, which shared a long border with the German Democratic Republic (GDR). Second, about eight million displaced Germans from Eastern Europe arrived in West Germany after World War II, initially gathering mainly in the eastern parts of the country. The inflow accelerated structural change away from low-productivity agriculture (Braun and Kvasnicka 2014) and increased income per capita in the long run (Ciccone and Nimczik 2022; Peters 2022). Third, between 1949 and 1961, nearly 3 million people fled the GDR to West Germany, many highly skilled (Becker et al. 2020). Fourth, the immigration of so-called "guest workers" in the late 1950s and 1960s, mainly from southern and south-eastern Europe, also followed a spatial pattern. Migrants came first to southern Germany's industrial centers and later to western and, finally, northern Germany. Fifth, the influx of refugees in 2015–16 was also concentrated in regions in western Germany, despite the existence of allocation quotas (Gehrsitz and Ungerer 2022). Sixth, bombing damage during World War II was higher along the northern coastline due to its proximity to Great Britain (Vonyó 2012) and reduced long-term private wealth in Germany (Halbmeier and Schröder 2024). Finally, Germany's western integration after 1945 may have disproportionately benefited regions in western Germany (Redding and Sturm 2008). We show in different checks that adding controls for these shocks leaves our results unchanged.

3.2 Baseline results

Table 1 reports OLS (Panel A), 2SLS (Panel B), and reduced form (Panel C) estimates of the effect of early industrialization on economic development in 1926–2019. The first two columns report the impact on changes in percentile rank in the per capita income distribution between 1926 and 2019 (Column (1)) and between 1957 and 2019 (Column (2)). Columns (3) through (5) report the (underlying) effect on the position in the income distribution in 1926, 1957, and 2019. These years include the starting and ending points of our sample period and the first year for which we have GDP per capita data.

Columns (1) and (2) show that early (coal-based) industrialization has an economically and statistically significant negative impact on the change in a labor market's position in the per capita income distribution. The OLS estimate in Column (1) implies that a one standard deviation increase in the industrial employment share in 1882 led to a 19.3 percentile deterioration in income position between 1926 and 2019. The 2SLS estimate implies an even larger decline of 30.0 percentiles. Notably, the effect sizes for 1926–2019 and 1957–2019 are very similar. Thus, the decline of the early industrialized regions did not begin until after 1957, just before the coal crisis began with the collapse of demand in the winter of 1957/58.

Columns (3) to (5) show that the decline of the early industrialized regions is not only due to the waning positive effects of early industrialization but also to its long-run adverse effects. The 2SLS estimate in panel B of Column (3) implies that a one standard deviation increase in the 1882 industrial employment share improves the 1926 rank in the income distribution by 12.2 percentiles. The 2SLS estimate is very similar to the OLS estimate. Thus, early industrialization was still conducive to economic development in 1926. The same is true for 1957 (see Column (4)). In 2019, on the other hand, early industrialization harmed the position in the income distribution (Column (5)). While the OLS estimate in Panel A is relatively small, the 2SLS estimate is sizable (Panel B), mirroring the significant negative reduced-form estimate in Panel C. The 2SLS estimate implies that a one standard deviation increase in the 1882 industrial employment share reduces a labor market's rank in the 2019 income distribution by 17.8 percentiles.

Overall, our analysis shows that early coal-based industrialization had a long-lasting positive effect on economic development that eventually turned negative. Figure 5 plots the coefficient estimates of β_t from equation (2) for 1926, 1935, 1950, 1957, 1961, 1970, 1980, 1992, 2000, 2010, and 2019. The positive effect of early industrialization persisted (and even increased slightly over time) in 1926–1957.[21] The positive effect of industrialization in the nineteenth century began to shrink in 1957, paralleling the onset of the coal crisis. The point estimate turns negative in 1992 and has been declining ever since.

Table 1 shows that the 2SLS estimates are comparable to the OLS estimates in 1926 and 1957 but are markedly more negative in 2019. What is the reason for this pattern? In this context, it is worth highlighting that the IV estimate in Franck and Galor (2021) of the effect of early industrialization on regional GDP per capita in France "reverses the OLS estimates [...] from positive to negative" in 2001–2005.[22] In contrast, for earlier periods, the positive effect of past industrialization on economic development in Franck and Galor (2021) is much larger in the IV regressions than the corresponding OLS estimates. The authors argue that omitted characteristics may have harmed development in earlier periods but may be conducive to development today. As an example, they cite government capacity, which may have promoted industrialization but also reduced per capita income in the past by facilitating the protection of the agricultural sector. Thus, a first explanation for our result is that early industrialization is correlated with omitted local characteristics that promote economic development today but had little impact in 1926 and 1957.

A second related explanation is that the exogenous aspects of early industrialization—isolated in the 2SLS regressions by coal access—have a more negative effect than the OLS estimate suggests, while the endogenous aspects—which are independent of coal—favor economic development today. In this explanation, the differences between the two aspects of early industrialization emerge only after the crisis of old German heavy industry in the late 1950s and 1960s (because only then do the two aspects differ in their effects). A third, less favorable explanation is that access to coal picks up local characteristics associated with longer-term decline after 1957 (but not earlier). We address this concern in several robustness checks that consider the effects of other large shocks that asymmetrically affected German regions in the postwar period.

3.3 Robustness checks

We run several tests, listed in Appendix Table A-3, to assess the robustness of our 2SLS results. As mentioned earlier, a major concern is that our instrumental variable is correlated with "spatial shocks" that could explain differences in regional economic development after 1957. To address this concern, we add control variables that proxy for these shocks in an initial set of checks in Panel B. First, we add control variables that account for the consequences of German division and re-unification (see Panel B1). Specifically, we add distance to the former inner-German border that separated West and East Germany

[21] The estimated coefficient β_t increases from 8.9 in 1935 to 15.3 in 1950 and 15.8 in 1957. This increase does not reflect a change in the variable used to construct the percentile ranks because we use per capita sales for 1935 and 1950.

[22] Also Esposito and Abramson (2021) find that the negative effect of historical coal mining on current income is 2–3 times larger (in absolute magnitudes) than the OLS estimates in their IV regressions.

Table 1 Early industrialization and regional economic development, 1926–2019

	1926–2019 (1)	1957–2019 (2)	1926 (3)	1957 (4)	2019 (5)
Panel A. OLS					
Employment share industry 1882	− 19.33***	− 22.26***	15.31***	18.24***	− 4.02***
	(3.06)	(2.83)	(2.79)	(2.75)	(1.51)
	[2.76]	[2.93]	[2.31]	[2.68]	[1.73]
Panel B. 2SLS					
Employment share industry 1882	− 30.04***	− 33.62***	12.22***	15.80***	− 17.82***
	(7.52)	(7.24)	(3.25)	(3.14)	(6.89)
	[5.75]	[6.18]	[2.96]	[3.14]	[6.03]
Panel C. Reduced form					
Log access to coalfields	− 65.12***	− 72.87***	26.50***	34.25***	− 38.62***
	(10.20)	(8.77)	(9.24)	(9.90)	(8.64)
	[12.76]	[11.03]	[11.26]	[11.18]	[7.58]

The table shows results from OLS (Panel A) and 2SLS (Panel B) regressions of the effect of early industrialization on (changes in) regional economic development as well as reduced form regressions of the effect of coal access on development (Panel C). The ranking in 1926 is based on sales per capita, the rankings in 1957 and 2019 are based on GDP per capita. The 1882 employment share in industry, our explanatory variable of interest, is standardized with a mean of zero and a standard deviation of one. The instrument used in the 2SLS regressions is the log weighted average distance to European coal fields where coalfield sizes serve as weights (see Sect. 2.4). All regressions include land accessibility and the number of towns per area in 1700 as control variables. Conley standard errors (Bartlett kernel, 100 km cut-off) are reported in round brackets; standard errors clustered at the level of administrative districts (*Regierungsbezirke*) in square brackets. ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively, based on Conley standard errors. The first-stage Kleibergen-Paap F-statistics for the 2SLS estimates are 19.72 with Conley standard errors and 11.82 with clustered standard errors

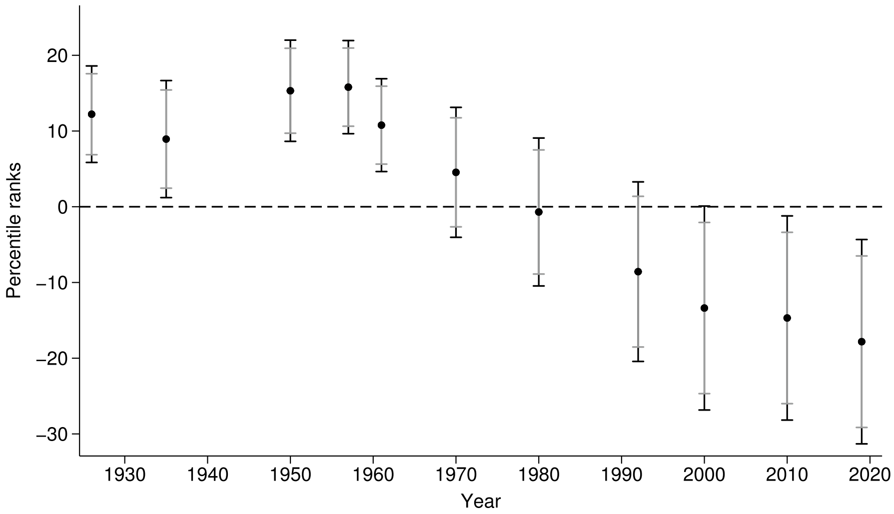

Fig. 5 Impact of early industrialization on the per capita income rank, 1926–2019. *Notes* The figure plots the β_t coefficients from 2SLS estimations of equation (2). Point estimates are marked by a dot. The vertical bands in gray and black indicate 90% and 95% confidence intervals, respectively. The dependent variable is the percentile rank in the income per capita distribution. The 1882 employment share in industry, our explanatory variable of interest, is standardized with a mean of zero and a standard deviation of one

between 1949 and 1990, a direct measure for the market access lost (and gained) due to the division (and later reunification) of Germany based on Redding and Sturm (2008), and distance to Germany's eastern border. We also add an indicator variable for redevelopment regions that after the war received governmental aid for reconstruction and industry promotion. Many of these regions were heavily war damaged or suffered from being close to the inner-German border. Second, we add control variables for different immigration episodes (see Panel B2).[23] We add the population share of displaced persons in 1950 and of GDR refugees in 1961, the share of foreigners in 1970 and 1987 as a measure of the local influx of guest workers,[24] and the share of refugees in 2016. Third, we proxy war damage by the amount of rubble per capita in 1946 and by the fraction of dwellings built before 1945 that were damaged in the war (see Panel B3). Finally, we account for Germany's integration into (Western) Europe by adding distance to Germany's western border and to the Schengen area in 2008 (see Panel B4). Our results are robust to all of these checks.

A related concern is that our instrumental variable picks up omitted geographic characteristics that affected economic development differently in 1926, 1957, and 2019. We consider this less of a threat to identification because our baseline regression already controls for a region's favorable location. Nevertheless, in our second set of robustness checks in Panel C, we add several controls for local geographic and climatic conditions to our baseline specification, including distance to rivers and oceans, soil quality, remoteness within Germany, and mean sunshine hours. None of these controls has a marked impact on our baseline estimate.

Our instrumental variable may also be correlated with state-level policies that have affected economic development in the postwar period. Therefore, in a third set of checks in Panel D of Appendix Table A-3, we add state-level fixed effects to our controls (with and without additional geographic controls). We are reluctant to include state-level fixed effects in our baseline specification because they eliminate most of the variation we are interested in (much of the change in relative prosperity occurs between distant regions in different states). Nevertheless, our main estimates are only slightly smaller when we add fixed effects. We find that a one standard deviation increase in the share of industrial employment in 1882 led to a worsening of the rank in income distribution by 22.4 (without additional geographic controls) and 25.5 (with geographic controls) percentiles between 1957 and 2019. Adding fixed effects for states in pre-industrial Germany yields very similar results. Moreover, accounting for early membership in the German Customs Unions of 1834, which promoted market integration among member states (Keller and Shiue 2014), leaves our baseline results unchanged.

Appendix Table A-4 reports additional robustness checks. In Panel B we measure early industrialization in the subsequent 1895 and 1907 occupation censuses and add the tertiary employment share in 1882 as an additional control. Panel C constructs the instrument using alternative cost vectors for the least-cost paths to the coal fields.[25] It also uses alternative measures of coal deposits to address the concern that the location of historical coal

[23] The regional distribution of migrants might be endogenous, as it follows regional economic development. For example, the regional quotas for the distribution of refugees in 2015/16 are two-thirds based on local tax revenues.

[24] By far the most foreigners in West Germany at the time came to the country as part of the guest worker program. The recruitment of guest workers ended in 1973.

[25] Among other things, we construct the instrument using squared transport costs. This alternative instrument gives less weight to more distant coal fields, reflecting the fact that immediate access to coal may be more important than proximity to multiple coal fields.

fields, measured in our baseline regression as of 1931, may be endogenous to exploration efforts (as noted by Fernihough and O'Rourke 2020).[26] The miscellaneous checks in Panel D exclude the Ruhr from our sample, estimate population-weighted regressions, and use log GDP per capita as the dependent variable instead of percentile ranks. Our main result is robust to all of these checks: early industrialization led to a sharp decline in per capita income after 1957, driven in large part by a negative income effect in the long run.

3.4 Effect size

Using GDP per capita as the dependent variable (instead of ranks) also sheds additional light on the effect size. According to the estimates in Panel D of Appendix Table A-4, a one standard deviation increase in the share of industrial workers in 1882 raised GDP per capita by 0.16 and 0.13 log points in 1926 and 1957, respectively. However, today's GDP per capita falls by 0.11 log points. Therefore, real GDP per capita increased by about 0.24 log points or 27% less in 1957–2019 (regional GDP per capita increased on average by 313% or almost 40,000 DM in 1957–2019).

3.5 Spillover effects

Finally, we re-estimate our regression at the more aggregate level of districts (*Regierungsbezirke*), of which there are 36, to test for spillover effects across labor markets (which our baseline specification ignores). Positive spillovers could result from agglomeration effects that radiate across labor market regions. Negative spillovers could arise from the relocation of economic activity to early industrializing regions (or away from them when they decline). Differences between labor market and district level estimates would hint at such regional spillovers. However, the results in Panel E of Appendix Table A-4 are relatively similar to those at the labor market level and we continue to find negative long-run effects of early industrialization.[27]

[26] Our focus on distance to all European coal fields should mitigate this concern, since, for example, coal mining in England, crucial to northern Germany, is unlikely to have been driven by German industrialization. Nevertheless, the robustness checks in Panel C address the concern of endogenous coal location in two ways: First, we use the distance to carboniferous surface strata rather than the actual coal fields, though this results in a weaker first stage, with a Kleibergen-Paap F-statistic of 10.20. While many coal fields are located in areas with carboniferous strata at the surface, others lie below the surface and are covered by other strata. In our data, only about half of the 1931 coal fields are located in areas with carboniferous surface strata. Second, we supplement the 1931 data with later data from the Pergamon World Atlas of 1967 (Polish Army Topographical Service 1968). The combined list should give a reasonably accurate picture of where coal could have been discovered in the nineteenth century.

[27] Comparing estimates at different levels of aggregation is a common strategy for detecting regional spillovers (see, for example, Criscuolo et al. 1999; Franck and Galor 2021). The approach assumes that spillovers occur only across labor markets within the same district. While it is possible that spillovers also affect more distant areas, it is likely that they are strongest between nearby labor markets. The lower district-level coefficient for 1926 and 1957 suggests negative spillovers, but the large standard errors caution against drawing firm conclusions. Nevertheless, in unreported regressions we find that after the onset of the coal crisis, late industrializing regions experienced higher net migration in 1961–1970 (although we cannot distinguish between migration from other German regions and from abroad).

4 Lopsided economic structure and limited adjustment capacity

What explains the slow and protracted decline of the early industrialized regions in Germany? And why were these originally rich regions unable to revitalize their economic base? Existing hypotheses point to the regions' one-sided economic structure. Old industrial regions, the argument goes, were historically characterized by monostructural agglomerations, typically in heavy and extractive industries, dominated by large corporations (Hu and Hassink 2016). This lopsided structure led to high adjustment pressure after Germany's old industries fell into crisis in the late 1950s and 1960s. At the same time, it limited the regional ability to adapt and innovate (e.g. Junkernheinrich 1989; Hamm and Wienert 1990; Grabher 1993). This section provides tentative evidence consistent with these hypotheses.

4.1 Economic structure in 1907

Using detailed three-digit sectoral employment data from the 1907 manufacturing census, Table 2 provides evidence that (coal-based) early industrialization indeed produced a large-firm-dominated and highly concentrated economic structure. Column (1) shows that early industrialization led to a larger average firm size in industry. A one standard deviation increase in the share of employment in industry in 1882 increased the average firm size by 2.9 employees per firm in 1907 (compared to a mean of 4.6). Similarly, Columns (2) and (3) show that early industrialized regions had higher employment shares in sectors dominated by large firms. We focus on sectors with a Germany-wide employment share of at least 50% in firms with at least 501 (Column (2)) or 1000 (Column (3)) employees. The effect sizes are considerable: a one standard deviation increase in the industrial employment share in 1882 increased the 1907 employment share in sectors dominated by firms with at least 501 employees by 7.1 percentage points (relative to a mean of 2.3%) or more than one standard deviation. Finally, Column (4) shows that early industrialized regions were much more specialized within the industrial sector in 1907. A one standard deviation increase in early industrial employment increased the HHI of industry concentration by 0.05 (relative to a mean of 0.06).[28]

Existing hypotheses suggest that the negative impact of early industrialization on long-term economic development is mediated by the lopsided economic structure it created. Unfortunately, quantifying this mediation effect is only possible under strong assumptions. Typically, causal mediation analysis focuses on settings where the treatment is exogenous given the pretreatment covariates (Celli 2022).[29] Since this assumption does not hold in our context, we rely instead on recent results in Dippel et al. (2020a). The authors present a framework for estimating causal mediation effects in IV settings with endogenous treatment using a single instrument.[30] The key additional identifying assumption is that

[28] We still observe a positive effect on sectoral concentration in 1950, shortly before the coal crisis began (see Column (1) of Appendix Table A-8).

[29] In addition, standard causal mediation analysis requires that the mediator is exogenous, or independent of potential outcomes, given the actual treatment and the pretreatment covariates (Imai et al. 2010). This sequential ignorability assumption is not guaranteed to hold even when treatment and mediator are randomized.

[30] See Dippel et al. (2020b) for implementation details and Dippel et al. (2021) for an application. The framework complements alternative IV approaches that require two separate instruments, one for the treatment and one for the mediator (Frölich and Huber 2017).

unobserved confounding variables that jointly cause the treatment (early industrialization in our case) and the mediator (lopsided economic structure) are independent of confounding variables that jointly cause the mediator (lopsided economic structure) and the outcome (change in GDP per capita ranking). This assumption is violated if a common confounder jointly causes the treatment, the mediator, and the outcome.

The method developed by Dippel et al. (2020a) can only identify the mediating effect of a single mediator (but omitting other mediators does not bias the results). Thus, following Dippel et al. (2021), we focus on the first principal component of our four economic structure variables as the mediating variable.[31] Column (5) of Table 2 shows that a one standard deviation increase in the industrial employment share in 1882 increases the principal component by more than one standard deviation. Applying the mediation analysis of Dippel et al. (2020a) suggests that about three-quarters of the total effect of early industrialization on the change in GDP per capita ranking between 1957 and 2019 works through the effect of industrialization on economic structure.[32] We find this value plausible and consistent with the strong focus in the historical literature on the negative effect of the lopsided economic structure of early industrializing regions dominated by large firms, but reiterate the strong identifying assumptions required.

4.2 Adjustment pressure and capacity

What were the consequences of the lopsided economic structure that led to the decline of Germany's early industrialized regions in the second half of the twentieth century? It has been hypothesized that the dominance of large corporations in heavy industries created high adjustment pressure post-1957 and limited adjustment and innovation capacity (Junkernheinrich 1989; Hamm and Wienert 1990; Grabher 1993).

Large corporations and close interregional business ties dominated local economies in early industrializing regions. These tightly knit industrial networks created a "cognitive lock-in" that prevented the regional economy from adapting (Grabher 1993). Large corporations created a tradition of dependent employment and a corresponding lack of entrepreneurial role models (Stuetzer et al. 2016). As a result, they crowded out entrepreneurial activity and dampened growth in the long run (Chinitz 1961; Glaeser et al. 2015). Large corporations were also closely tied to local governments and unions that supported the old mining industry structures. Extensive subsidies to the coal, iron, and steel complex maintained outdated structures (Hamm and Wienert 1990; Hassink and Kiese 2021).

The dominance of large corporations in Germany's industrial heartland has been contrasted with the "decentralized industrial order" prevalent especially in southwestern Germany (Herrigel 2000). The small and medium-sized enterprises that dominate there[33] often

[31] This first principal component explains 78% of the total variation and is the only component with an eigenvalue greater than one.

[32] To get at the mediation effect, we regress the change in GDP per capita ranking on our measure of lopsided economic structure as instrumented by access to coal, controlling for covariates and early industrialization. The effect of economic structure on the GDP per capita ranking is then multiplied by the effect of early industrialization on economic structure. Appendix Table A-5 shows all the underlying estimates. In addition, the table also reports the results of mediation analyses that directly use our four measures of lopsided economic structure as mediating variables, one at a time. In these alternative specifications, lopsided economic structure explains 56–94% of the total effect of early industrialization.

[33] In addition to the lack of coal, the emergence of a decentralized industrial order has been fostered historically by equal division inheritance rules that divided property equally among all children (Herrigel 2000; Bartels et al. 2024). Farmers with small landholdings in equal division areas often supplemented their agri-

Table 2 Early industrialization and industry structure in 1907 (2SLS estimates)

	Average firm size	Employment share in sectors dominated by large firms		HHI index of industry concentration	First principal component of (1)–(4)
		≥ 501 workers	≥ 1000 workers		
	(1)	(2)	(3)	(4)	(5)
Employment share industry 1882	2.875***	0.071***	0.060***	0.049**	2.249***
	(0.554)	(0.019)	(0.020)	(0.022)	(0.654)
	[0.542]	[0.019]	[0.021]	[0.027]	[0.691]
Outcome statistics					
Mean	4.592	0.023	0.012	0.058	− 0.000
Standard deviation	2.394	0.057	0.049	0.062	1.771
Causal mediation analysis					
Total effect					− 33.62*** [6.18]
Direct effect					− 8.49 [6.03]
Indirect effect					− 25.13** [12.81]

The table shows results from 2SLS regressions of the effect of early industrialization on the regional economic structure in 1907. The dependent variables are the average number of employees per firm in industry (Column (1)), the employment share in sectors in which at least 50% of employees work in firms with at least 501 workers (Column (2)) or 1000 workers (Column (3)), the HHI-Index of industry concentration with $\alpha = 2$ (Column (4)), and the first principal component of the four indicators in Columns (1) to (4) (Column (5)). The 1882 employment share in industry, our explanatory variable of interest, is standardized with a mean of zero and a standard deviation of one. The lower panel also presents second stage results of the causal mediation framework for linear IV models introduced in Dippel et al. (2020a). The mediation analysis decomposes the total effect of early industrialization on the change in the GDP per capita rank between 1957 and 2019 into a direct effect and an indirect effect running through lopsided economic structure. All regressions include land accessibility and the number of towns per area in 1700 as control variables. Conley standard errors (Bartlett kernel, 100 km cut-off) are reported in round brackets; standard errors clustered at the level of administrative districts (*Regierungsbezirke*) in square brackets. ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively, based on Conley standard errors

emphasize customized quality production, requiring high skill and flexibility in production (Herrigel 1999, 2000). Flexible, decentralized production, in turn, has been cited as a key factor for adapting to rapidly changing global market environments and thus for sustained competitive success during the globalization process (Streeck 1991; Simon 1992; Herrigel 2000; Simon 2009).

Undisputed, the old industrial regions were exposed to high adjustment pressure after 1957. Table 3 shows that in 1950, shortly before the coal crisis outbreak, early industrialization's positive effect on industrial employment was exclusively attributable to the coal, iron, and steel industries. A one standard deviation increase in early industrialization raised the industry employment share by 7.4 percentage points in 1950 (Column (1)). However, the effect on iron, coal, and steel industries was even larger at 8.0 percentage points

Footnote 33 (continued)

cultural incomes with income from secondary industrial employment. In the long run, this industrial by-employment formed the breeding ground for adaptive small- and medium-sized firms (Bartels et al. 2024).

(Column (2)). It was precisely these industries that fell into crisis in the 1960s and 1970s. In contrast, early industrialization slightly reduced employment in "modern industries", such as electrical engineering, the automobile industry, and the chemical industry, already in 1950 (Column (3)). These modern industries continued to flourish after 1945 and are still associated with Germany's economic strength today. Column (5) of Table 3 shows that Germany's former industrial heartland has failed to revitalize its industrial base in new growth industries and has suffered from deindustrialization. We find that a one standard deviation increase in early industrialization lowers the industrial employment share by 5.9 percentage points in 2019.[34]

Do we also find evidence of limited regional adaptive capacity, possibly reflected in lower human capital, lower entrepreneurial activity, a rigid policy environment, and ultimately lower innovation? Previous work on the long-term effects of industrialization suggests adverse effects on human capital. Franck and Galor (2021) show that early industrialization has a negative impact on the share of the population in France with a post-secondary degree (from a vocational school or university). They also show that second-generation migrants whose parents originally came from historically industrial departments have lower human capital aspirations today and are more likely to leave the school system at the end of middle school. Esposito and Abramson (2021) find that former coal mining regions in Europe invested less in tertiary education.

In our context, it is unlikely that a lack of investment in tertiary education, which in Germany is mainly financed by the federal states rather than the local governments,[35] explains the adverse long-term effects of early industrialization. In the Ruhr region, for example, universities were opened in Bochum (1965), Dortmund (1968), Duisburg (1972), and Essen (1972). Today, the Ruhr area is the largest university region in Germany (Kriegesmann et al. 2016). Appendix Figure A-5 shows that early industrializing regions indeed tend to have more universities today, especially larger ones with 7500 or more students. Consequently, we find that the number of students enrolled as a share of the population is higher in early industrialized regions in 2019, a finding that holds in all subjects (see Table A-6 in the Appendix).

Appendix Table A-7 confirms that early industrialized regions do not have a lower share of individuals with a university degree today (Columns (1)–(2)).[36] However, we find that

[34] Appendix Figure A-3 shows that early industrialization positively affected employment in industry only until 1970. After that, the effect becomes increasingly negative, consistent with earlier results for France (Franck and Galor 2021). The figure also shows that the negative effect on industrialization is accompanied by positive effects on employment in services. Appendix Figure A-4 shows that industrial employment peaks around 1970 for both regions with above- and below-median 1882 industrial employment shares. In fact, more than 70% of all labor market regions record their peak industrial employment share in 1970, and another 20% record their peak in 1961 or 1980 (the data points before or after 1970). However, the early industrializing regions experience much greater deindustrialization and have lower industrial employment shares today.

[35] The same holds for spending on schools. In 2020, 53.2% of total education spending was financed by the states, 11.8% by the federal government, 18.4% by local governments, and 16.4% by the private sector. The state's share of funding was particularly high at 78.4% for general education schools and 69.4% for university programs (Statistisches Bundesamt 2023).

[36] We use data on individuals with a university degree from the 1970 and 2011 censuses. Earlier censuses did not ask about educational attainment. The coefficient for 1970, during the university expansion, is negative and borderline significant. The coefficient estimate for 2011, after the expansion, is very close to zero. Note that the null effect of early industrialization on tertiary education may reflect two opposing forces: lower preference for, but better supply of, university education (we thank an anonymous reviewer for this suggestion).

Table 3 Early industrialization and adjustment pressure (2SLS estimates)

	Industrial employment share (%)				
	1950				2019
	Total	Coal, iron and steel	Modern industries	Other industries	Total
	(1)	(2)	(3)	(4)	(5)
Employment share industry 1882	0.074***	0.080***	– 0.004	– 0.002	– 0.059***
	(0.012)	(0.016)	(0.007)	(0.012)	(0.018)
	[0.013]	[0.016]	[0.005]	[0.010]	[0.016]
Outcome statistics					
Mean	0.310	0.032	0.060	0.218	0.287
Standard deviation	0.110	0.065	0.037	0.077	0.074

The table shows results from 2SLS regressions of the effect of early industrialization on employment shares in industry. The dependent variable is the total industrial employment shares in 1950 (Column (1)) and 2019 (Column (5)), and the 1950 shares in coal, iron, and steel (Column (2)), in "modern industries" (Column (3)), and in all other industries (Column (4)). Modern industries encompass mechanical engineering, road vehicle and aircraft construction, electrical engineering, precision mechanics, optics, the chemical industry, and plastics. The 1882 employment share in industry is standardized with a mean of zero and a standard deviation of one. All regressions include land accessibility and the number of towns per area in 1700 as control variables. Conley standard errors (Bartlett kernel, 100 km cut-off) are reported in round brackets; standard errors clustered at the level of administrative districts (*Regierungsbezirke*) in square brackets. ***, **, and * denote statistical significance at the 1%, 5%, and 10% level, respectively, based on Conley standard errors

early industrialization led to a lower share of individuals with secondary or vocational degrees (Columns (3)–(4)) and increased the share of school dropouts without a school-leaving qualification (Columns (5)–(6)). The effect magnitudes are economically relevant: A one standard deviation increase in early industrialization increased the share of high school dropouts in 2011 by 1.1 percentage points (compared to a mean of 4.5%), or almost one standard deviation.

Outside the old industrial regions, with their large-scale heavy industry, an extensive vocational and technical training system ensured a steady supply of skilled labor for small and medium-sized enterprises (Herrigel 2000). Consistent with this argument, we find that the employment share of industrial apprentices is much lower in early industrialized regions. A one standard deviation increase in early industrialization reduced the share of apprentices in industrial employment in 1970 by 1.9 percentage points relative to an average of 5.4% (see Column (1) of Appendix Table A-8). Vocational education and training, in turn, is an essential institutional prerequisite for the flexible production of diversified, high-quality products, often seen as the key to Germany's ability to adapt to rapid product and technological change (Streeck 1991; Herrigel 2000).

Large firms and the lack of smaller suppliers are seen as key factors dampening local entrepreneurship (Chinitz 1961; Glaeser and Kerr 2009; Glaeser et al. 2015; Stuetzer et al. 2016).[37] Consistent with this argument, Appendix Table A-8 shows that early industrializing regions had low entrepreneurial activity, as measured by self-employment rates,

[37] See, for instance, Glaeser and Kerr (2009) and more recently Barrios et al. (2021) for studies comparing different potential determinants of local entrepreneurial activity.

in 1950, just before the onset of the coal and later steel crisis. A one standard deviation increase in early industrialization led to a 3.9 percentage points decline in the self-employment rate in 1950 (Column (3)), relative to a mean of 16.8%. This result is consistent with earlier evidence in Fritsch and Wyrwich (2014) who show that already in 1925, self-employment rates were much lower in the Ruhr region, historically characterized by large-scale heavy industry, than in southwestern Germany. Such local differences in entrepreneurship were very persistent in Germany between 1925 and 2005, possibly testifying to the long-lasting impact of a local entrepreneurial culture.

Moreover, we also find that early industrialization led to a rigid policy environment with little political change (see Columns (4)–(6) of Appendix Table A-8). We find that in the old industrial regions, it was less likely that the mayoralty was held by a party other than the dominant one. Of the major parties, the social democratic SPD benefited most from early industrialization, both in local and federal elections. The SPD has traditionally represented the interests of the working class, especially unionized workers. Maintaining the heavily unionized coal and steel sector was in the interest of politicians and unions struggling to defend their political base. Overall, adherence to the existing economic structure was the consensual denominator of local action by companies, politicians, and unions (Junkernheinrich 1989; Grabher 1993).

Finally, Fig. 6 shows the impact of early industrialization on per capita patenting activity over time (taken from Bergeaud and Verluise 2024). Although the early industrialized regions were much more prosperous and more industrialized immediately after World War II, they did not have a head start in patenting activity. They then gradually fell behind the later industrialized regions. Today, a one standard deviation increase in industrial employment in 1882 is associated with a 17.5 percentiles lower rank in the per capita patent distribution. This result goes hand in hand with the deindustrialization effect reported earlier. Deindustrialization in historically industrial regions hinders local innovation, as patent applications are mainly filed in the industrial sector (Kiese 2019). Low levels of innovation, in turn, are likely to slow regional economic growth (e.g., Akcigit et al. 2017). Today, the value added per employee in the industrial sector is almost 20 percent higher than in the German economy as a whole.

5 North–South reversal and changing inequality

We conclude our analysis by exploring whether regional differences in nineteenth-century industrialization can explain two empirical patterns that have received much public attention: the widening economic gap between northern and southern Germany and the return of regional inequality in recent decades.

5.1 Germany's reversal of fortune

First, consider the growing North–South divide. The regions that lost ground in the income distribution between 1926 and 2019 are predominantly in the West and North, while the winning regions are predominantly in the South.[38] The North–South divide, which is the

[38] In fact, the declining labor markets in Fig. 1 (dots below the dotted bisector) are concentrated in northern Germany, while the rising labor markets (dots above the bisector) are concentrated in the south. Appendix Figure A-6 illustrates this fact by distinguishing between northern and southern labor markets in a plot of percentile rank in 2019 versus rank in 1926.

subject of current political debates (e.g., Schrader and Laaser 2019), has thus emerged over the last 100 years or so. How much of this divide can be attributed to differences in nineteenth-century industrialization?

Table 4 compares the actual gap with the predicted gap resulting from our main 2SLS estimates (in Table 1). Panel A measures the North–South gap as the average difference in percentile ranks between northern and southern regions.[39] The predicted gap is the average difference that would have resulted if the regions had differed only in their 1882 industrial employment share.[40] As shown, the actual mean difference evolves from +20.7 percentiles in 1926 to −18.2 percentiles in 2019. The mean difference in predicted income ranks follows a similar, though less pronounced, trajectory. Panel B reports average differences in (log) income per capita. While northern labor markets had, on average, 0.141 log points higher GDP per capita in 1957, they trailed southern labor markets by 0.098 log points in 2019 (recall that the 1926 value is not directly comparable to the 1957 and 2019 values when considering levels).

Our estimates imply that if the regions had differed only in the 1882 share of employment in industrial occupations, per capita income in 1957 would have been 10.0 percentile ranks or 0.085 log points higher in the North than in the South. This northern advantage in predicted income is due to the fact that the average industrial employment share in 1882 was much larger in the North than in the South (0.223 versus 0.158) and that early industrialization still had a positive effect on economic development in 1957. By 2019, the average differences in predicted income have become negative at −11.2 percentile ranks or −0.067 log points, reflecting the adverse effect of early industrialization on current development. A "back-of-the-envelope" calculation suggests that early industrialization explains about 62% (= 11.2/18.2) of the current North–South gap when the latter is measured in income ranks, and about 68% (= 0.067/0.098) when we use income levels instead. Thus, the blessing and curse of early industrialization contributed significantly to the North–South reversal. Today, after decades of industrial leadership, the North has a much smaller industrial base than the South (see Appendix Figure A-9 for trends in industrial employment shares over the period 1882–2019).

5.2 Regional inequality

Next, consider the decline and rise in regional inequality. How much of the overall change in inequality can be attributed to regional differences in early industrialization and its differential impact on economic development over time? To answer this question, we decompose the total change in inequality into an "industrialization effect" and a residual. We calculate the

[39] Our baseline definition of northern labor markets adheres to state boundaries. It classifies as northern the labor markets located in Bremen, Hamburg, Lower Saxony, North Rhine-Westphalia, and Schleswig-Holstein. Southern labor markets are those in Bavaria, Baden-Württemberg, Hesse, and Rhineland-Palatinate (see Appendix Figure A-7 for an illustration). Appendix Figure A-8 shows that the reversal of fortune does not hinge on this specific classification. It remains visible if we also assign the northern parts of Hesse and Rhineland-Palatinate to the North or if we use latitude as a continuous measure to divide labor markets into northern and southern ones.

[40] We first use the 2SLS estimate of β_t in Eq. (2) to predict each labor market's income rank, given its 1882 industrial employment share. We then estimate the slope coefficient $\tilde{\beta}_t$ from a regression of the *predicted* income rank on N_i, where N_i equals one if labor market i is in the North and zero otherwise. The estimate yields the mean difference in the predicted GDP per capita rank between the northern and southern labor markets.

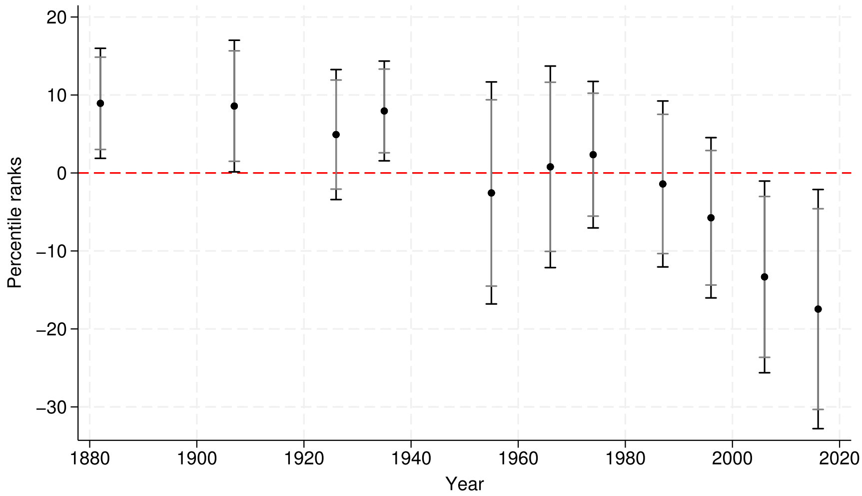

Fig. 6 Impact of early industrialization on the rank in the patent per capita distribution, 1882–2016. *Notes* The figure plots slope coefficients from 2SLS estimations of patents per capita on early industrialization. The dependent variable is the percentile rank in the patent per capita distribution. Point estimates are marked by a dot. The vertical bands in gray and black indicate 90% and 95% confidence intervals, respectively. The 1882 employment share in industry, our explanatory variable of interest, is standardized with a mean of zero and a standard deviation of one

industrialization effect as the difference between observed changes in inequality and the counterfactual change in inequality that would have occurred in the absence of differences in early industrialization. The industrialization effect thus measures the contribution of differences in

Table 4 Mean differences in per capita income between northern and southern labor markets

	1926 (1)	1957 (2)	2019 (3)
Panel A. Income per capita rank			
Actual mean difference	20.67	15.31	− 18.24
	(5.23)	(7.33)	(5.47)
Predicted mean difference	7.70	9.95	− 11.23
	(3.97)	(5.13)	(5.78)
Panel B. Log income per capita			
Actual mean difference	0.300	0.141	− 0.098
	(0.074)	(0.058)	(0.034)
Predicted mean difference	0.100	0.085	− 0.067
	(0.052)	(0.044)	(0.035)

The table reports actual and predicted mean differences in per capita income ranks (Panel A) and log income (Panel B) between northern and southern labor markets in 1926 (Column (1)), 1957 (Column (2)), and 2019 (Column (3)). The actual and predicted mean differences are the slope coefficients from a regression of actual and predicted income, respectively, on an indicator variable for northern labor markets. We calculate predicted income as $\hat{\beta}_t I_{i,1882}$. Income in 1926 is proxied by sales per capita, income in 1957 and 2019 are based on GDP per capita. Conley standard errors (Bartlett kernel, 100 km cutoff) are reported in round brackets early industrialization to the change in regional inequality. Following the literature on sigma-convergence within countries (e.g. Sala-i Martin 1996; Persson 1997; Young et al. 2008), we use the unweighted standard deviation of log GDP per capita as our baseline measure of income dispersion. Yet, our results are robust to alternative measures, as we show below.[41]

Let y^c_{it} denote the counterfactual log income per capita of a labor market i in year t, i.e., the income that would result if the 1882 share of industrial employment had been equal to the mean across all labor markets.[42] For the period $t-1$ to t, the contribution of the industrialization effect to the total change in σ_{y_t}, the standard deviation of log income per capita, is given by:

$$\begin{aligned}\Delta IND_{t,t-1} &= \overbrace{\left[\sigma_{y_t} - \sigma_{y_{t-1}}\right]}^{\text{Actual change}} - \overbrace{\left[\sigma_{y^c_t} - \sigma_{y^c_{t-1}}\right]}^{\text{Counterfactual change}} \\ &= \underbrace{\left[\sigma_{y_t} - \sigma_{y^c_t}\right]}_{\text{Effect on } \sigma \text{ in } t} - \underbrace{\left[\sigma_{y_{t-1}} - \sigma_{y^c_{t-1}}\right]}_{\text{Effect on } \sigma \text{ in } t-1}.\end{aligned} \tag{4}$$

The second line of Eq. (4) shows that $\Delta IND_{t,t-1}$ also reflects the difference in the within-year effect of early industrialization on inequality.

Table 5 reports σ_{y_t} and $\sigma_{y^c_t}$ for 1957, 1980, and 2019 and the changes in 1957–1980, 1980–2019, and 1957–2019. The first key observation is that the waning effect of early industrialization explains much of the decline in σ between 1957 and 1980. In 1957, regional differences in early industrialization increased the dispersion of real per capita income by 0.054 log points (the difference between $\sigma_{y_{1957}}$ and $\sigma_{y^c_{1957}}$ reported in the last row). By 1980, however, this effect had vanished,[43] since early industrialization no longer has a sizeable effect on economic disparity in this year (see Fig. 5). Overall, the industrialization effect explains −0.054 log points—or almost three-quarter—of the actual change in σ of − 0.073 over the 1957–1980 period.

The second key result from Table 5 is that the industrialization effect cannot explain the increase in regional inequality since 1980. The changes in σ_{y_t} and $\sigma_{y^c_t}$ move largely in parallel over the 1980–2019 period. Thus, the increase in regional inequality would have occurred even if regions had not differed in their industrialization paths. If anything, regional differences in early industrialization dampened the increase by reducing current inequality. We find that differences in early industrialization reduced the dispersion of real per capita income by 0.021 log points in 2019. Because labor markets with higher counterfactual per capita income tend to have a higher 1882 industrial employment share, a

[41] We use unweighted inequality measures because we are interested in inequalities between spatial units (within a country). Instead, population-weighted measures can be interpreted as measures of inequality between groups, where people are grouped according to where they live (Achten and Lessmann 2020). First proposed by Williamson (1965), population-weighted measures are often used to compare inequality between countries with regions of different sizes.

[42] The standardized industrial employment share, $I_{i,1882}$, is then zero. We calculate the counterfactual log income per capita as $y^c_{it} = y_{it} - \hat{\beta}_t I_{i,1882}$ where $\hat{\beta}_t$ is the 2SLS estimate from the regression model (2) (with log income per capita as the dependent variable).

[43] Earlier work for Germany documented that industrialization increased inequality in the late nineteenth century (see, e.g., Frank 1993; Gutberlet 2014; Braun and Franke 2022). Together with our results, these findings are consistent with the argument that regional disparities first increase, then stabilize, and finally decrease as industrialization progresses (Kuznets 1955).

moderately negative effect of early industrialization on economic development compresses the regional income distribution in our specific context.

Appendix Table A-9 shows that both of our main results also hold when we use the coefficient of variation, the Gini coefficient, and the ratio of per capita income in the labor market at the 90th percentile to that at the 10th percentile as alternative measures of regional inequality. The 90/10 ratio yields even more pronounced results than our baseline measure, with the dwindling effect of industrialization now explaining all of the decline in regional inequality between 1957 and 1980. Finally, Appendix Table A-10 shows that our results are also robust to an alternative decomposition that isolates the change in inequality due to changes in β_t, the effect of early industrialization on income. Under this alternative decomposition, we again find that all of the decline in regional inequality between 1957 and 1980 is explained by the diminishing effect of industrialization—as captured by the decline in β_t.

6 Conclusion

In recent decades, the spatial distribution of economic activity has changed fundamentally in many advanced countries. Germany is no exception. The former industrial powerhouses in the northwest of the country began their long and protracted decline after World War II. While regional per capita incomes converged strongly in the 1960s and 1970s, regional inequality in West Germany has increased again in recent decades. Such protracted decline and rising regional inequality are often seen as causes of populism in Europe and the US (Rodríguez-Pose et al. 2023).

This paper has shown that the profound changes in the economic geography of West Germany cannot be understood without taking into account the long-lasting legacy of regional differences in nineteenth-century industrialization. Early industrialization still strongly favored regional economic development in 1957. However, the positive effect diminished between 1957 and 1980, and industrialization became a drag on economic development at the turn of the twenty-first century. For identification, we exploit variation in access to coal resources in Europe, while controlling for connectedness to European markets. A one standard deviation increase in coal-based industrialization improved the rank of a labor market in the West German income distribution by 15.8 percentiles in 1957 but reduced the rank by 17.8 percentiles in 2019. Thus, early industrialization led to a massive decline in per capita income rank after World War II.

The initial blessing and later curse of early industrialization strongly influenced key trends in regional inequality. We show that the declining advantage of early industrializing regions significantly reduced regional inequality between 1957 and 1980. Moreover, the North–South divide that has emerged in the last forty years cannot be understood without recourse to regions' paths to industrialization 140 years ago. Our estimates suggest that differences in early industrialization can explain more than half of the current North–South gap.

Our results have important implications for the policy discourse on regional inequality and economic decline. First, they illustrate that the interpretation of contemporary changes in regional inequality, which have received much attention recently (Iammarino et al. 2018; Floerkemeier et al. 2021), requires careful consideration of the past. Not only do development processes have lasting effects, but they can also lead to future changes. Second, our results show that initial gains from industrialization may come at the expense of long-run losses (see also Matheis 2016; Franck and Galor 2021). This intertemporal trade-off raises the question

Table 5 Components of changes in regional per capita income disparity, 1957–2019

	1957 (1)	1980 (2)	2019 (3)	1957–1980 (2)–(1)	1980–2019 (3)–(2)	1957–2019 (3)–(1)
σ_{y_t}	0.234	0.162	0.191	− 0.073	0.029	− 0.043
$\sigma_{y_t^c}$	0.181	0.162	0.212	− 0.019	0.050	0.032
Δ	0.054	− 0.000	− 0.021	− 0.054	− 0.021	− 0.075
	(0.009)	(0.008)	(0.012)	(0.009)	(0.008)	(0.013)

The table reports σ_{y_t} and $\sigma_{y_t^c}$, the standard deviation of actual and counterfactual log per capita income, for 1957 (Column (1)), 1980 (Column (2)), and 2019 (Column (3)). The last row reports $\sigma_{y_t} - \sigma_{y_t^c}$, i.e., the effect of early industrialization on GDP per capita dispersion in year *t*. The last three columns report changes between 1957–1980, 1980–2019, and 1957–2019, respectively. Bootstrapped standard errors based on 200 bootstrap replications are in round brackets

of whether policy interventions can prevent adverse effects in the long run. Indeed, Germany has managed to avoid the shortage of university graduates in early industrialized regions observed elsewhere in Europe (Esposito and Abramson 2021), presumably by establishing new universities in its former industrial heartland. Third, our results suggest that early industrialization favored long-term economic decline by creating a lopsided economic structure dominated by large firms in a few heavy industries. This finding aligns well with prior results for the U.S. and Great Britain that the historical presence of large firms hinders entrepreneurship and growth (Chinitz 1961; Glaeser et al. 2015; Stuetzer et al. 2016). A more diversified economic structure—as in the Italian industrial triangle of Piedmont, Lombardy, and Liguria (Fenoaltea 2003)—could thus avoid the negative long-term effects of industrialization in the first place. After all, Italy's old industrial triangle still generates above-average GDP per capita (e.g. Felice 2018), in stark contrast to Germany's old industrial heartland.

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Declarations

Competing interests The authors declare that they have no competing interests.

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