Fickle Fossils. Economic Growth, Coal and the European Oil Invasion, 1900-2015*

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Abstract

Fossil fuels have shaped the European economy since the industrial revolution. We use new long-run panel data to analyse the effect of both, coal and oil on economic growth between 1900 and 2015, exploiting variation at the level of European NUTS2 and NUTS3 regions. We show that the reversal of fortune of coal regions resulted from the second energy transition. Specifically, an "oil invasion" in the early 1960s turned regional coal abundance from a blessing into a curse. Human capital accumulation contributed to this reversal of fortune and fully explains the negative effects until today. Moreover, we find substantial heterogeneity between former coal regions that is in line with Glaeser's "reinvention hypothesis": regions with a higher skill-level adjusted much better to the decline of coal. In particular, we show that coal regions with a higher urban density before 1800 were much more resilient than others.

JEL Classification: O13, O44, Q32, N14, R10, I25
Keywords: Coal, Oil Invasion, Second Energy Transition, Education, Reinvention, Growth

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1 Introduction

Are natural resources a "fundamental" driver of economic growth? Economists have long struggled to understand how geographic characteristics matter for economic growth, notably, why the same type of resources sometimes appear as a blessing and sometimes as a curse. A prominent example is the role of coal for the European economy. As shown by Fernihough and O'Rourke (2020), coal abundance caused some regions to grow faster than others from about 1800 onward. Yet, in recent decades, coal abundance has turned into a curse (Esposito and Abramson (2021)).

Figure 1 uses the data from Rosés and Wolf (2021) to illustrate how the reversal of fortune of European coal regions[1] took place. The figure shows, at the level of NUTS 2[2], the difference in GDP per capita (in logs) between coal and non-coal regions in roughly ten-year intervals over the last century. From the beginning of the 20$^{\text{th}}$ century to the end of World War II coal regions display a higher GDP per capita compared to all other regions. Starting in the 1960s this pattern is reversed as now regions without coal resources overtake the coal producing regions. Moreover, this change is surprisingly persistent. Former coal regions do not seem to recover, but instead are further falling behind.

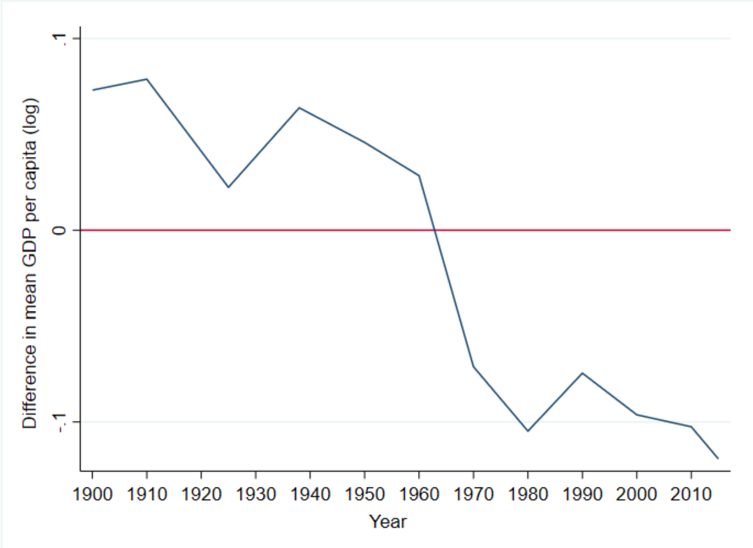
In this paper we want to answer two related questions. First, what can explain this reversal? What factors turned coal abundance from a blessing to a curse for European regions? And second, what mechanisms prevented coal regions from adjusting to this shock in the past 50 years until today? To answer these questions, we construct new panel data on GDP, population, employment, resource endowments and education covering five European countries (Belgium, France, West-Germany, the Netherlands, and the UK) at the level of NUTS 2 and NUTS 3 regions from 1900 to 2015.

Regarding the first question, we proceed in several steps. We first use a simple difference-in-difference approach with a flexible (i.e. time-varying) treatment and controls to show how growth in real GDP per capita differed between regions with and without coal. We find a positive (but not significant) difference from 1900 until about 1960, and a strongly significant negative difference thereafter. In a next step we estimate the average causal treatment effect of coal after 1960 by pooling all years in a pre-treamtent and post-treatment period using carboniferous strata as an instrument. With this, we find that coal regions experienced 20 % less growth after 1960 than non coal regions. In a third step, we show that this was a consequence of the "second energy transition" (Kander, Malanima, and Warde (2013)). Specifically, the influx of very cheap oil, mostly from Northern Africa

[1] We define "coal region" as a region with at least on active coalfield in 1921. This overlaps very strongly with alternative definitions such as the share of land area covered by carboniferous strata, or the share of coal mining employment in 1900.

[2] NUTS stands for the European Nomenclature of territorial units for statistics. It is a hierarchical system for dividing up the economic territory of the EU and the UK.

Figure 1: The Reversal of Fortune. Coal vs. Non-Coal Regions, 1900 - 2015 at NUTS2



Notes: Differences in log GDP per capita between coal regions (defined as regions that have a share larger than zero of land area covered by coalfields as of 1921) and non-coal regions (defined as regions that have no land areas covered by coalfields as of 1921). Sources see text.

which started in the late 1950s, can explain this reversal to a large extent. This "oil invasion" caused a negative labor demand shock in mining, which in turn led to the decline in GDP per capita. We measure the decline in mining employment as the share of total employment in a region between 1960 and 1970 and then instrument for this exploiting the exogenous variation from national level oil imports weighted with a region's share in national carboniferous strata. Our results suggest that this "oil shock" can explain up to 40 % of the decline in growth rates in coal regions relative to non coal. We also show that this shock was extremely persistent, which leads us to our second question.

Why did regions fail to adjust to the "oil invasion", even half a century later? Our basic hypothesis is about human capital, more specifically about rates of human capital accumulation in coal regions after 1960 that were too low compared to non coal regions. To show this, we again exploit our new panel data and proceed in several steps. We first show how coal had a causal effect on underachievement in terms of tertiary education in coal regions. Next, we test whether this can be seen as an indirect effect of coal on GDP per capita growth, using a mediation analysis. In fact, we can show that nearly all of the negative effect of coal on economic development in recent decades occurred due to this indirect effect via low attainment in tertiary education. In the final part of the paper, we place these findings into the bigger picture of European development since 1700, and focus on the heterogeneity of effects within our sample of coal regions. Here we show that coal regions with a higher density of cities before the onset of the industrial revolution were more capable to adjust to the decline of coal.

We see our paper as related to two broad strands in the literature. To start with, many contributions have explored the role of natural resources for economic growth, including Cordon and Neary (1982), Sachs and Warner (2001), Papyrakis and Gerlagh (2007), Matheis (2016) on the US, and Kander, Malanima, and Warde (2013) on Europe in the long-run. More recently Fernihough and O'Rourke (2020) have documented that European industrialization was strongly linked to the access to cheap energy provided by coal abundance. They show that proximity to coalfields had a strong causal *positive* effect on subsequent growth patterns of European cities, in line with a large literature on the European industrialization (e.g. Pollard (1981)). In contrast, several other papers document a detrimental effect of coal on levels of economic development and growth at the level of European regions in more recent decades. Esposito and Abramson (2021) show for one cross-section of European NUTS 2 regions as of 2010 that proximity to coal had a strong and causal negative effect on GDP per capita. Berbée, Braun, and Franke (2022) show for German labor market regions, how early industrialization turned from an advantage to a burden between 1926 and 2019, and exploit access to coal as an instrument. Related, Rosés and Wolf (2021) document how from 1950 onward, proximity to coalfields increasingly limited convergence between European regions. Our contribution to this literature is twofold. We use long-term regional GDP per capita data as well as newly collected data on human capital to estimate the changing causal effect of coal in a panel from 1900 until 2015. First of all, this panel data allows us to deal with omitted variable bias at the regional level. More importantly, we document that the switch from a positive to a negative effect of coal occurred around 1960. That switch in sign can, to a large extent, be explained by the "oil invasion" that started in the late 1950s. We show that the decline in mining, driven by the rise of cheap oil imports since the late 1950s, had a strong causal effect on GDP per capita. This speaks to the literature on long-run energy transitions (Kander, Malanima, and Warde (2013)). To the best of our knowledge, we are the first to show that the second energy transition had an important regional dimension.

We relate to a second strand of literature, which analyzes the pattern and causes of regional inequality in the long-run, including the role of human capital. Autor, Dorn, and Hanson (2013), Storper (2018), Iammarino, Rodriguez-Pose, and Storper (2018), Rosés and Wolf (2018), and others have documented the increase in regional disparities for the US, Europe, and other parts of the world, notably from the 1980s onward. Several authors have suggested that human capital might play an important role in this process, including Gylfason (2001), Glaeser, Saiz, et al. (2004), Glaeser, S. Kerr, and W. Kerr (2015) and Gennaioli et al. (2013). We add to this literature by stressing the particular role of former coal regions in contributing to these disparities. While coal abundance had fostered population and income growth in many formerly poor regions during the industrialization in 19^{th} century, we show how it caused regions to fall behind, starting in the 1960s. We use a mediation analysis, following Pinto et al. (2019), and find that about 90% of the negative effect of coal on income today is explained by (low) attainment in tertiary education. We assembled new panel data on human capital at the NUTS3 level to show that the human capital channel gained importance over time. After one decade the direct negative effect of coal abundance is vanishing and an increasing proportion of the overall effect can be explained by the mediator. Moreover, we can show that this is both due to the inability of former coal regions to accumulate human capital over time and the increasing importance of human capital for explaining economic prosperity. We therefore add to the findings of Esposito and Abramson (2021) who have shown before for a cross-section of European regions that former coal regions display both lower human capital levels and lower GDP per capita as of 2010. They attribute this lower human capital endowment to underinvestment in educational infrastructure, such as universities. Franck and Galor (2021) show for French regions that early industrialization harms economic development in the long-run due the adaption of unskilled-intensive technologies during industrialization. Our paper points at the importance of yet another channel for explaining the lack of human capital accumulation in former coal regions that pre-dates industrialization and is linked to the urban history of places. The industrialization of European regions is to a large extent driven by first nature geography, notably access to coal. The discovery of coal resources therefore sparked rapid urban and economic growth in both places with and without pre-existing major urban structures. Yet, from a long-run perspective, the growth of cities built on the green field did not turn out to be sustainable. Once the initial natural advantage disappeared, they experienced persistent decline. Exploiting the heterogeneity across coal regions, we find that the failure to accumulate human capital and therefore the inability to recover is driven by coal regions without major pre-industrial urban settlements. Pre-industrial urban success entails a persistently higher sectoral diversity and most importantly, a higher stock in human or entrepreneurial capital. These qualities can be activated in times of structural change to attract new industries. Our paper therefore speaks to the "reinvention city hypothesis" as proposed Glaeser, Saiz, et al. (2004), stating that places, which had to reinvent themselves repeatedly in history became more resilient over time.

The remainder of our paper is organized in four sections. In section 2 we discuss our data and provide descriptive evidence on the reversal of fortune for European coal regions. In section 3, we explain this development by the "oil invasion" of the 1960s. In section 4 we discuss the remarkable persistence of this oil shock and show that human capital played a central role in both, the short-run and the very long-run. We conclude in section 5.

2 Data and descriptive evidence

The key variables of our study are coal, employment, GDP per capita, and human capital. Our unit of observation are NUTS regions for five Western European countries (specifically

NUTS 2 for developments 1900 - 2015, and NUTS 3 for developments 1950 - 2010), which allows us to exploit variation between and within countries over more than a century.

Let us start with our main explanatory variable, coal. To capture a region's "abundance" in coal, we rely on historical as well as geological sources. First, the location and size for historical coalfields (as of 1921) are derived from the detailed maps of Les Houillères Européennes by Châtel and Dollfus (1931). With this, we calculate the share of a region's land area covered by coalfields as of 1921 to define "(former) coal regions". We focus on the major coal producing countries in Western Europe, namely the UK, West-Germany, Belgium, France, and the Netherlands. We exclude all regions that were part of the former German Democratic Republic to avoid confounding effects of the iron curtain and its fall.[3]

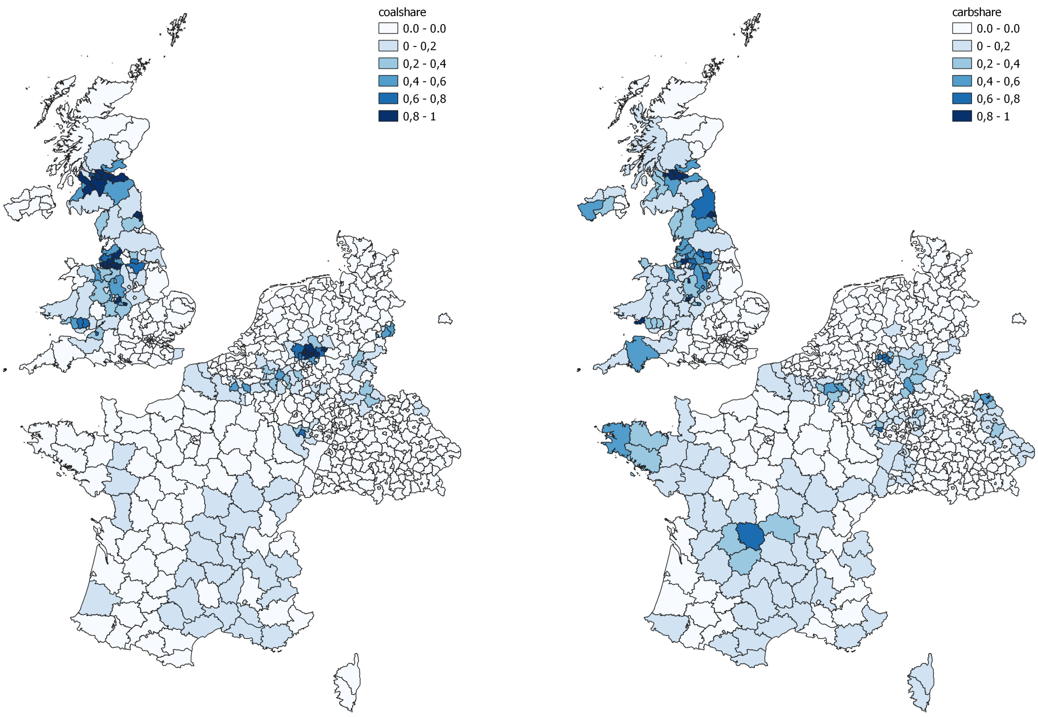
The existence of coalfields is the endogenous result of previous large-scale investment decisions. To capture variation in their location that is exogenous to previous economic activity we follow Fernihough and O'Rourke (2020) and measure carboniferous "coal-bearing" rock strata, which are the geological prerequisite for coal mining activity.[4] The geological map provided by the German Federal Institute for Geosciences and Natural Resources (BGR) is generally used to derive information about below-surface geological information. However, this source only discloses the age and type of the upper rock layer.

Figure 2 compares the coal abundance of each region as measured by the (possibly endogenous) share of land area covered by coalfields (panel 2a) to the share of land with carboniferous strata (panel 2b). There are some regions such as Recklinghausen, Gelsenkirchen, and Bottrop in the northern part of the Ruhr mining area that have a negligible share of carboniferous strata but very large coalfields (and considerable mining employment). In these cases, the carboniferous strata are located below the upper surface and are therefore not covered by the standard source (Asch (2003)). In other cases the opposite is true. There are regions such as Corse that have a large share of their total area covered by carboniferous strata but no existing coalfields in 1921. There might be several reasons why - despite the existence of carboniferous strata - no substantial mining activity can be observed. One important factor is accessibility, which varies with regional topography. To account for this, we exclude all carboniferous strata that is covered by mountain massifs. Data on mountain massifs is provided by Kapos et al. (2000) via the European Environmental Agency and is defined according to a combination of criteria concerning the altitude, ruggedness and slopes of the surfaces. Figure 3 shows at the level of NUTS 3 the correlation between the percentage share of land covered by historical coalfield ("coalshare") and the percentage of land area covered by carboniferous

[3]Furthermore, there has never been any economic activity in hard coal mining in the GDR, only in lignite (or brown coal) mining.

[4]In the following coal mining is used synonymous to Anthracite or hard coal mining as well Bituminous coal

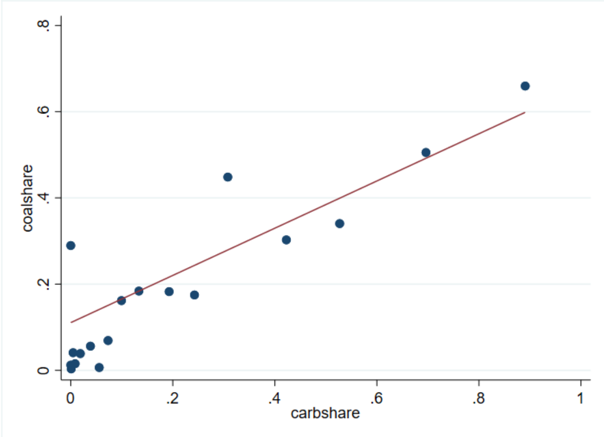
Figure 2: Coal abundance in European Regions



(a) % share covered by coalfields (b) % share covered by carboniferous strata

Notes: Panel a) depicts the share of land area covered by coalfields (Source: Own measurement based on digitized maps from Châtel and Dollfus (1931). Panel b) shows the share of accessible land area covered by carboniferous strata. (Source: Own measurement based on maps from Asch (2003) and Kapos et al. (2000).

Figure 3: Correlation coal measures



Notes: Binned scatterplot of the bivariate relationship between the percentage share of land covered by historical coalfields ("coalshare") and the percentage of land area covered by carboniferous strata at the level of NUTS 3 regions. Sources see text.

strata excluding mountain massifs ("carbshare"). The coefficient of correlation between the two measures is 0.56. The correlation is equally strong at the NUTS2 level (compare figure A1). Further below we will show that "carbshare" is indeed a strong instrument for "coalshare".

In section 3.2 we modify our explanatory variable to directly model the labour demand shock caused by the increase in the availability of cheap oil imports coming from the Middle East. To capture the decline in mining jobs, we collected regional mining employment in 1900 and for every decade between 1950 to 2010 based on the occupation and population census data of each country at the level of NUTS3. To construct the share of people employed in mining, we also collected aggregate employment from the same sources. There is a high correlation between "coalshare" and the share of people employed in mining in 1900 and still in 1960, before European coal mining started its long decline (see figure A2). Data on overall import quantities of crude oil as well as quantities imported from each partner country for (West-)Germany, Belgium, France, and the Netherlands are taken from various issues of the yearbook Energy Statistics, published first by Statistical Office of the European Communities (1950-1975) between 1950 and 1975, and later by Eurostat and Europäische Kommission (1984-1997). For the UK, we derive the same information based on data provided by the Energy Security & Net Zero (n.d.) To analyze the relationship between a region's coal abundance and economic development we use two data sets. For evidence on the long-run, we employ the new data set by Rosés and Wolf (2021).[5] This data provides estimates for GDP (in 2011 International Dollars), employment, population, and population density at the NUTS 1 and NUTS 2 level for ten-year intervals spanning the period from 1900 to 2015. While we lose some regional variation at this higher aggregation level, this has the advantage of absorbing small scale

[5]This extends the data by Roses and Wolf (2019), including some corrections. It is available at `https://cepr.org/node/424487`

spatial interdependence, notably for labor markets that often encompass several NUTS3 regions. In addition, we use GDP and population data at the NUTS 3 level from the ARDECO database (n.d.), formerly published by Cambridge Econometrics. GDP data at this level of dis-aggregation for all five countries is only available from 1980 onward.

We describe the evolution of human capital using the share of the population aged 15 and above that has completed tertiary education (obtained a post-secondary degree), comparable to Glaeser, Saiz, et al. (2004). For this, we collect and digitize census data and published aggregate statistics by the statistical offices of the respective countries. Census data for Belgium and the UK is published every ten years, for France census data is published every six years. In contrast, the German census was only conducted in 1950, 1961 and 1970, 1987 and 2011. For the missing data in 2000, we rely on data imputation assuming a local, linear trend. Since regional boundaries change over time, we harmonized the census data for each country by re-estimating aggregate data in current boundaries using a combination of area and population weights (for an explanation of this procedure and more details see the Data Appendix). Since for most countries educational attainment was not covered by the census questionnaires before 1970, we proxy educational attainment in earlier decades using information about the location and foundation date of universities as published by The European Tertiary Education Register (n.d.)

As further controls, we also collected data on first and second nature variables, namely mean temperature, rainfall, crop quality, distance to the coastline, landshare covered by mountain areas, distance to the next harbour, dummies for whether a region includes the capital or a metropolitan region, as well as past and current population densities. To further explain potential heterogeneity across the coal regions, we measure the urban density in 1700, before industrialization. The Clio-Infra database on urban settlement sizes by Buringh (n.d.) provides the population size and geo-location of European cities between 1500-2000. We aggregated urban population of all cities that fall within the current NUTS3 boundaries to get a measure for the overall pre-industrial urban population density of a region. To capture the industry mix and population density of regions in the pre-shock period in 1960 at the NUTS3 level, we collected and digitized additional census data. Based on the employment share across six different industries we construct a Herfindahl-Index (for further details see Data Appendix).

In figure 4 we provide some descriptive evidence for coal regions and other regions for the main variables of interest. In line with our evidence on GDP per capita, shown above (figure 1) we see that in 1900 coal regions used to have a higher share of manufacturing in total employment compared to non-coal regions. This share continued to increase in the first decades after 1945, before it started a steep decline (see figure 4a). The share of mining in total employment in coal regions (figure 4b) stayed roughly stable between 1900 and 1950, but declined strongly between 1950 and 1970. The decline slowed down during the well-known oil crises of the 1970s, but continued thereafter until mining became a negligible part of total employment. It is remarkable that the first large decline in European mining employment occurred during the "golden age of growth", when the demand for energy in Western Europe was strongly increasing as shown by Malanima (2021). While labor productivity in mining was increasing, this is unlikely to be the main factor behind the reduction in employment. Rather, mining employment declined due to competition from cheap imported oil as a substitute (see Pfister (2010)). We will explore the role of oil imports in some detail further below. Moreover, we compare the evolution of human capital formation for coal and non-coal regions for NUTS 2 regions (see figure 4c). Due to the educational expansion starting in the 1970s, educational attainment grew rapidly. As a result, variation in terms of primary and secondary education across European regions became negligible, which is why we focus on tertiary education. The average share of the workforce which completed tertiary education in our sample was 23 percent in 2010, about five times the share in 1970. Our figure 4c shows that former coal producing regions were not different to other regions in 1970, when our data begins. But they were rapidly falling behind, due to a lower increase in human capital over time. This suggests that the failure to accumulate human capital in former coal regions might help to explain, why their decline in GDP per capita was so persistent.[6] Finally, we show in figure 4d that coal regions had a somewhat higher population density compared to others between 1900 and 1960, but lost this lead in the wake of the second energy transition.

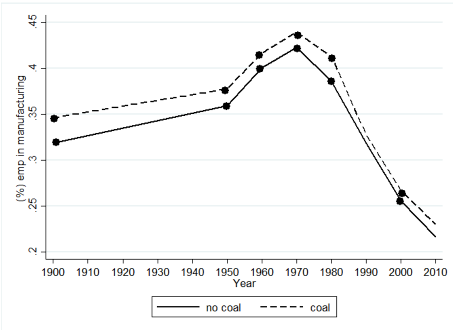
Table A 1 in the Appendix provides further descriptive statistics for coal regions and regions without coal at NUTS2 and NUTS3. While in 1950 the average level of GDP per capita was still higher in coal regions than in non-coal regions, we see how coal regions were falling behind thereafter. If we consider educational attainment, where our data starts later, we see how coal regions fail to catch up and continue to fall behind non-coal regions between 1980 and 2010. In this case, it is important to take country-specific differences in terms of definition and institutional structure into account. If we normalize by respective country means, so that we only compare coal and non-coal regions within a country, we see that the differences are clearly getting more pronounced over time. In our panel analysis below we always include country fixed effects.

To summarize, our descriptive evidence suggests that it was around 1960 that coal abundance turned from being a blessing into a curse, as reflected in the development of GDP per capita, and mining employment. In the next section, we formally test for the changing causal effect of coal abundance on income and suggest an new explanation for this reversal of fortune.

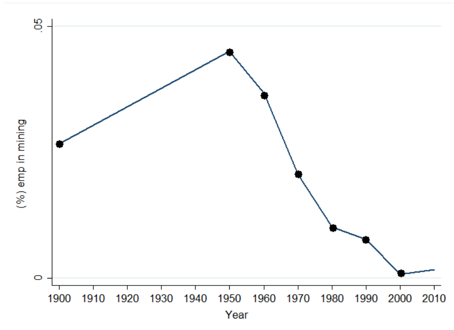
[6]Note that figure 4c ignores differences in education systems and definitions between countries. Once we take them into account (as we will do throughout our empirical analysis using country effects), the educational gap between coal and non coal regions becomes even more pronounced.

Figure 4: Descriptive statistics

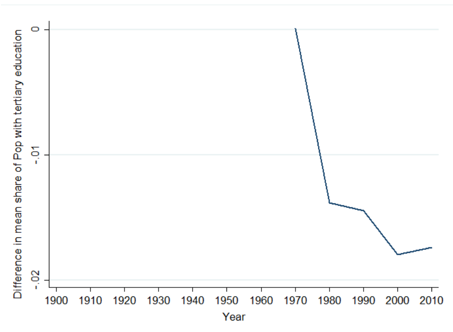
(a) Share Manufacturing Employment



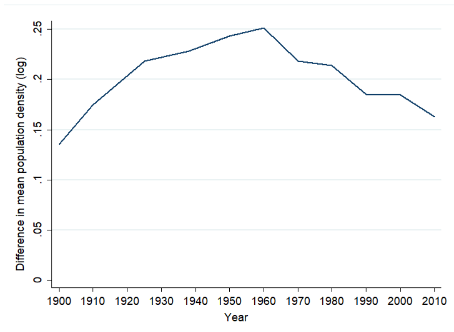
(b) Share Mining Employment



(c) Share Tertiary Education



(d) Population Density



Notes: Panel (a) shows the the evolution of the manufacturing employment share outside of mining for coal and non coal regions. Panel (b) shows the number of jobs in mining normalized by total employment in 1960 for all coal regions. Panel (c) shows the difference in the share of the population with tertiary education between non coal regions and coal regions. Panel (d) shows the difference in log population density between non coal regions and coal regions. Coal regions are here defined as regions with a coalshare larger then 5 percent (27 out of 82 regions). All data refers to the NUTS2 level. Sources see text.

3 From blessing to curse: how the "oil invasion" caused the decline of coal

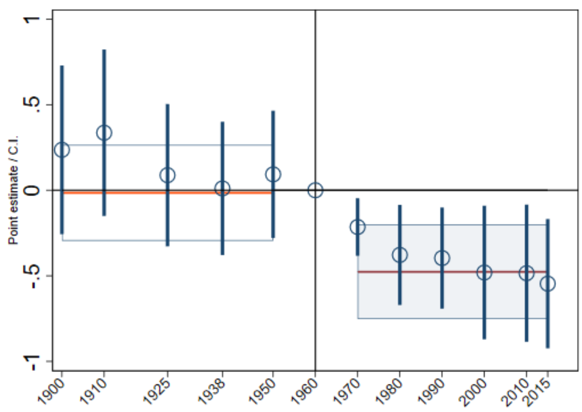
3.1 The reversal of fortune, 1900 - 2015

To identify the effect of coal abundance on economic development more formally we start with a difference-in-difference approach with a time-varying and continuous treatment.[7] At this stage, we want to be agnostic about the exact timing of the treatment. In analogy to Fernihough and O'Rourke (2020) we interpret the treatment as the changing availability of substitutes for coal. We estimate:

$$Y_{it} = \alpha_i + \gamma_t + \delta_{jt} + \sum_{t=1900}^{2015} \beta_{1t} * coalshare * I_t + \sum_{t=1900}^{2015} \beta_{2t} * X_i * I_t + \epsilon_{it} \quad (1)$$

The dependent variable is GDP per capita from our long-run data at the NUTS2-level. The explanatory variable of interest is the share of each region's area covered by a coalfield in 1921 (coalshare) interacted with a time dummy (I). In each specification we use observation fixed effects α_i for each region i, time fixed effects γ_t for each decade, time-varying country effects δ_{jt} for each country j and the full set of controls X_i interacted with decadal dummies. Controls include all first and second nature geographical variables, population density and the employment share in manufacturing, both fixed to their pre-shock level in 1960.

Figure 5: The effect of coal abundance on GDP per capita (time-varying treatment effect).



Notes: Notes: N= 960 ; This figure reports the OLS coefficient estimates for β_{1t} in (1) and 95% confidence intervals for these estimates. Control variables include the time interactions of the employment share in manufacturing in 1960, population density 1960 and the set of first and second nature geographical controls as specified in the text. Coal abundance is measured as the percentage of land area covered by coalfields. All specifications include observation, time and time-varying country fixed effects. Standard errors are clustered at the level of observation (NUTS 2).

Figure 5 shows the result, with 1960 as the omitted category. The coefficient on coalshare relative to this reference is in 1900 and 1910 positive, drops in the interwar

[7] Note that our panel data allows us to control for region fixed effects and to discuss changes in GDP per capita between 1900 and 2015. This is in contrast to Esposito and Abramson (2021), who consider one cross-section as of 2010.

period, seems to recover in 1950, but is never significant. After 1960 we observe that the effect declines and becomes significantly negative throughout. Hence, similar to our descriptive evidence above, we find that coal turned from blessing to curse around 1960. This evidence is quite robust, including region fixed effects and a rich set of time-varying controls. Based on this evidence, we next use 1960 as a fixed treatment date and estimate the following equation:

$$Y_{it} = \alpha_i + \gamma_t + \delta_{jt} + \beta_1 * coalshare * I_{Post1960} + \sum_{t=1900}^{2015} \beta_{2t} * X_i * I_t + \epsilon_{it} \qquad (2)$$

Again, we add fixed effects for each region α_i, time fixed effects γ_t, country-year effects δ_{jt}, and the full set of controls X_i each interacted with decadal dummies. In this specification we focus on $coalshare * I_{Post1960}$, the interaction between the share of land area covered by coalfields (coalshare) and a dummy for decades after 1960.

In order to pin down the effect causally, we need an instrument. Regions that started to engage in coal mining activity in the 18$^{\text{th}}$ and 19$^{\text{th}}$ century are not likely to be randomly selected. The demand for coal was probably higher in more urban and densely populated areas. Due to high transport costs, coal production might have been located closer to pre-industrial urban agglomerations. Also, innovation itself was conducive to industrialization and productivity growth which additionally increased the demand for coal (compare Allen (2012)). In the presence of (unobserved) regional characteristics that were favourable to the specialization into coal production at the beginning of the industrial revolution and which are still affecting current economic development, a simple OLS regression will suffer from a positive selection bias. Despite controlling for a wide range of observable first and second nature geography, such as pre-industrial urban density, distance to ports as well as climate and soil quality we cannot rule out omitted variable bias. Additionally, the explanatory variable might be biased due to possible measurement errors: The maps by Châtel and Dollfus (1931) depict the major coalfields in 1921. Using this source, we fail to detect very small coalfields as well as coalfields that were already exploited and therefore no longer operated.[8] Hence, we use geological rock strata combined with information on the mountain topography as described in section 2 as an instrument for existing coalfields in the early 20$^{\text{th}}$ century.

Table 1 shows the results of running specification 2 as an OLS as well as a 2SLS specification using "carbshare" (carboniferous rock strata) as an instrument for "coalshare". In

[8] Running a simple regression with the share of land area covered by coalfields (coalshare) as a dependent variable and first and second nature variables as independent variables we do not find a strong selection effect. However, distance to the next border, distance to coast line, mean temperature and mean rain fall are positively associated with specialization in coal, while soil quality and number of universities in 1900 are negatively correlated. Pre-industrial city density, however, seems to be uncorrelated with coal abundance (compare Appendix table A 2)

column 1 and 2 we present the baseline effect for OLS and 2SLS respectively, whereas in column 3 and 4 the full range of first and second nature controls are included. In all cases, the instrument can be considered as relevant as the F-Statistic exceeds 10. When comparing the OLS results to those from the IV-regression, we see that the latter is considerably more negative while still highly significant. This suggests that there is indeed a positive selection into treatment, as discussed above. Including controls yields a larger and more significant β-coefficient for both the OLS and IV regression. In our preferred specification in column 4 using the instrument and a full set of controls, the estimate implies that a one percentage point increase in "coalshare" results on average in a 1.51 percent slower growth in GDP per capita after 1960. These are large effects: the average coal region (with a coalshare of 14 percent) experiences about 20 percent less growth after 1960 compared to a region without any coal.

Table 1: The effect of coal abundance on GDP per capita (fixed treatment date)

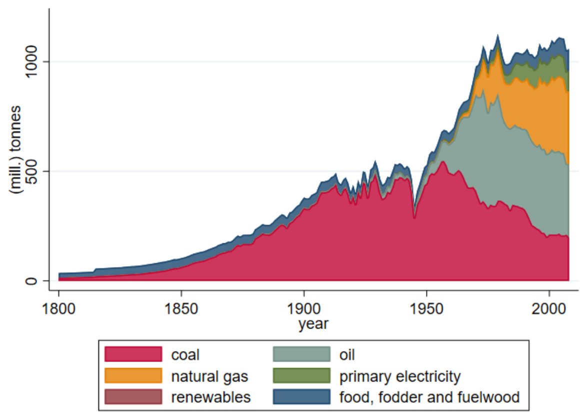
Dep. var.: GDP per capita (log)	OLS(1)	IV(2)	OLS(3)	IV(4)
coalshare x post1960	-0.44**	-0.90**	-0.56***	-1.51***
	(0.21)	(0.46)	(0.19)	(0.52)
FE	✓	✓	✓	✓
YearFE	✓	✓	✓	✓
YearCountryFE	✓	✓	✓	✓
Controls			✓	✓
Observations	960	960	960	960
Regions	80	80	80	80
R-squared	0.97		0.97	
KP (F-stat)		10.66		10.48

Notes: This table reports the 2SLS coefficient estimates for β_1 in (2) of the share of land area covered by coalfields as of 1921 on GDP per capita using as an Instrument the share of land area covered by carboniferous strata. Control variables include the time interactions of the employment share in manufacturing in 1960, population density 1960 and the set of first and second nature geographical controls as specified in the text. All specifications include observation and time fixed effects. Standard errors are clustered at the level of observation (NUTS 2).

3.2 The Oil Invasion

So what happened in 1960? What set of factors could have triggered the reversal of fortune for European coal regions? The mining employment share started to decline strongly after 1950 (see figure 4 above), which is remarkable given the rising demand for energy at the time. A likely explanation is the improved availability of substitutes for coal, notably oil, related to the "second energy transformation" (Kander, Malanima, and Warde (2013)). Figure 6 shows for our sample (excl. Belgium) the increase in total energy consumption and how the composition of energy consumption has changed dramatically since the late 1950s. Around that time, coal started to be replaced by oil, followed later by natural gas and other sources.

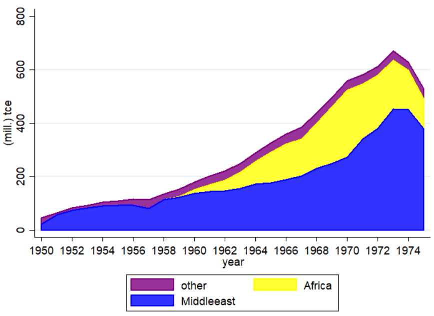
Figure 6: The first and second energy transition



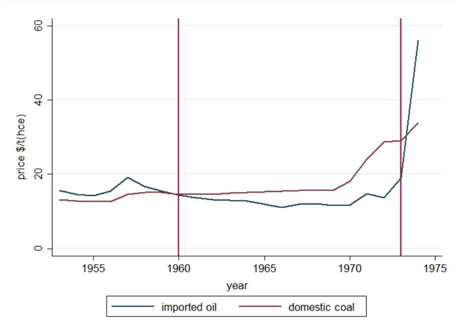
Notes: The figure shows the total energy consumption converted to million tonnes hard coal equivalents for France, Germany, the Netherlands and the UK. Belgium is not included due to incomplete data. Source: Own graphical illustration based on data from Kander, Malanima, and Warde (2013), downloaded from (https://histecon.fas.harvard.edu/energyhistory/sources.html).

To a large extent, the supply of oil to Europe increased in response to rapidly growing energy demand after the war. This led to efforts to coordinate European energy markets (such as the foundation of ECSC in 1951, Euratom and EEC in 1957), but also to intense exploration of oil fields in the Middle East and North Africa. Ghawar (discovery in 1948, production from 1951), Safaniya (1951, 1957) in Saudi Arabia, Zelten/ Nasser (1956/ 1961) in Libya and Edjeleh (1956/1960) and Hassi Messaoud (1956/ 1958) in Algeria are notable examples. Around the same time, political resistance in Europe against oil imports abated. The OEEC Hartley Report, published in May 1956, had recommended to facilitate more oil imports at least for the next two decades, because coal resources were considered to be limited and alternatives, such as nuclear power, still in their infancy (OEEC (1956), p. 56). As we see from figure 7 panel a, oil imports from the Middle East and particularly from (North) Africa were increasing rapidly after 1956. Importantly, at a time of rising energy demand, the supply of oil proved to be very elastic, such that oil prices remained low and even started to fall below equivalent coal prices just around 1960 as shown in figure 7 panel b. In consequence, oil could compete successfully with coal in several uses, ranging from transportation to heating, while employment in mining started its long decline (see figure 7, panel c).

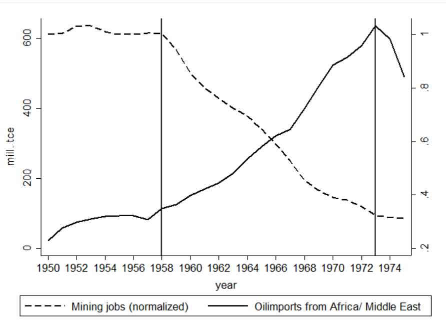
Figure 7: The oil shock



(a) oil imports by origin



(b) energy prices



(c) mining jobs and oil imports

Notes: Panel (a) shows total oil imports converted to million tonnes hard coal equivalents by country of origin for all countries in the sample. Panel (b) depicts the evolution of the US dollar price per 1 million tonnes hard coal equivalent for imported oil and domestic coal for France, Germany, the Netherlands and Belgium. The UK is excluded due to missing data. Panel (c) compares the evolution of number of mining jobs, normalized by the number of mining jobs in 1950 (y-axis to the right),to the total quantity of oil imports from the Middle East and Africa, measured in million tonnes hard coal equivalents for all countries in the sample. For Sources, see text.

Christian Pfister discussed these events as the "1950s syndrome" and suggested a parallel between the import of "dirt-cheap" oil in the late 1950s and the grain invasion of the late 1870s (Pfister, Bär, and Ogi (1996) and Pfister (2010)). Crucially for our case, this "oil invasion" changed the fortune of coal regions and led to an economic and geographical reconfiguration of Europe.[9] We argue that cheap oil imports caused a negative demand shock to coal mining regions that explain to a large extent the reversal of fortune documented in figures 1 and 5 above. As suggested by figure 7 (panel c), this first reduced the demand for labor in mining, before it led to a general economic decline in former coal regions. At the same time, oil could be used in many other ways with positive effects on other sectors, such as chemicals and car manufacturing. In appendix figure A3 we provide details on the changing use of various types of energy. Hence, it is likely that oil imports changed the relative position of coal producing regions via both, reducing demand for coal

[9]More specifically, Pfister (2010, p. 104) suggested that cheap oil imports jeopardized European energy security in a similar fashion as grain imports had undermined food security in many European countries during the First World War. O'Rourke (1997) showed how the "European grain invasion" caused the decline of European agriculture, but also a change in relative factor prices across Europe and various policy responses. More recently, Bräuer and Kersting (2023) show how the grain invasion during the first globalization affected income levels across Prussian regions before 1913.

and simultaneously lowering input costs in other sectors and across all regions.

Our aim here is to estimate to what extent the decline of coal regions relative to non-coal regions (in terms of GDP per capita) can be causally explained by the effect of oil imports on the decline in labor demand for coal miners. To capture this, we proceed in two steps. In a first step we measure the local labor demand shock to the mining industry, defined as jobs lost in the mining sector between 1960-1970 relative to initial employment in a region. Formally:

$$shock_{i196070} = -(\frac{\Delta L_{mi1960-1970}}{L_{i1950}}) \tag{3}$$

where L indicates employment, i indicates a region, and m stands for mining. Note that between 1960 and 1970 mining employment declined in all coal regions. To ease interpretation, we invert the sign, such that a high number indicates a large number of jobs lost. By construction, this measure is zero in non-coal regions.[10]

To establish a causal effect, we exploit variation coming from a region's exposure to changing oil imports at the national level j, in the spirit of Autor, Dorn, and Hanson (2013). We standardize the change in national level oil imports by the area of a given region and weight this with a region's share in all carboniferous strata of its country:

$$\widehat{shock}_{196070i} = \frac{Carboniferousstrata_i}{Carboniferousstrata_j}\frac{\Delta IMP_{j196070}}{Area_i} \tag{4}$$

Thus defined, causal identification comes from both the exogenity of the shift - the national level increase in import exposure - *and* the share - regional mining activity predicted by geology. As recently discussed in detail by Goldsmith-Pinkham, Sorkin, and Swift (2020) and Borusyak, Hull, and Jaravel (2022), the identification strategy is valid under the sufficient condition that *either* the shift or the share is uncorrelated to unobserved shocks. One of the usual concerns arising in empirical settings like this is that the outcome might be driven by a demand shock, here: an increase in overall energy demand. First of all the demand shock would need to be spatially correlated with the incidence of the supply shock, i.e. coal producing regions would have to see an increase in energy demand that was systematically different from that in other regions. This is possible, but unlikely. A related issue is that positive supply side effects of cheap oil on other sectors rather than negative effects on mining might drive our results. For both these reasons we add a control for the manufacturing share in total employment in each region, excluding mining. That the negative effect is not driven by a correlated deindustrialization trend is furthermore supported by the descriptive evidence presented in Figure 4a. The decline of manufacturing industries outside mining starts ten years later - in 1970 - and affects coal and non coal regions at a very similar pace and intensity. Moreover, in some

[10] In a similar manner, labour demand shocks have been constructed before by Feyrer, Sacerdote, and Stern (2007) and Charles, Hurst, and Schwartz (2019).

specifications we further add controls of population density and first and second nature characteristics as described at the end of section 2 above.

We use these variables to regress GDP per capita (in logs) on our labor demand shock, as OLS and instrumented by exposure to oil imports, together with a vector of controls as discussed:

$$Y_{it} = \alpha_i + \gamma_t + \delta_{jt} + \beta_1 * shock_{1960-1970} * I_{Post1960} + \sum_{t=1950}^{2015} \beta_{2t} * X_i * I_t + \epsilon_{it} \quad (5)$$

The results are shown in table 2. In the first column we show that our shock measure of jobs lost in mining between 1960 and 1970 is significantly negatively correlated with the decline in GDP per capita. In column (2) we exploit exogenous variation to the exposure to oil imports, which suggests a negative and significant causal effect of very similar magnitude. Moreover, the F-stats suggest that our instrument is quite strong.Once we add the total set of controls, including manufacturing share in total employment, we see that the negative effect of the decline in coal mining on GDP per capita growth becomes larger and the statistical significance increases.

Table 2: The effect of the oil invasion on GDP per capita (fixed treatment date)

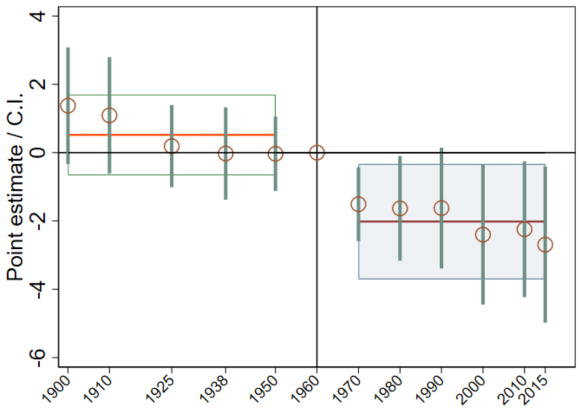
Dep. var.: GDP per capita (log)	OLS(1)	IV(2)	OLS(3)	IV(4)
shock x post1960	-1.97**	-1.87**	-2.90***	-3.87***
	(0.98)	(0.81)	(1.10)	(1.30)
FE	✓	✓	✓	✓
YearFE	✓	✓	✓	✓
YearCountryFE	✓	✓	✓	✓
Further Controls			✓	✓
Observations	960	960	960	960
Regions	80	80	80	80
R-squared	0.99		0.99	
KP (F-stat)		160.71		53.74

Notes: This table reports the OLS and 2SLS coefficient estimates for β_1 in (3). Control variables include the time interactions of the employment share in manufacturing in 1960, population density 1960 and the set of first and second nature geographical controls as specified in the text. All specifications include observation and time fixed effects. Standard errors are clustered at the level of observation (NUTS 2).

The results in table 2 imply that on average real GDP per capita grew 8% less in coal regions compared to regions without coal after 1960, due to the oil shock. Is this a lot? We can compare this to our finding from table 1 above. Form this perspective, the oil shock captures about 38% of the overall difference in growth rates between coal- and non-coal regions after 1960.[11] Moreover, figure 8 illustrates our findings on running a specification as in table 2, col. 4, interacting the coefficient on the oil shock with time

[11] With a median job loss of 2.1% and a coefficient of 3.87 we get an effect of about 8% reduced growth. This amounts to roughly 38 % of the 21% growth reduction estimated above. Note that our shock is restricted to jobs lost between 1960 and 1970, which will miss effects of job losses in mining before and directly after.

Figure 8: The effect of the oil invasion on GDP per capita (time-varying treatment effect)



Notes: N= 960 ; This figure reports the OLS coefficient estimates for β_{1t} in (3), interacting the coefficient on the oil shock with time dummies, and 95% confidence intervals for these estimates. Control variables include the time interactions of the employment share in manufacturing in 1960, population density 1960 and the set of first and second nature geographical controls as specified in the text. The specification includes observation and time as well as time-varying country fixed effects. Robust standard errors are clustered at the level of observation (NUTS 2).

dummies. Remarkably, we find that the shock of 1960 has very persistent effects. In fact, while the standard errors increase over time, we even find slightly increasing point estimates (in absolute terms). Apparently, coal regions struggled to adjust to the oil shock, which brings us to our next section. How can we explain this persistence?

4 Explaining Persistence: the role of human capital

In this section we aim to explain why the relative decline of coal regions was so persistent. Our main argument is that human capital, or better the lack thereof, prevented regions to adjust and to recover from the shock. An earlier literature, including notably Esposito and Abramson (2021) have argued that former coal regions lagged behind in terms of the number of universities, and increasingly so since 1800. Moreover, they show for a cross-section of regions in 2010 how a history of coal mattered for underachievement in tertiary education, in line with Franck and Galor (2021) on early industrialization and French regions. However, many European regions experienced a substantial expansion of secondary and tertiary education after 1960, including former coal regions. To understand, why this expansion of education was not good enough to help regions adjust and recover, we need evidence on the *dynamics* of educational attainment over time. We use our data on the share of people with tertiary education, which is available at the level of NUTS3 (and obviously also at NUTS 2) regions from 1970 onward, as described in section 2. We will first show how the educational gap between coal and non-coal regions developed over time between 1970 and 2010 for both, the NUTS 2 and the more detailed NUTS 3 sample. Next, we exploit the NUTS3 sample to answer two further questions: First, how much of the negative effect of coal abundance after 1960 can be explained by human capital as a mediator, compared to any direct effects? And second, broadening our perspective

Table 3: The effect of coal abundance on educational attainment

Dep. var.: educational attainment	OLS(1)	IV(2)	OLS(3)	IV(4)
coalshare x post1970	-0.08***	-0.14***	-0.05***	-0.09***
	(0.03)	(0.04)	(0.01)	(0.02)
Sample	NUTS2	NUTS2	NUTS3	NUTS3
FE	✓	✓	✓	✓
YearFE	✓	✓	✓	✓
YearCountryFE	✓	✓	✓	✓
Controls	✓	✓	✓	✓
Observations	400	400	3355	3355
Regions	80	80	671	671
R-squared	0.91	0.95	0.94	0.94
KP (F-stat)		9.61		37.33

Notes: This table reports the OLS and 2SLS coefficient estimates for β_1 in (2) of the share of land area covered by coalfields as of 1921 on GDP per capita and using as an instrument the share of land area covered by carboniferous strata. Control variables include the time interactions of the employment share in manufacturing in 1960, population density in 1960 and the set of first and second nature geographical controls as specified in the text. Column (1) and (2) report the results for the NUTS 2 sample, column (3) and (4) report the same results for the NUTS 3 sample. All specifications include observation and time as well time-varying country fixed effects. Robust standard errors are clustered at the level of observation.

we ask whether variation in human capital *before the age of coal* and *within* the group of coal regions affected their ability to adjust. Put differently, do we find evidence that some regions were better positioned to deal with negative shocks due to their pre-industrial history of human capital accumulation?

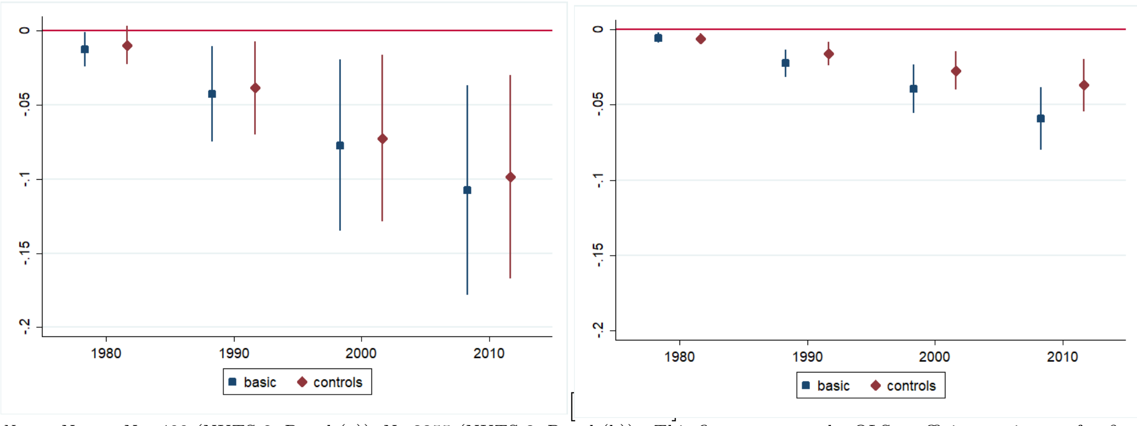
4.1 The dynamic effect of coal on educational attainment

We know that educational attainment improved everywhere (see appendix table A 1). To estimate the gap between coal and non-coal regions, we use the same approach as in equation (1) and table 1 above, but with the share of tertiary education as dependent variable. Due to data availability, we can only measure effects against 1970. In table 3 we show that coal had a substantial negative effect on education, which becomes larger when using carboniferous strata as an instrument. According to the IV specification in column (2) a one percentage point increase in the share of the area covered by coalfields results in 0.14 percentage points less growth in the share of the population obtaining a post-secondary degree. This implies that the median coal region experienced 6 percentage point less growth in educational attainment after 1980. Using the larger NUTS 3 sample instead, we likewise observe a strongly significant negative but somewhat smaller effect. Hence, in spite of rapidly expanding access to tertiary education, coal regions fall behind relative to non-coal regions.

Figure 9 depicts the changes in this effect over time (estimated with OLS), again for our NUTS 2 sample (left panel) and the larger NUTS 3 sample (right panel). As in table 3 the reference year is 1970. We see that for both samples coal regions started to lag behind in 1980, and that this lag was increasing over time and turned significant from 1990 onward.

Figure 9: The effect of coal abundance on educational attainment (time-varying treatment date)

(a) NUTS2 sample (b) NUTS3 sample



Notes: Notes: N= 400 (NUTS 2, Panel (a)), N=3355 (NUTS 3, Panel (b)) ; This figure reports the OLS coefficient estimates for β_{1t} in (1) and 95% confidence intervals for these estimates. Control variables include the time interactions of the employment share in manufacturing in 1960, population density 1960 and the set of first and second nature geographical controls as specified in the text. Coal abundance is measured as the percentage of land area covered by coalfields. All specifications include observation and time as well as time-varying country fixed effects. Standard errors are clustered at the level of observation.

4.2 Mediation analysis: human capital as a transmission channel

It is likely that the decline in coal mining activity, caused by the "oil invasion", had a direct negative effect on economic growth: income suffered because demand for coal and hence demand for coal miners declined. Yet, given the very rapid decline of mining, we would have expected this negative effect to weaken over time. In contrast, our evidence on a growing educational gap between coal and non-coal regions suggests that coal also mattered indirectly. If this latter effect increased over time, this would help to explain the persistence of the "oil invasion" shock.

How much of the observed negative effect of coal abundance on GDP per capita is due to a direct effect, how much due to an indirect effect mediated by human capital? Following the empirical strategy by Pinto et al. (2019), we perform an IV mediation analysis to explore the relative importance of human capital as a transmission channel for lower income levels. Given that data on educational attainment is only available from 1970 onward, we focus on the post-treatment period.

We will use the instrument Z ("carbshare") for our mediator variable M (human-capital) once we condition on the treatment variable T ("coalshare"). The underlying necessary condition is that endogeneity cannot arise from confounders that jointly influence our treatment variable T and the dependent variable Y (GDP per capita), which do not run primarily via the mediating variable M. Hence, this allows for omitted variables that jointly influence M and Y and also other missing variables that impact jointly T and M. This yields the following new set of equations:

$$T = \theta_{jt} + \gamma_t + \beta_{TZ}(Z) + X_{it} + \epsilon_{it} \tag{6}$$

$$M = \theta_{jt} + \gamma_t + \beta_{MT}(\hat{T}) + X_{it} + \epsilon_{it} \tag{7}$$

$$M = \theta_{jt} + \gamma_t + \delta_{MT}(T) + \delta_{MZ}(Z) + X_{it} + \epsilon_{it} \tag{8}$$

$$Y = \theta_{jt} + \gamma_t + \beta_{YM}(\hat{M}) + \beta_{YT}(T) + X_{it} + \epsilon_{it} \tag{9}$$

Instead of one, we have now two first stages and we measure three effects. The first two equations measure the effect of T on M instrumented by Z and yield the coefficient β_{MT}. Equation 7 combines the effect of M on Y conditioned on T and controlling for Z (β_{YM}) as well the direct effect of T on Y (β_{YT}). The indirect effect is obtained by multiplying $\beta_{YM} * \beta_{MT}$. We furthermore add θ_{jt} (time varying) fixed effects at the country–level, time fixed effects γ_t and the given set of controls at the regional level X_{it}.

The total effect is the sum of the direct and indirect effect and equals the 2SLS regression of the outcome variable (Y) on T instrumented by Z. This is shown by substituting equation (5) into (7):

$$Y = \theta_{jt} + \gamma_t + (\beta_{YM} * \beta_{MT} + \beta_{YT})(\hat{T}) + X_{it} + \epsilon_{it} \tag{10}$$

$$Y = \theta_{jt} + \gamma_t + \theta_{YT}(\hat{T}) + X_{it} + \epsilon_{it} \tag{11}$$

Table 4 shows the results of the IV mediation analysis, decomposing the total effect into a direct and indirect effect. The coefficients represent the average effect for the entire post-treatment period. The F-Stats for the two first stages are both well above 10 and therefore confirm the relevance of carboniferous strata as an instrument. Consider column (1): while the direct effect of coal abundance on GDP per capita is not significant, we find a highly significant indirect effect, which turns out to be almost as large as the total effect. The lower level in educational attainment thus explains the entire negative effect of coal abundance on GDP per capita levels. Note that in all specifications we allow for time-varying country effects, to account for changes in education systems over time. Our finding remains also unchanged when including NUTS1-fixed effects to control for variation within countries, for example between German Federal States (see column 2).

As suggested above, the relative importance of the direct effect might have decreased, while the indirect effect might have increased over time. Pooling all years into one regression hides such dynamics over time. Appendix Table A 3 shows the mediating effect of educational attainment by rerunning the IV mediation analysis as a repeated cross section for each decade. In fact, in 1980 coal abundance still has a (weakly) significant direct effect on regional GDP per capita and we find no statically significant indirect effect. But starting in 1990, the indirect effect of coal via human capital on income explains an increasing share of the overall effect. These findings seem rather plausible, given the shrinking size of the mining industry and the growing role for human capital (Jones (2014)). It would be interesting to clarify whether the large and growing indirect effect is due to the inability to invest sufficiently in the education by (local) governments, or due to a weaker predisposition towards higher education on the side of the local population and therefore endogenously driven (as e.g. suggested by Esposito and Abramson (2021)). It might also be caused by skill-biased inter-regional migration and therefore reflect a change in the composition of the workforce. Yet, these questions are beyond the scope of this paper.

Table 4: IV mediation analysis: The direct and indirect effect of coal abundance on GDP per capita levels

Dep. var.: GDP per capita (log)	IV(1)	IV(2)	IV(3)
total effect	-0.800***	-0.755***	-0.800***
	(0.083)	(0.106)	(0.083)
direct effect	-0.017	-0.057	-0.055
	(0.072)	(0.062)	(0.102)
indirect effect	-0.783***	-0.698***	-0.745***
	(0.158)	(0.169)	(0.220)
M: Edushare	✓	✓	
M: Uniden 1950			✓
Country FE	✓	✓	✓
Time FE	✓	✓	✓
Timevarying Country FE	✓	✓	✓
NUTS 1 FE		✓	
Observations	3353	3353	3353
KP (F-stat) (T on Z)	203.35661	137.26284	203.35661
KP (F-stat) (M on Z|T)	38.468324	32.661622	18.006197
% of effect explained by mediator	97.881703	92.424423	93.180288

Notes: The Table depicts the total effect θ_{YT}, decomposed in the direct effect β_{YT} and indirect effect $\beta_{YM} * \beta_{MT}$ of coal abundance on the level of GDP per capita as specified in the set of equations (4)-(7). The share of the population that completed tertiary education is used as the mediator variable in (1) and (2), the university density as of 1950 is used in (3). We furthermore add (time varying) fixed effects at the country level, time fixed effects and the given set of first and second nature geographical controls as specified in the text. Coal abundance is measured as the percentage of land area covered by coalfields instrumented by the land area covered by carboniferous strata. Robust standard errors are used.

Our approach remains valid in the presence of confounders that jointly influence human capital attainment and GDP per capita, as discussed above. Therefore, the main threat to identification lies in the issue of reversed causality. Especially, more prosperous places might attract a higher share of college graduates, and have a higher budget for public investment in higher education. To account for such effects we rely in all specifications on a ten-year lagged variable for human capital. Although this time lag alleviates the concern, it cannot fully rule out reversed causality. We address this concern using a proxy for human capital levels in the *pre-shock* period: university density in 1950. This is similar to the approach of Moretti (2004) or Abel and Deitz (2012) who both use the presence of land-grant colleges to proxy for the current human capital stock in U.S. metropolitan areas. Glaeser, Saiz, et al. (2004) and Shapiro (2006) likewise use the college density in 1940 to proxy human capital levels in 2000. The advantage is that the university density in 1950 is not affected by the decline of local economies and tight public budgets nor a result of potential inter-regional migration with a skill-bias after the shock. University density can be considered as the extensive margin for measuring human capital stock as we do not observe the number of students in each university. Therefore, we will capture only parts of the predictive power of this variable.

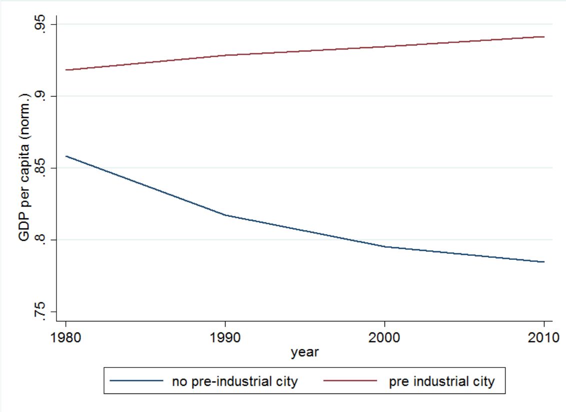
The results of using university density 1950 as a mediator are shown in table 4 column (3). The total effect is identical to the one shown in column (1), as it should be. Reassuringly, the direct effect is still not significant and the indirect effect via university density in 1950 explains the entire negative effect of coal abundance on GDP per capita levels after 1980. The F-Stat of the second first stage is weaker but still passes the threshold of 10. To conclude, we find strong evidence that former coal regions suffered due to their failure to close the gap in terms of human capital compared to non-coal regions. While the share of people with tertiary education in former coal regions increased quite substantially, this increase was nevertheless lagging behind the growth in non-coal regions. This suggests that "geography" can have a strong and persistent bearing on regional development, but that this is down to changeable factors, not destiny. Therefore, in our last section we want to broaden our perspective and explore whether and to what extent some coal regions were better equipped to reinvent themselves after the "oil invasion" than others.

4.3 Coal and Human capital in the long-run: the Reinvention Hypothesis

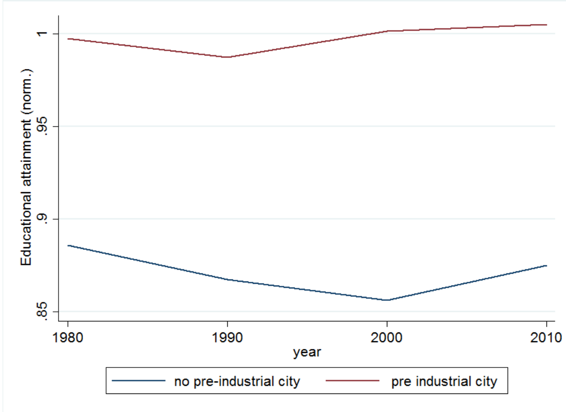
We documented how coal abundance turned from being a blessing to a curse around 1960, showed that this was triggered by an "oil invasion", and highlighted the role of human capital to explain the lack of adjustment. In this last section, we want to show that there is in fact substantial heterogeneity between coal regions. While many regions failed to adjust to the decline of coal, some succeeded. Why?

Glaeser, Saiz, et al. (2004) suggest that a regions' skill base is important for the ability to "reinvent" itself in response to a shock. Furthermore, regions that have reinvented themselves repeatedly in history become more resilient over time. Testing the reinvention hypothesis they show that Metropolitan regions in the U.S. that had been specialized in manufacturing in the first part of the 20th century were quicker to switch to new industries if they displayed a higher initial skill level. Glaeser (2005) illustrates for the case of Boston how a strong skill-base enabled the city to re-invent itself multiple times in history. In a similar vein, we show that coal regions that had an urban tradition before 1800, that is, *before* coal started to become a relevant factor for economic growth, were better able to accumulate human capital and to recover from the shock. As discussed in the previous section, the endowment with coal resources can be considered as random and largely unrelated to other economic fundamentals. The discovery of coal, however, sparked rapid

Figure 10: Former coal areas and pre-industrial citydensity



(a) GDP per capita



(b) Tertiary Education Share

Notes: The figures show the deviation from respective country averages in terms of GDP per capita and tertiary education shares for coal regions only. We distinguish between coal regions that contained at least one city with at least 5000 inhabitants (preindustrial city) and coal regions that did not (no preindustrial city). Sources: see text.

urbanization and economic development irrespective of these fundamentals.[12] We argue that regions that already contained major urban settlements in 1700 grew more sustainable compared to cities built on "the green field". We show that pre-industrial urban success entails indeed persistently higher levels in population density and sectoral diversity as well as a larger employment share in services. These qualities can be activated in times of structural change to attract employment in the expanding service industries.

Figure 10 shows the difference in the evolution of GDP per capita and educational attainment between 1980 and 2010 within our group of coal regions, between those that contained a city with a population exceeding 5000 inhabitants in 1700 and those that did not. In each case, we show their performance relative to the respective national average (=1). The differences are striking in terms of both, levels and dynamics. Coal regions with major pre-industrial settlements perform much better in terms of GDP per capita and educational attainment. In terms of GDP per capita (left panel) they stay below the national average, however, in terms of educational attainment (right panel) they even reach above average levels. The poor relative performance in both measures by coal regions documented earlier might have been driven by coal regions without a major pre-industrial city.[13]

A simple way to test whether and to what extent pre-industrial city density moderates the effects of coal is to introduce interaction effects. In table A 4 in the appendix we show the effect of coal abundance interacted with pre-industrial city density on ed-

[12]Formerly small settlements located close to coalfields such as Bochum in the Ruhr mining area and Manchester and Stoke-on-Trent in the UK increased their population sizes by the factor 145,87 and 86 respectively between 1700 and 1950.

[13]One caveat here might be that pre-industrial city density could capture a lower specialization in coal-intensive industries in the first place. Yet, Appendix Table A 2 shows that there is no significant relationship between these measures.

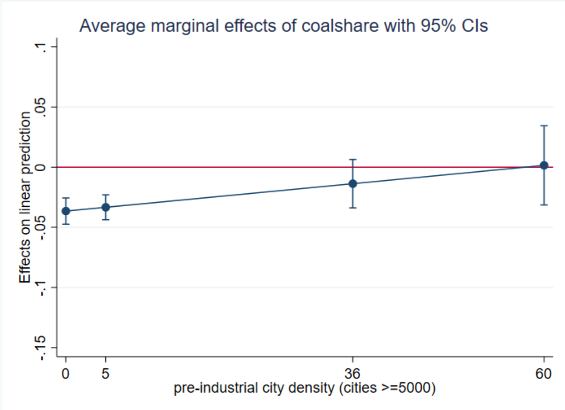
ucational attainment levels in a pooled cross-section combining all relevant years in the post-treatment period. We first show the baseline effect for the OLS regression and IV regression, each including time varying country fixed effects but no additional controls. If a former coal region has a higher pre-industrial city density the negative effect of coal abundance on human capital becomes much weaker. The IV estimation yields a coefficient for both the coalshare and the interaction term that is twice as high as in the simple OLS-regression. For a former coal region with the average pre-industrial city density (36 people per square kilometer) the negative effect of a one percentage point increase in coalshare is reduced by roughly 50 % $((0.0012 * 36)/0.09)$. Next, we add first and second nature geographical controls to account for potential transmission channels. Adding first nature controls such as soil quality and mean temperature does not reduce the interaction effect, indicating that the effect is not operating through initial conditions that are still favourable for economic development today. Adding second nature controls such as the population density in 1970 and university density in 1950 reduces the mediating effect of pre-industrial city density to 25 percent.[14] This shows that roughly half of the effect works through path dependency in the population density and a better educational infrastructure. Figure 11 depicts the marginal effect of coalshare for different levels of pre-industrial city density (at zero, the median (=5), the mean (=36) and top 10 percent (=60) of the citysize distribution in 1700) as given by our preferred specifications with a full set of first nature controls (OLS, left panel) and (IV, right panel) [15]. Whereas for a region with the average pre-industrial city density the negative effect of coal abundance is reduced by roughly one half, the leading ten percent regions of the urban density distribution in 1700 do not experience a statistically significant negative effect any longer.

In a final step we directly test how a higher pre-industrial city density affects pre-shock conditions of former coal regions in 1960. First, we test for the presence of path dependency in density due to sunk costs, increasing returns, spillover effects, or some combination thereof. Canonical economic geography models predict that urban density is positively related to productivity and income (Ahlfeldt et al. (2015)). This is also in line with Wahl (2016), who finds that European regions with a medieval trade centre still exhibit higher levels of GDP per capita today. Second, pre-industrial urban success might entail a higher sectoral diversity outside of mining and a higher specialization in service sector activities due to its longer entrepreneurial tradition. In times of structural change, this entrepreneurial base can be activated to attract new industries. A higher specialization in services is particular importance, since recent urban success has been defined by the shift out of manufacturing into knowledge intensive services. We test for the presence of

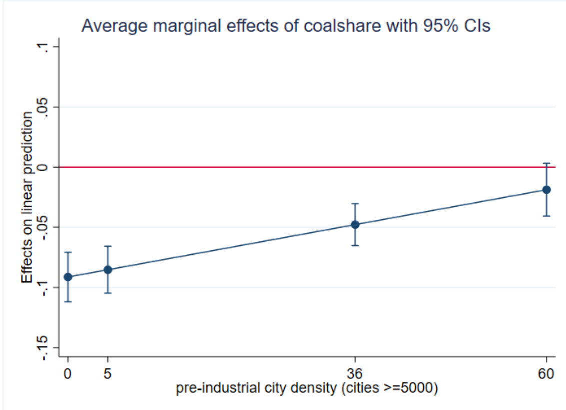
[14] The mediating effect of pre-industrial city density for a former coal region with an average pre-industrial city density of 36 people per square kilometer is calculated based on the coefficients in A 4, column (6): $((0.0008 * 36)/0.116)$.

[15] Second nature geographical variables are bad controls because they can be considered as direct outcomes of pre-industrial city density.

Figure 11: The effect of the coalshare on educational attainment depending on different levels of pre-industrial citydensity



(a) OLS



(b) IV

Notes: This figure shows the marginal effect of of coal abundance on the level of educational attainment for different level of pre-industrial city density at the NUTS 3 level. Estimates are based on the coefficient θ_{YT} for the total effect in equation (8) interacted with pre-industrial city density: $Y = \theta_{jt} + \gamma_t + \theta_{YT}(coalshare) * (preindcity) + X_{it} + \epsilon_{it}$ as shown in table A 4, col. 3 (OLS) and col. 4 (IV) in the appendix. The specifications include the set of first nature geographical controls as shown in table A 4 as well as (time varying) fixed effects at the country level and time fixed effects. Coal abundance is measured as the percentage of land area covered by coalfields instrumented by the land area covered by carboniferous strata. Robust standard errors are used.

these different channels by running a simple regression of our coalshare measure interacted with the preindustrial city density on all of these initial conditions - namely population density, industrial diversity, and the employment share in services. We proxy industrial diversity by constructing a Herfindahl index based on employment shares in six different sectors excluding mining employment. The outcomes are measured in levels as of 1960 and therefore reflect the conditions of the pre-treatment period. As shown in Appendix table A 5, there is some evidence in favor of each of these channels. Apparently, coal regions with a pre-industrial urban centre had somewhat higher employment in services, a more diversified industrial structure outside of mining, and a higher population density before they were hit by the “oil invasion”. Yet, we acknowledge that this evidence is only tentative and would require a more rigorous analysis, which is beyond the scope of this paper.

5 Conclusion

The starting point of our paper were two questions: when and why did coal, the pre-eminent fossil fuel of European industrialization, turn from blessing to curse? And what explains the puzzling persistence of the coal curse, long after coal mining stopped being a sizeable economic sector? These questions and our answers to them have renewed relevance today. We show that the turning occurred around 1960 and argue that it was the second energy transition, namely the sudden replacement of one type of fossil fuel (coal) by another (oil) starting in the late 1950s that can explain the timing and largely also the extent of the reversal of fortune. An “oil invasion” from the Middle East and Northern

Africa, triggered by the enormous demand for energy after the war, led to a reconfiguration of Europes' economic geography. As argued by Pfister (2010), this influx of "dirt-cheap" oil ended the history of hard coal mining in Western Europe and led to the decline of coal regions relative to non-coal regions in terms of levels and growth rates of GDP per capita. The repercussions of this long neglected "oil invasion" on European economic development were probably much larger than this. For example, it would be worthwhile to analyse how the availability of cheap energy affected the various European growth miracles, but also, how this contributed to the increase of carbon emissions with their devastating environmental consequences.

But why did coal regions fail to adjust, even decades after the "oil invasion" was over? In the second part of our paper, we exploit our new panel data to document how coal mattered for education attainment, and hence also had an indirect effect on growth. Based on a mediation analysis we can show that this indirect effect dominated from the 1990s onward. While coal mining became a negligible sector, coal regions continued to fall behind, because they failed to *expand* tertiary education fast enough. This analysis leaves a few questions open, for example to what extent this was an institutional failure or related to behavioral aspects, which should be followed up in future research. In the final part of our paper, we highlight the very substantial heterogeneity between coal regions, related to their pre-industrial history: We show that regions with pre-industrial cities were much better able to adjust, especially because they managed to catch up in terms of educational attainment relative to non-coal regions. Again, this opens some new questions, which we leave to further research.

Let us end the paper with a few broader thoughts and (very tentative) policy implications. In a long-run perspective, abundance in natural resources, in particular in fossil fuels, is neither a blessing nor a curse per se. After all, trade theory stresses the importance of comparative advantage, which is always the result of endowments interacting with technology and institutions. How endowments matter for economic growth depends on a variety of other factors, including in our case mechanisms to foster human capital accumulation. We have seen how some regions managed to benefit from coal abundance, and adjusted to their sudden decline by catching up in terms of educational attainment. These regions had a local urban history that apparently helped them to reinvent themselves even after major shocks, in the spirit of Glaeser, Saiz, et al. (2004). We think that this opens a new research agenda for the conduct of successful regional policy. In particular, we need to understand better why urban history seems to be such a good predictor for regional resilience.

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A1 Appendix

A1.1 Appendix Tables

Table A 1: Descriptive Statistics NUTS2 and NUTS3 sample

	NUTS2 non coal region	NUTS2 coal region	NUTS3 non coal region	NUTS3 coal region
GDP per capita 1900	4231.50	4232.03		
	(1296.09)	(1187.57)		
GDP per capita 1950	6491.28	6608.90		
	(1731.67)	(1415.57)		
GDP per capita 1980	23130.49	20187.68	21891.87	17352.07
	(6389.85)	(2460.91)	(19004.96)	(5124.85)
GDP per capita 2010	40390.34	34275.56	32440.59	28006.44
	(10829.06)	(6441.39)	(31158.66)	(8878.58)
Population density 1900	322.08	139.31	272.26	237.24
	(726.65)	(95.18)	(1008.19)	(406.47)
Population density 1950	467.24	202.38	447.83	418.16
	(925.46)	(156.23)	(1148.97)	(582.07)
Population density 2010	579.30	263.90	566.50	458.90
	(996.75)	(196.24)	(1224.72)	(582.07)
Pop with higher edu 1980 (in %)	0.08	0.06	0.08	0.07
	(0.04)	(0.02)	(0.04)	(0.02)
Pop with higher edu 2010 (in %)	0.25	0.23	0.23	0.23
	(0.07)	(0.05)	(0.09)	(0.07)
Pop with higher edu 1980 (norm.)	1.04	0.96	1.02	0.93
	(0.27)	(0.14)	(0.37)	(0.23)
Pop with higher edu 2010 (norm.)	1.04	0.96	1.03	0.92
	(0.24)	(0.14)	(0.35)	(0.21)
Pre-industrial urban pop density (1700)	25.90	5.86	36.36	7.31
	(60.61)	(6.26)	(182.65)	(14.44)
Employed in mining 1950 (in %)	0.00	0.05	0.02	0.08
	(0.00)	(0.07)	(0.02)	(0.09)
Coalfields (% of landarea)	0.00	0.14	0.00	0.33
	(0.00)	(0.13)	(0.00)	(0.35)
Carboniferous strata (% of landarea)	0.03	0.11	0.02	0.21
	(0.08)	(0.10)	(0.09)	(0.28)
Number of Observations	43	39	508	171

Notes: The data in our NUTS2 sample cover 82 regions, the data in our NUTS3 sample cover 679 regions. The numbers show the mean of each variable for both, the control group (regions without coalfields in 1921) and our treatment group (regions with a coalfield in 1921). The standard deviation is shown in parentheses below.

Table A 2: Explaining coal abundance

	(1) coalshare
preind city	-0.00004
	(0.00010)
lnmeantemp	0.04636
	(0.11941)
lnrain	0.24365***
	(0.06946)
lncrop	-0.29089***
	(0.06523)
mountain type	0.01639
	(0.01252)
coast type	0.03442***
	(0.01216)
lndistharb	-0.00612
	(0.01124)
capital	-0.14470***
	(0.03364)
uniden1900	-0.06375*
	(0.03269)
lnpopden70	0.04789***
	(0.00805)
Country FE	✓
Observations	671
R-squared	0.32

Notes: This table shows the correlates of the explanatory variable coalshare with initial regional characteristic. The specification includes country fixed effects. Heteroskedasticity-robust standard errors are used. Data refers to the NUTS3 level.

Table A 3: IV-mediation analysis: The effect on GDP per capita (log) over time

Dep. var.: GDP per capita (log)	(1) 1980	(2) 1990	(3) 2000	(4) 2010
total effect	-0.623***	-0.849***	-0.898***	-0.920***
	(0.204)	(0.160)	(0.175)	(0.186)
direct effect	-0.283*	-0.110	-0.011	0.118
	(0.165)	(0.107)	(0.098)	(0.113)
indirect effect	-0.341	-0.739***	-0.887***	-1.038***
	(0.339)	(0.261)	(0.272)	(0.303)
Country FE	✓	✓	✓	✓
Time FE	✓	✓	✓	✓
Timevarying Country FE	✓	✓	✓	✓
Observations	630	630	631	631
KP (F-stat) (T on Z)	40.562677	40.562677	40.579178	40.579178
KP (F-stat) (M on Z|T)	10.243118	13.581359	12.176075	12.159471
% of effect explained by mediator	54.64787	86.990346	98.765003	112.79663

Notes:The table depicts the total effect θ_{YT}, decomposed in the direct effect β_{YT} and indirect effect $\beta_{YM} * \beta_{MT}$ of coal abundance on the level of GDP per capita as specified in the set of equations (4)-(7) as a repeated cross-section for years 1980- 2010. The share of the population that completed tertiary education is used as the mediator variable in (1)-(4). We furthermore add fixed effects at the country level and the given set of first and second nature geographical controls as specified in the text. Coal abundance is measured as the percentage of land area covered by coalfields instrumented by the land area covered by carboniferous strata. Heteroskedasticity-robust standard errors are used.

Table A 4: Interaction effect with pre-industrial city density on educational attainment

	(1)	(2)	(3)	(4)	(5)	(6)
coalshare	-0.03953***	-0.09039***	-0.03650***	-0.09130***	-0.05473***	-0.11605***
	(0.00589)	(0.00947)	(0.00558)	(0.01051)	(0.00671)	(0.01281)
pre-ind city	0.00016***	0.00015***	0.00015***	0.00015***	0.00009***	0.00008***
	(0.00005)	(0.00003)	(0.00005)	(0.00003)	(0.00003)	(0.00003)
coalshare × pre-ind city	0.00059**	0.00118***	0.00063**	0.00121***	0.00052**	0.00083***
	(0.00023)	(0.00020)	(0.00030)	(0.00021)	(0.00023)	(0.00021)
lnmeantemp			0.09298***	0.10599***	0.05300***	0.05819***
			(0.02305)	(0.01245)	(0.01970)	(0.01097)
lnrain			0.02474	0.04073***	0.05597***	0.07081***
			(0.01576)	(0.00867)	(0.01407)	(0.00818)
lncrop			0.01778	0.00824	-0.01278	-0.03067***
			(0.01082)	(0.00699)	(0.01120)	(0.00772)
mountain type			0.00038	0.00156	0.00035	0.00112
			(0.00230)	(0.00125)	(0.00215)	(0.00117)
coast type			0.00222	0.00424***	0.00544***	0.00761***
			(0.00211)	(0.00112)	(0.00203)	(0.00111)
lndistharb					-0.00633***	-0.00678***
					(0.00211)	(0.00122)
capital					0.03129***	0.02225***
					(0.00864)	(0.00502)
lnpopden70					0.01130***	0.01505***
					(0.00172)	(0.00121)
uniden1945					-0.00018	0.00063**
					(0.00012)	(0.00027)
Observations	3355	3355	3355	3355	3355	3355
R-squared	0.76		0.77		0.80	
KP (F-stat)		125.43		108.32		87.98

Notes: Estimates are based on the coefficient θ_{YT} for the total effect in equation (8) interacted with pre-industrial city density: $Y = \theta_{jt} + \gamma_t + \theta_{YT}(coalshare) * (preindcity) + X_{it} + \epsilon_{it}$ as shown in figure A 4. The specifications include the set of first and second nature geographical controls as shown in table 11 as well as (time varying) fixed effects at the country level and time fixed effects. Coal abundance is measured as the percentage of land area covered by coalfields instrumented by the land area covered by carboniferous strata. Heteroskedasticity-robust standard errors are used.

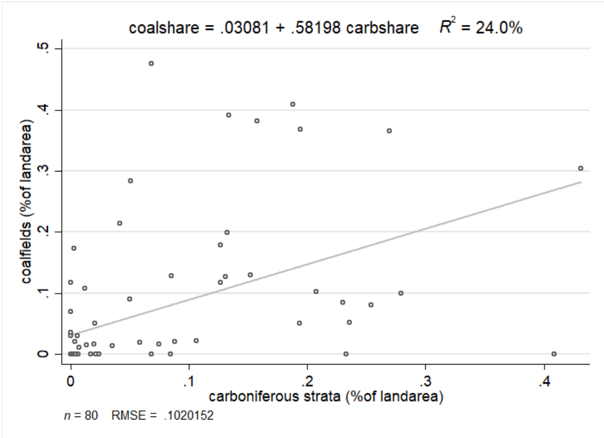
Table A 5: Pre-industrial city density and pre-shock conditions

	(1) empshare services	(2) industry diversity	(3) pop density
coalshare	-0.05042***	-0.05510***	2.00989***
	(0.01063)	(0.01656)	(0.17416)
preind city	0.00008	-0.00001	0.00286*
	(0.00007)	(0.00001)	(0.00156)
coalshare × preind city	0.00062**	0.00087*	0.02001***
	(0.00031)	(0.00046)	(0.00728)
lnmeantemp	-0.04092	0.03098	1.58654**
	(0.05204)	(0.03892)	(0.62495)
lnrain	-0.05682*	0.02444	-0.00588
	(0.03132)	(0.02303)	(0.38163)
lncrop	-0.06468***	0.03307**	2.14075***
	(0.02301)	(0.01640)	(0.40057)
mountain type	-0.00631	0.00704*	0.11809**
	(0.00497)	(0.00404)	(0.05097)
coast type	-0.03952***	0.01750***	-0.09292
	(0.00517)	(0.00324)	(0.07196)
lndistharb	-0.01826***	0.01158***	0.09681
	(0.00565)	(0.00316)	(0.07711)
capital	0.06610***	0.01713***	1.84421***
	(0.01843)	(0.00641)	(0.25452)
Observations	624	624	630
R-squared	0.36	0.28	0.48

Notes: Column (1)-(3) show the results for a simple OLS regression of coalshare measure interacted with the pre-industrial city density on the employment share in service in 1960, industry diversity, excluding the employment share in mining, as measured with the Herfindahl Index across six different sectors (agriculture, manufacturing, construction, trade and transport, financial and business services as well as public and other services) in 1960 and population density in 1960 at the NUTS3 level. All specifications include the listed controls as well as country-fixed effects. Heteroskedasticity-robust standard errors are reported. The sample excludes the Netherlands due to the lack of data.

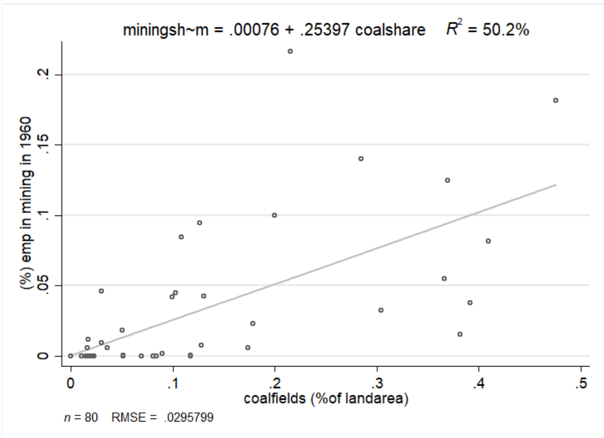
A1.2 Appendix Figures

Figure A1: Correlation between the share of area covered by coalfields and carboniferous strata (NUTS2)



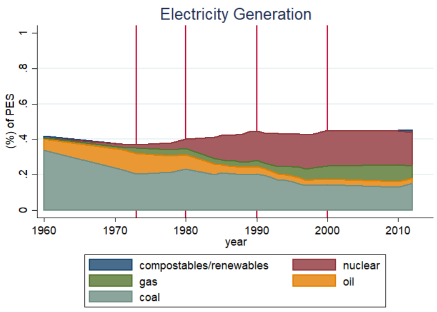
Notes: Bivariate relationship between the percentage share of land covered by historical coalfields ("coalshare") (1921) and the percentage of land area covered by carboniferous strata at the level of NUTS 2 regions. Sources see text.

Figure A2: Correlation between share of area covered by coalfields and the employment share in the mining sector in 1960

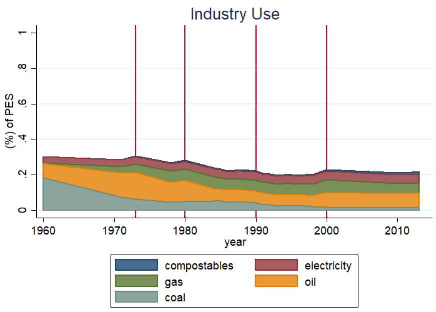


Notes: Bivariate relationship between the percentage share of land covered by historical coalfields ("coalshare") (1921) and the employment share in the mining sector in 1960 at the level of NUTS 2 regions. Sources see text.

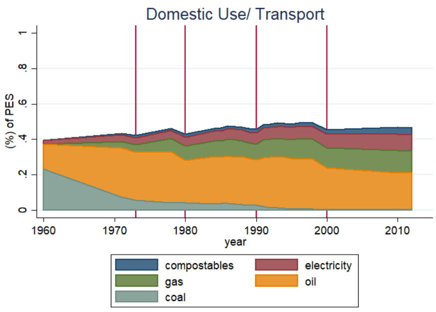
Figure A3: Energy use



(a)



(b)



(c)

Notes: Own illustration, based on data published by International Energy Agency and Organisation for Economic Co-operation and Development (2000-2015), International Energy Agency (1996) and International Energy Agency, Secretariat and Organisation for Economic Co-operation and Development (1986-2016, various issues.) This figure depicts the overall energy use (as a percentage of Primary Energy Supply) by energy source (type of fuel) for the different end-uses.

A1.3 Data Appendix

A1.3.1 Data sources for variables

Educational attainment and population

We measure human capital by using the share of the population (above the age of 15) that has completed tertiary education (obtained a post-secondary degree). For this, we collect and digitize census data of the respective countries. Census data for Belgium and the UK is published every ten years, for France, census data is published every six years. In contrast, the German census was only conducted in 1950, 1961, 1970, 1987 and 2011. For the Netherlands, data for educational attainment and population is collected from different data sources. Unfortunately, the data for educational attainment for the years 1980 and 1990 is unavailable. For the missing data, we rely on data imputation assuming a local, linear trend. Due to boundary changes, the data is re-estimated for the current 2016 NUTS 3 boundaries (see section below). Data is collected for the years 1950, 1960, 1970, 1980, 1990, 2000, and 2010. If there was no census in a given country in the respective year, the closest available data point was taken instead. Data on educational attainment for all countries is only available starting in 1970.
France:

- Reseau Quetelet. lil-0352: Recensement de la population 1968 : tableaux standards par communes, - 1968 (INSEE)
- Reseau Quetelet.lil-0343: Recensement de la population 1975 : tableaux standards par communes, - 1975 (INSEE)
- Reseau Quetelet.lil-0342: Recensement de la population 1982 : tableaux standards par communes, - 1982 (INSEE)
- Reseau Quetelet.lil-0143: Recensement de la population 1990 : tableaux standards, - 1990 (INSEE)
- Reseau Quetelet. lil-0144: Recensement de la population 1999 : tableaux analyses, - 1999 (INSEE)
- Reseau Quetelet. lil-0255: Recensement de la population 1999 : tableaux cantons, - 1999 (INSEE)
- Reseau Quetelet. lil-0874: Recensement de la population 2011 : chiffres clés, - 2011 (INSEE)
- Reseau Quetelet. lil-0879: Recensement de la population 2011 : fichier détail - Activité professionnelle

- Données harmonisées des recensements de la population à partir de 1968 Recensement de la population - Fichier détail. INSEE, accessed via https://www.insee.fr/fr/statistiques/6023301?sommaire=2414232#consulter.

Belgium:

- Census data for the years 1950 to 1980 is digitized from scanned census records provided by KU Leuven, Project Belgian Historical Censuses, accessed via https://bib.kuleuven.be/english/ebib/project-historical-census
  - Recensement général de la population, de l'industrie et du commerce au 31 décembre 1947. (1949). Institut National de Statistique.
  - Recensement de la population 1961.(1963). INS.
  - Recensement de la population - 31 décembre 1970. (1973). Institut national de statistique.
  - Algemene volks- en woningtelling op 1 maart 1981: algemene resultaten. (1982). NIS.
- Census data for the years 1990 to 2011 is either directly requested from the Belgian statistical office (Statbel) or accessed via https://statbel.fgov.be/fr/propos-de-statbel/que-faisons-nous/recensement-census

United Kingdom:

- Census 1971 for England Wales (and Scotland): UK data Service, Caseweb, https://casweb.ukdataservice.ac.uk/ shapefiles accessed via
- Census 1981 and 1991 for England Wales and Scotland: Office of National Statistics, accessed via https://www.nomisweb.co.uk/Nomis.
- Census 2001 and 2011 for England Wales: Office of National Statistics, accessed via https://www.nomisweb.co.uk/Nomis. Data is provided in current NUTS3 boundaries.
- Census 2001 and 2011 for Scotland: Scotland's Census National Records of Scotland, accessed via https://www.scotlandscensus.gov.uk

Germany:

- Census 1950 - 1987: Schmitt, Karl; Rattinger, Hans; Oberndörfer, Dieter (1994): Kreisdaten (Volkszaehlungen 1950-1987). GESIS Datenarchiv
- Census 2011: https://www.zensus2011.de/DE/Home/home_node.html

Netherlands:

- Census 1971: Centraal Bureau voor de Statistiek (CBS); NIWI-KNAW; (1999): Thematic collection: Dutch censuses 1795-1971. DANS. Downloaded from `https://doi.org/10.17026/dans-x6t-brh5` and `http://www.volkstellingen.nl/nl/volkstelling/jaartellingdeelview/BRT1971B4C/index.html`
- Data for 2003: Centraal Bureau voor de Statistiek, downloaded from `https://opendata.cbs.nl/statline/portal.html?_la=nl&_catalog=CBS&tableId=84703NED&_theme=245` urlhttps://opendata.cbs.nl/statline//CBS/nl/dataset/84703NED/table?ts=16159013070

Employment in six different industries (1960)

To capture the industry mix of regions in the pre-shock period in 1960 at the NUTS 3 level, we collect and digitize additional census data on employment in six different industries (agriculture, manufacturing, construction, trade and transport, financial and business services, as well as public and other services). Based on the employment share across these different industries, excluding mining, we construct a Herfindahl-Index.

France:

- Reseau Quetelet. lil-0351: Recensement de la population 1962 : tableaux standards par communes. 1962 (INSEE).

Belgium:

- Recensement de la population 1961.(1963): Data digitzed from scanned census records provided by KU Leuven, Project Belgian Historical Censuses, accessed via `https://bib.kuleuven.be/english/ebib/project-historical-census`. R. INS.

United Kingdom:

- Lee, Clive Howard. 1979. British Regional Employment Statistics. 1841-1971. Cambridge: Cambridge University Press.

Germany:

- Schmitt, Karl; Rattinger, Hans; Oberndörfer, Dieter (1994): Kreisdaten (Volkszaehlungen 1950-1987). GESIS Datenarchiv

Mining employment

- Germany

- Industrie und Handwerk. Regionale Verteilung der Industriebetriebe und deren Beschäftigte nach Industriegruppen. Reihe 4. Sonderbeiträge zur Industriestatistik. Statistisches Bundesamt Wiesbaden. Verlag W.H. Kohlhammer.(1958, 1962, 1974)
- Produzierendes Gewerbe. Regionale Verteilung der Betriebe im Bergbau und im Verarbeitenden Gewerbe und deren Beschäftigte. Fachserie 4, Reihe 4. 1 .3. Statistisches Bundesamt. Metzler-Poeschel, Stuttgart. (1978- 1990) `https://www.statistischebibliothek.de/mir/receive/DESerie_mods_00007169`
- Census 2011: `https://www.zensus2011.de/DE/Home/home_node.html`

• Belgium

- Census 1900-1980: Data digitzed from scanned census records provided by KU Leuven, Project Belgian Historical Censuses, accessed via `https://bib.kuleuven.be/english/ebib/project-historical-census` (for details see above)
- Census 1990-2011: requested via Statbel or accessed via `https://statbel.fgov.be/fr/propos-de-statbel/que-faisons-nous/recensement-census`

• France

- Tableaux de l'économie française [Texte imprimé] / Institut national de la statistique et des études économiques ; dir. publ.Paris : INSEE, 1956.`https://gallica.bnf.fr/ark:/12148/bpt6k6478595s/f18.item`
- Recensement General de la Population de mai 1954. Resultats du Sondage Au 1/20eme. Volume A. Population active. Institut National de la Statistique et des etudes economiques.`https://www.bnsp.insee.fr/bnsp/`
- Reseau Quetelet. lil-0351: Recensement de la population 1962 : tableaux standards par communes. 1962 (INSEE).
- Reseau Quetelet. lil-0352: Recensement de la population 1968 : tableaux standards par communes, - 1968 (INSEE)
- Reseau Quetelet.lil-0343: Recensement de la population 1975 : tableaux standards par communes, - 1975 (INSEE)
- Reseau Quetelet.lil-0342: Recensement de la population 1982 : tableaux standards par communes, - 1982 (INSEE)
- Reseau Quetelet.lil-0143: Recensement de la population 1990 : tableaux standards, - 1990 (INSEE)
- Reseau Quetelet. lil-0144: Recensement de la population 1999 : tableaux analyses, - 1999 (INSEE)

• United Kingdom

- Lee, Clive Howard. 1979. British Regional Employment Statistics. 1841-1971. Cambridge: Cambridge University Press.
- Census 1981-2011: Office of National Statistics, accessed via https://www.nomisweb.co.uk/Nomis Data is provided in current NUTS3 boundaries. For Scotland: Scotland's Census National Records of Scotland, accessed via `https://www.scotlandscensus.gov.uk`

- Netherlands [16]
  - Uitkomsten der Beroepstelling in het Koninkrijk der Nederlanden gehouden op den een en dertigsten December 1899. Elfde deel. Provincie Limburg. Bijdragen tot de Statistiek van Nederland Uitgegeven door het Centraal Bureau voor de Statistiek. Nieuwe Volgreeks No. 12, 's-Gravenhage: gebrs. Belinfante 1902.
  - Centraal Bureau voor de Statistiek, 12e Volkstelling annex woningtelling 31 Mei 1947. Serie A. Rijks- en provinciale cijfers. Deel 2. Beroepstelling, Utrecht: Uitgeversmaatschappij W. de Haan, 1952.

Energy import and price data

Data on the primary energy supply (consumption), and the use in different sectors is digitized from different publications from the International Energy Agency (IEA):

- International Energy Agency (1996). Oil information. issn: 1683-4259.
- International Energy Agency and Organisation for Economic Co-operation and Development (2000-2015). Energy balances of OECD countries. IEA statistics. International Energy Agency: Paris [France] .
- International Energy Agency, Secretariat and Organisation for Economic Co-operation and Development (1986-2016, various issues.). Coal Information. OECD/IEA: Paris. isbn: 9789264258624

Specific information about the coal industry such as production, consumption, employment and price data at the national level, as well as overall import quantities of crude oil and quantities imported from each partner country are digitized from the Energy Statistics published by Statistical office of the European communities, and later by Eurostat:

- Statistical Office of the European Communities (1950-1975). "Energiestatistik. Jahrbuch." (Various issues).

[16] We thank Ben Gales for pointing out the relevant sources and for providing us with the digitized mining employment data for both 1900 and 1947 for Limburg.

- Eurostat and Europäische Kommission (1984-1997). "Energy. Statistical Yearbooks." (Various issues).

For the UK, the following additional data sources are used:

- Number of employees in mining between 1853-2018 were downloaded from: Department for Energy Security & Net Zero (DESNZ), Historical coal data: coal production, availability and consumption 1853 to 2022, Digest of UK Energy Statistics (DUKES), annual data, downloaded from `https://www.gov.uk/government/statistical-data-sets`

- Data on oilimports by origin prior to 1973 were used from Department for Energy Security Net Zero (DESNZ): Energy Security Net Zero (n.d.). Historical crude oil and petroleum data: production, imports and exports. Digest of UK Energy Statistics (DUKES), annual data, downloaded from: `https://www.data.gov.uk/dataset`.

For Germany, the following additional data sources are used:

- Energy consumption and primary energy supply differentiated for East and West Germany was taken from: Arbeitsgemeinschaft Energiebilanzen, accessed via `https://ag-energiebilanzen.de/daten-und-fakten/zeitreihen-bis-1989/`

- Number of employees in mining between 1950-2018 was downloaded from Statistik der Kohlewirtschaft e.V., `https://kohlenstatistik.de/downloads/steinkohle`,

First and second nature controls

- Pre-industrial city density: Buringh, Eltjo (n.d.). Urbanization Hub. The Clio-Infra database on urban settlement sizes: 1500-2000, accessed via `http://www.cgeh.nl/urbanisation-hub`, The Clio-Infra database on urban settlement sizes provides the population size and geo-location of European cities between 1500-2000. We aggregate urban population of all cities with at least 5000 inhabitants in 1700 that fall within the current NUTS 3 boundaries and divide it by the area to get a measure for the overall pre-industrial urban population density of a region.

- Average yearly temperature (lnmeantemp) and average yearly rainfall (lnrain): Fick, S.E. and R.J. Hijmans, 2017. Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology,

- Average soil productivity of croplands (soil quality): Ramankutty, Navin, et al. "The Global Distribution of Cultivable Lands: Current Patterns and Sensitivity to Possible Climate Change." Global Ecology and Biogeography, vol. 11, no. 5, 2002, pp. 377–92

- Indicator for being a coastal region (coast): Eurostat, https://ec.europa.eu/eurostat/web/coastal-island-outermost-regions/methodology. A NUTS 3 regions is classified according to one of the following three critera: any NUTS level 3 region with a sea border (coastline) (1) ; any NUTS level 3 region that has more than half of its population within 50 km of the coastline, based on population data for 1 km^2 grid cells (2); No coastline (3)
- Dummy indicating an urban region (urban): Eurostat, https://ec.europa.eu/eurostat/web/rural-development/methodology. Urbanity is measured according to the three-step approach following the Urban-rural typology from Eurostat.
- Indicator for being a mountain region (mount): Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Territorial_typologies_manual_-_mountain_regions#Published_indicators. A NUTS 3 regions is classified according to one of the following four critera: any NUTS level 3 region where more than 50 % of the surface is covered by topographic mountain areas (1); any NUTS level 3 region where more than 50 % of the regional population lives in topographic mountain areas (2); any NUTS level 3 region where more than 50 % of the surface is covered by topographic mountain areas and where more than 50 % of the regional population lives in these mountain areas (3); no mountain area (4).
- Log Population density (lnpopden): Constructed from population size (see sources for population above) and area of NUTS 3 regions (derived via GIS from shapefiles provided by Eurostat https://ec.europa.eu/eurostat/web/nuts/nuts-maps)

A1.4 Data set harmonization: Boundary changes over time

United Kingdom

The Local Governemnt Act of 1974 (becoming effective in 1974) was a major local government reform reorganizing districts and counties. All existing administrative counties, county boroughs, urban districts, and rural districts were abolished. In their place, new metropolitan and non-metropolitan counties were created and these counties were in turn divided into districts. Under these changes, the number of districts was reduced from 1756 to 379. Data until 1971 is either reported in historical county boundaries or historical district boundaries. The data is therefore re-estimated into current boundaries with population weights based on historical districts' population sizes in 1961. Shapefiles for district and county boundaries for 1961 are extracted here: https://geoportal.statistics.gov.uk/search?collection=Dataset&sort=name&tags=all(BDY_CEN_1961). Shapefiles for district and county boundaries starting 1971 are extracted here: https://borders.ukdataservice.ac.uk/easy_download_data.html?data=England_dt_1971. Each historical county j can be expressed as a sum of historical districts k. Likewise each modern county i (NUTS3 region) can be expressed as the sum of historical districts k. In some cases the former districts are not perfectly overlapping with current NUTS 3 regions [17]. In these cases, a constant population density within historical districts k is assumed, and the district level data is distributed across NUTS 3 regions i based on the areashare of the overlap:

$$Y_i = \sum Y_k * \frac{area_{ik}}{area_k}$$

In a few cases, the relevant data is only provided at the more aggregate level of historical counties (overall employment and mining employment in 1950). This data gets re-estimated into current boundaries by constructing populations weights based on historical districts. In a first step, we derive the sum of the population over all historical districts k that are both within old county boundaries j and new county boundaries i. If historical districts k are overlapping with several new counties i, the areashare of the overlap is used to map the historical population of each district k to the current NUTS 3 areas i:

$$pop_{ijk} = \sum pop_{jk} * \frac{area_{ijk}}{area_{kj}}$$

In a next step, we take the share of the population in historical county j that lives in the part of that lies within the new county boundaries i to derive population weights:

$$popweight_{ij} = \frac{\sum pop_{ijk}}{pop_j}$$

In a final step, these population weights are used to map data provided at the historical county level j to current NUTS 3 regions i:

$$Y_i = \sum Y_j * popweight_{ij}$$

Germany

Census data is available for the years 1951, 1961, 1970, 1987 and 2011. Due to the time gaps between 1970 and 2011, the data for 1980 and 2000 is imputed using a linear projection. County boundaries have changed considerably over time. Shapefiles for the county boundaries for the years 1896-1987 are taken from censusmosaic `https://censusmosaic.demog.berkeley.edu/data/historical-gis-files`, shapefiles for the current NUTS 3 regions in the version of 2016 are provided by Eurostat `https://ec.europa.eu/eurostat/de/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts`. The county-level data in the boundaries of 1896-1971 are therefore recalculated for the current county-boundaries (NUTS 3 regions in the version of 2016) using GIS data. Be-

[17] 85 percent of all historical districts have at least a 90 percent overlap with a current NUTS 3 region

tween 1965 and 1978, major land reform acts across all federal states reduced the number of counties from 564 to 442 (328 NUTS3 regions today). The census data used is provided at the historical county level. In order to re-estimate the data for the current NUTS 3 boundaries, historical population data at the current municipality level is used provided by Felix Roesel (2022): German Local Population Database (GPOP) (Version 1.0).`https://leopard.tu-braunschweig.de/receive/dbbs_mods_00071017`. In a first step, for each historical county j the area overlap with the current municipality l is calculated. Within municipalities a constant population density is assumed. In a next step, these area weights are used to derive the proportion of the historical population within current municipality borders l that lives in the part that is overlapping with the historical county j. Current counties i are the sum of several municipalities l. Therefore, we aggregate the area weighted historical population within the current municipalities l that are overlapping with historical counties j to the current county level i by summing over all municipalities l that belong to current county i :

$$pop_{lij} = \sum_{lij} pop_l * \frac{area_{lj}}{area_l}$$

Pop_{lij} is therefore historical size of the population of each historical county j that lives within the boundaries of county i. To construct population weights, we then use the population share of historical county j that lives within the boundaries of county i:

$$popweight_{ij} = \frac{pop_{ijl}}{pop_j}$$

In a final step, these population weights are the used convert data available only for counties in historical boundaries to current boundaries according the following expression:

$$Y_i = \sum Y_j * popweight_{ij}$$

Belgium

County boundaries (Arrondisment) stayed constant over the entire period of interest with only few exception: Arr. Halle-Vilvoorde (BE241) and Arr. Bruxelles-capitale (BE100) were founded in 1963 from the the Arr. Brussel pheripque; Arr Mouscron (BE324) was founded from parts of Arr Ypres (BE253) and Arr Countrai (BE254). These changes occurred in 1963 when the linguistic border was created. For these cases, data of the affected counties has been aggregated.

France

In France, the county boundaries (Departments) stayed constant over the entire period of interest with a few exceptions: The historical Department Seine-et-Oise was subdivided into the new Departments of Essonne, Val-d'Oise and Yvelines in 1968; Seine was subdivided into Hauts-de-Seine, Seine-Saint-Denis Val-de-Marne and Paris in 1968. For the analysis, we aggregate the new departments according to the old boundaries which reduces the number of observations but does not require any information about the distribution within the old counties. These new departments all belong to the metropolitan area /agglomeration Paris and therefore form an integrated labour market.