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. In this paper, we analyse the effect of coal and oil on long-run economic growth, exploiting variation at the level of European NUTS-2 and NUTS-3 regions over the last century. We show that an "oil invasion" in the early 1960s turned regional coal abundance from a blessing into a curse, using new detailed data on carboniferous strata as an instrument. Moreover, we show that human capital accumulation was the key mechanism behind this reversal of fortune.

Using a mediation analysis, we establish that nearly all of the negative effect of coal on economic growth was due to an indirect effect of coal that limited educational attainment. However, we also find that regions with a higher density of established urban areas before the onset of the industrial revolution were more capable to adjust to the decline of coal, and some of these actually managed to fully adjust to the "oil invasion".

1 Introduction

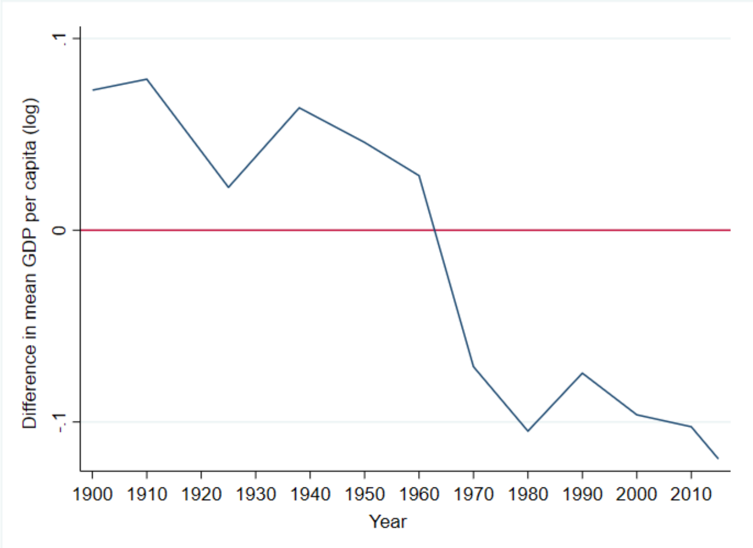
Are natural resources a "fundamental" driver of economic growth? Economists have long struggled to understand how geographic characteristics matter for economic growth, notably, why they sometimes appear as a blessing and sometimes as a curse. A prominent example is the role of coal for the European 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 illustrates how the reversal of fortune of European coal regions took place, at the level of NUTS2. The figure shows 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 abundant regions display a higher GDP per capita compared to all other regions. Starting in the 1960s this pattern is reverted 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 kind of shock was it that turned coal abundance from a blessing to a curse for European regions? And second, what mechanisms prevented coal regions to adjust to this shock until today? To answer these questions we construct new panel data on GDP, population, employment, and education at the level of NUTS-2 and NUTS-3 regions covering five European countries (Belgium, France, West-Germany, Netherlands, and UK) 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 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 use 1960 as a fixed treatment date and use carboniferous strata as an instrument. With this we find that coal regions experienced 20 percent less growth after 1960 than non coal regions. In a third step, we show that the influx of very cheap oil, mostly from Northern Africa, which started in the late 1950s, can explain this to a large extent. Our hypothesis is that an "oil invasion" caused a negative labor demand shock in mining, which in turn led to the decline in GDP per capita. Following Feyrer, Sacerdote, and Stern (2007) and Charles, Hurst, and Schwartz (2019), we measure the decline in mining employment as a share of total employment in a region between 1960 and 1970 and then instrument for this using 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

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



Notes: Sources see text.

us to our second question.

Why did regions fail to adjust to the "oil invasion"? Our basic hypothesis is about human capital, more specifically to rates of human capital accumulation in coal regions after 1960 that were high, but nevertheless too low compared to non coal regions. To show this we again 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 the idea that 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 growth in recent decades occurred due to this indirect effect via low attainment in tertiary education. In a 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, in line with the "reinvention hypothesis" proposed by Ed Glaeser. Some regions were actually able to fully adjust to the "oil invasion".

We see our paper as related to three 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), or Matheis (2016) on the US. More recently Fernihough and O'Rourke (2020) 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 a 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. Berbee, 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 new, more detailed data on coalfields and geological carboniferous strata to estimate its changing causal effect in a panel from 1900 until 2015. This panel data allows us to show that the switch from a positive to a negative effect of coal occurred around 1960. Second, and more importantly we show how the "oil invasion" in the late 1950s can explain this switch in sign. We capture the decline of coal with the jobs lost in the mining sector as a fraction of overall initial employment at the level of NUTS-3 regions. To address concerns of endogeneity, we instrument for the change in mining employment using exposure to import substitution from oil weighted by the share of land area with carboniferous strata in overall area. With this, we show that the decline in mining, driven by the rise of "dirt-cheap" oil imports since the late 1950s had a strong causal effect on GDP per capita (at both levels of NUTS-3 and NUTS-2).

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. We contribute to this literature by stressing the particular role of coal mining for these disparities and importantly, their changes over time. While coal abundance had fostered population and income growth in many formerly poor regions during the 19^{th} century, we show how it caused regions to fall behind, starting in the 1960s. 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. P. Kerr, and W. R. Kerr (2015), Gennaioli et al. (2013) and Franck and Galor (2021) for French regions, and recently Esposito and Abramson (2021) for a cross-section of European regions as of 2010. Our contribution is to show how the human capital channel gained importance over time, based on a new panel of European regions at the level of NUTS-2 and NUTS-3 over the last 120 years. To this end, we use a mediation analysis, following Pinto et al. (2019), and find that about 90% of the effect of coal on income is explained by (low) attainment in tertiary education. 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. 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.

Finally, our paper speaks to the "reinvention city hypothesis" as proposed by Glaeser, Saiz, et al. (2004). Accounting for heterogeneity in the treatment effect across coal regions, we find that regions with pre-industrial urban settlements could better adjust to the decline in coal mining. A possible interpretation is that places, which had to reinvent themselves repeatedly in history become more resilient over time. Pre-industrial urban success entails 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. We show that coal mining activity itself cannot be predicted by the pre-industrial settlement history of a region. Instead, the discovery of coal resources sparked urban growth in both places with and without preexisting major urban structures. Yet, from a long-run perspective the growth of these cities built on the green field did not turn out to be sustainable. As a consequence they experience persistent urban decline once the initial natural advantage disappeared.

The remainder of our paper is organized into 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.

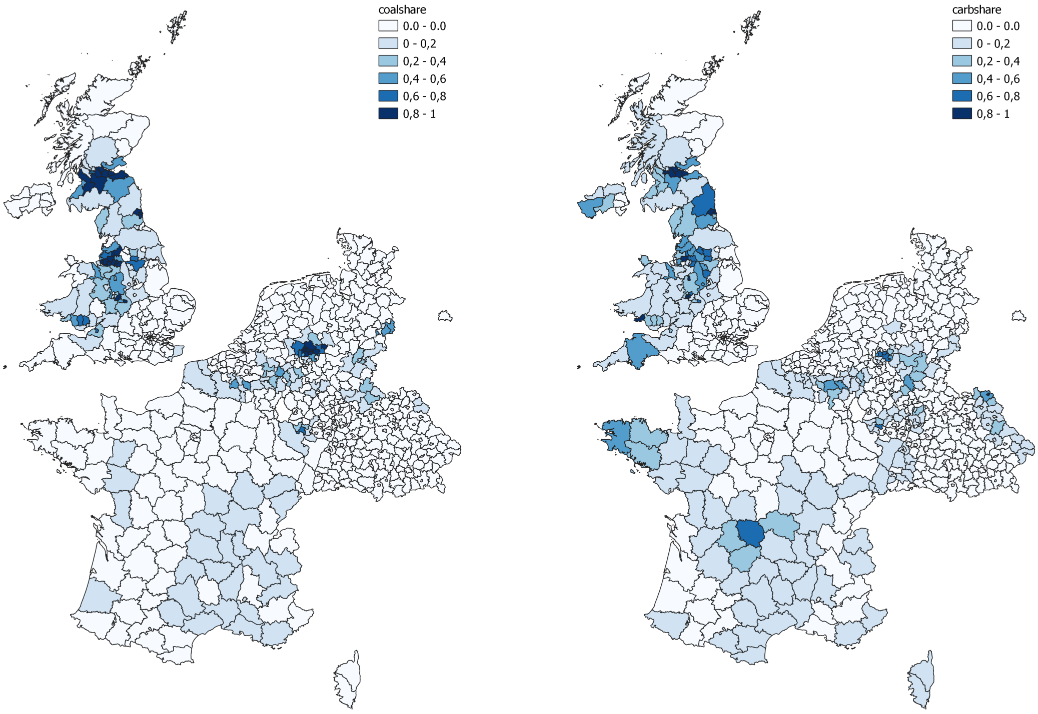
2 Data and descriptive Evidence

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 NUTS2 for developments 1900 - 2015, and NUTS3 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 Houilleres Europeennes, 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.[1]

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

Figure 2: Coal abundance in European Regions



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

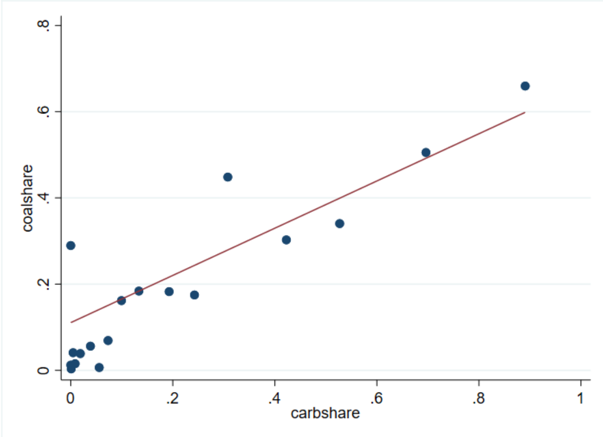
Notes: Panel a) depicts the share of land area covered by coalfields (Source: Own measurement based on digitized maps from Châtel and Dollfus (1931). Panel b) shows the share of accessible land area covered by carboniferous strata. The measurement based on data from the German Federal Institute for Geosciences and Natural Resources (BGR) Asch (2003) and the European Environmental Agency EEA Kapos et al. (2000).shapefiles downloaded from `https://www.eea.europa.eu/data-and-maps/data/european-mountain-areas/`

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.[2] 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 (German Federal Institute for Geo-

[2]In the following coal mining is used synonymous to Anthracite or hard coal mining as well Bituminous coal. These two types of coal have a higher carbon amount and higher heat value compared to lignite or brown coal and can therefore be used both for electricity generation and industrial applications.

Figure 3: Correlation coal measures



Notes: Sources see text.

sciences and Natural Resources (BGR)). 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 the ease of accessibility, which varies with regional topography. To account for this, we exclude all carboniferous strata that are 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 NUTS3 the correlation between the percentage share of land covered by historical coalfield ("coalshare") and the percentage of land area covered by carboniferous strata, controlling for mountains ("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".

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)[3]. 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 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.

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

Next, 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 (see Data Appendix). 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 1950, before European coal mining started its long decline (see figure A2).

We describe the evolution of human capital using the share of the active population that has completed tertiary education (obtained a post-secondary degree), comparable to Glaeser, Saiz, et al. (2004). For this, we rely on census data and published aggregate statistics by the statistical offices of the respective countries (see Data Appendix). 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 1951, 1961 and 1971, 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 (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.)

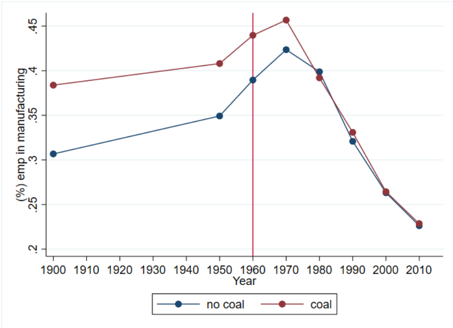
In figure 4 we provide some descriptive evidence for coal regions (defined as regions with coalfields as of 1921) and regions without coalfields. In line with our evidence on GDP per capita, shown above (figure 1) we see that in 1900 coal regions used to have a higher share of manufacturing in total 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 *within* 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. Finally, figure 4c compares the evolution of human capital formation for coal and non-coal regions for NUTS2 regions. 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 shows that former coal producing regions had a slightly lower share in 1970, when our data begins, and were increasingly 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. Note that figure 4c ignores differences in education systems and definitions between countries. Once we take them into account, the educational gap between coal and non coal regions becomes even more pronounced.

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. In contrast, population densities have always been somewhat lower in coal regions between 1900 and 2010. 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 countries 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 will always include country fixed effects.

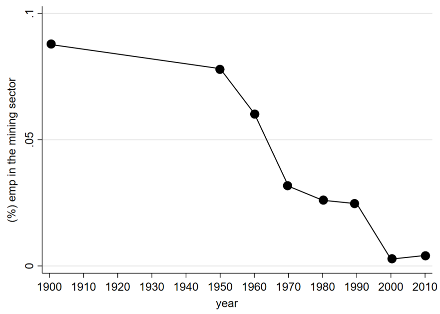
As further controls we also collected data on first and second nature variables, namely mean temperature, rainfall, crop quality, distance to the coastline, landshare covered by mountain areas, distance to the next harbour, dummies for whether a region includes the capital or a metropolitan region as well as past and current population densities (for sources see Data Appendix). To further explain potential heterogeneity across the coal regions we measure the urban density in 1700 before industrialization took off. 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 NUTS 3 boundaries to get a measure for the overall pre-industrial urban population density of a region.

To summarize, our descriptive evidence suggests that coal abundance turned around 1960 from being a blessing to 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.

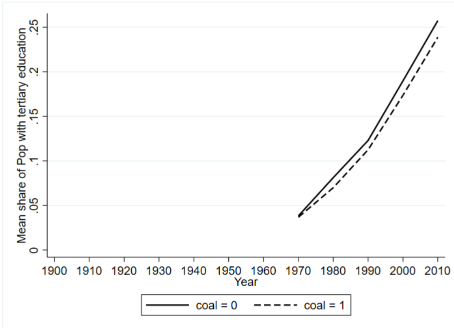
Figure 4: Descriptive statistics



(a) Share Manufacturing Employment



(b) Share Mining Employment



(c) Share Tertiary Education

Notes: Sources see text. All data refers to NUTS2 regions.

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

3.1 The reversal of fortune, 1900 - 2015

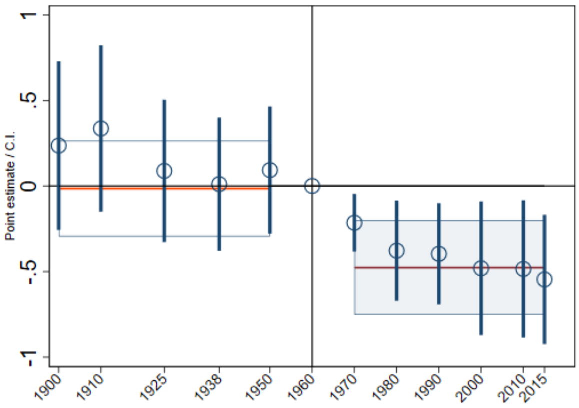
To identify the effect of coal abundance on economic development more formally we start with a standard Difference-in-Difference approach with a flexible treatment. At this stage, we want to be agnostic about the "treatment", but we can interpret it in analogy to Fernihough and O'Rourke (2020) as the changing availability of substitutes. We estimate:

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

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 fixed effects δ_{jt} for each country j and the full set of geographical controls X_i each interacted with decadal dummies.

Figure 5 shows the result, with 1960 as the omitted category. The coefficient on

Figure 5: The effect of coal abundance on GDP per capita (Flexible Treatment effect).



Notes: Coal abundance is measured as the percentage of land area covered by coalfields. All specifications include observation and time fixed effects. Robust standard errors are used. Population density as well as time interactions for all our geographical variables are used as controls.

coalshare relative to this reference is in 1900 and 1910 positive, drops in the interwar 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 $\delta_j t$, and the full set of geographical controls X_i each interacted with decadal dummies. In this specification we focus on $coalshare * I_{Post1960}$, the interaction between the areashare covered by coalfields 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^{th} and 19^{th} century are not likely to be randomly selected.[4]. We use geological rock strata combined with information about the mountain

[4]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 today, a simple OLS regression will suffer from a positive selection bias. Despite controlling for a wide range of observable first and second geography such as pre-industrial urban density, distance to ports as well climate and soil quality we cannot rule out any omitted variable bias. Running a simple regression with the coalshare as a dependent variable and first and second nature variables as independent variables we do not find a strong selection effects.

topography as described in section 2 as an instrument for existing coalfields in the early 20th century. As shown, the instrument is highly correlated to the location of actual coalfields.

Table 1 shows the results running specification 2 as an OLS as well as a 2SLS specification using "carbshare" (carboniferous rock strata) as an instrument for "coalshare". In column 1 and 2 we present the baseline effect for OLS and 2SLS respectively, whereas in column 3 and 4 all controls are included.

Including controls yields a higher and more significant β-coefficient for both the OLS and IV regression. In both cases, the instrument can be considered as valid as the F-Statistic exceeds 10. When comparing the results from OLS to that from the IV-regression, we see that the latter is considerably larger while still highly significant. This suggests that there is indeed a positive selection into treatment, as discussed above, in addition to possible measurement error.[5] 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 median coal region (with a coalshare of 14 percent) experiences about 20 percent less growth after 1960 compared to a region without any coal.[6]

Table 1: Treatment effect Analysis: GDP per capita (log)

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	0.97	0.97
KP (F-stat)		10.66		10.48

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 seems to be uncorrelated with coal abundance (compare Appendix table A 2)

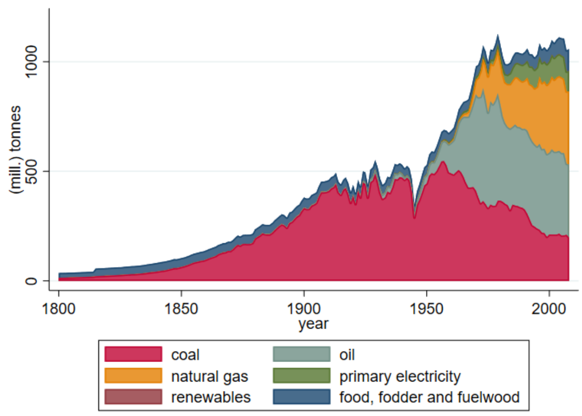
[5]The maps by (Châtel and Dollfus, 1931) depict the major coalfields in 1921. Using this source the researcher fails to detect very small coalfields as well as coalfields that were already exploited and therefore no longer operated.

[6]We show in the Appendix figure A3 that the β-coefficients are slightly declining and the standard errors are somewhat increasing the further we move away from 1960. If we were to set the treatment date prior to 1950, the effect would become insignificant, in line with our evidence from figure 5.

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) how total energy consumption increased and how the composition of energy consumption changed dramatically since the late 1950s. Around that time, coal started to be replaced by oil, followed later by natural gas and other sources.

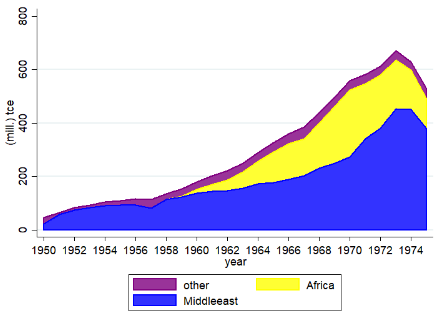
Figure 6: The first and second energy transition



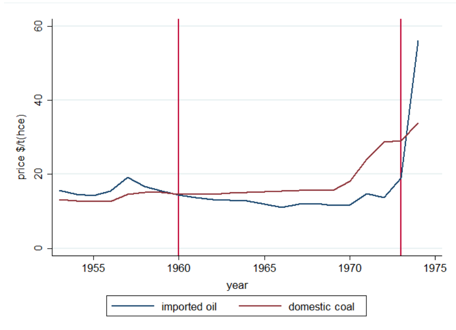
Notes: Own graphical illustration based on data from Kander, Malanima, and Warde (2013)https://histecon.fas.harvard.edu/energyhistory/sources.html. The figure shows the total energy consumption converted to million tonnes hard coal equivalents for France, Germany, the Netherlands and the UK. Belgium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

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 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. 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).

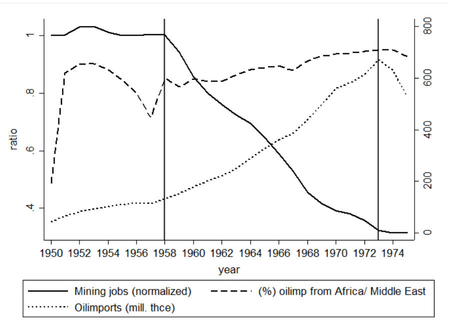
Figure 7: The oil shock



(a) oil imports by origin



(b) energy prices



(c) mining jobs and oil imports

Notes: sources see text and data appendix

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.[7] 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 A4 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 and simultaneously lowering input costs in other sectors and across all regions.

[7]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 Great 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, Hungerland, and Kersting (2021) show how the grain invasion during the first globalization affected income levels across Prussian regions before 1913.

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 coal mining via a decline in labor demand for coal miners. To capture this, we proceed in two steps, following Feyrer, Sacerdote, and Stern (2007) and Charles, Hurst, and Schwartz (2019). 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 total jobs in a region. Formally:

$$shock_{i196070} = -(\frac{\Delta L_{mi196070}}{L_{i1950}})$$

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.

While the loss of mining jobs is likely to be correlated with the decline in GDP per capita of coal regions, this is hardly a causal effect. In a next step, we exploit variation coming from a region's exposure to changing oil imports at the national level u, 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 a country. The latter provides us with exogenous variation:

$$\widehat{shock}_{i196070c} = \frac{Carboniferousstrata_i}{Carboniferousstrata_u} \frac{\Delta IMP_{u196070}}{Area_i}$$

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 always add a control for the manufacturing share in total employment, excluding mining. Moreover, in some specifications further 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:

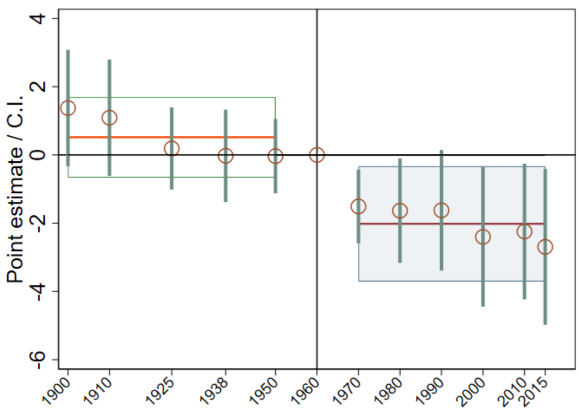
$$Y_{it} = \alpha_i + \gamma_t + \delta_{jt} + \sum_{t=1950}^{2015} \beta_{1t} * shock_{1960-1970} * I_t + \sum_{t=1950}^{2015} \beta_{2t} * X_i * I_t + \epsilon_{it} \quad (3)$$

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 of oil imports, which suggests a negative and significant causal effect of very similar magnitude. Once we add further controls, we see that the effect sizes are increasing and gain significance. Moreover, the F-stats suggest that our instrument is quite strong.

Table 2

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	0.99	0.99
KP (F-stat)		160.71		53.74

Figure 8



Notes: All specifications include Nuts2 and time fixed effects. Robust standard errors are used. Population density, the manufacturing share in employment as well as time interactions for a variety of geographical variables are used as controls.

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.[8] 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. Moreover, figure 8 illustrates our findings from table 2, col. 4, and its variation over time. 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 the curious persistence in the relative decline of coal regions. Our main argument is about human capital, or better the lack thereof, that prevented regions to adjust and 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 an 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 NUTS2) 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 NUTS2 and the more detailed NUTS3 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 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 figure 4c). To estimate the gap between coal and non-coal regions, we use the same approach as in equation

[8] 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.

Table 3: Treatment effect Analysis: 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

(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 "carbshare" as an instrument. According to the IV specification (2) a one percentage point increase in the coalshare results in 0.17 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 NUTS3 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 continued to fall behind relative to non-coal regions.

Figure 9 depicts the changes in this effect over time (estimated with IV), again for our NUTS2 sample (left panel) and the larger NUTS3 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.

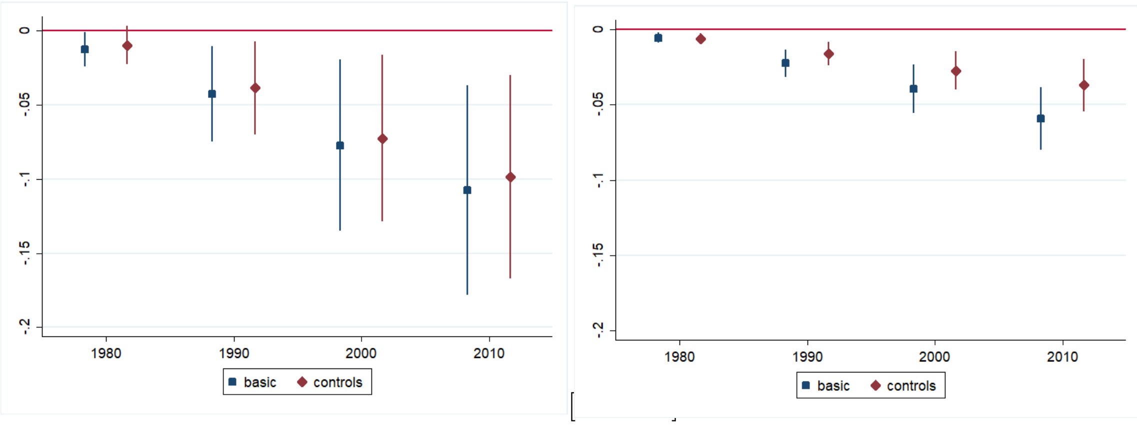
4.2 Mediation analysis: human capital as a transmission channel

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 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

Figure 9: The effect of coal abundance on educational attainment (flexible treatment effect)

(a) NUTS2 sample (b) NUTS3 sample



Notes: All specifications include region and time fixed effects. Robust standard errors are used. Population density, the manufacturing share in employment as well as time interactions for a variety of geographical variables are used as controls.

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:

$$T = \theta_{it} + \gamma_t + \beta_{TZ}(Z) + X_{it} + \epsilon_{it} \quad (4)$$

$$M = \theta_{it} + \gamma_t + \beta_{MT}(\hat{T}) + X_{it} + \epsilon_{it} \quad (5)$$

$$M = \theta_{it} + \gamma_t + \delta_{MT}(T) + \delta_{MZ}(Z) + X_{it} + \epsilon_{it} \quad (6)$$

$$Y = \theta_{it} + \gamma_t + \beta_{YM}(\hat{M}) + \beta_{YT}(T) + X_{it} + \epsilon_{it} \quad (7)$$

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_{it} (time varying) fixed effects at the country–level, time fixed effects γ_t and the given set of controls 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):

$$Y = \theta_{it} + \gamma_t + (\beta_{YM} * \beta_{MT} + \beta_{YT})(\hat{T}) + X_{it} + \epsilon_{it} \tag{8}$$

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

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 there is no significant direct effect of coal abundance on GDP per capita, 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. 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, controlling 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. 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 be also 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.

Our approach remains valid in the presence of con-founders 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

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

Dep. var.: GDP per capita (log)	(1)	(2)	(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	✓	✓	✓
Nuts1 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 direct and indirect effect of coal abundance on GDP per capita. 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). Robust standard errors are used. Population density as well as a variety of geographical variables are used as controls.

on a ten-year lagged variable for human capital. Although this time lag alleviates the concern, it cannot fully rule out reversed causality. Since educational attainment levels are persistent over time it might be as well the case that the decline of the coal industry led to an economic downturn that reduced the budget for local public investments in education, while more prosperous regions attracted a higher educated workforce due to higher amenity levels and/or higher investments in education.

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 the 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) suggests that regions might have been able to "reinvent" themselves after a shock if they had an urban tradition before 1800, that is, *before* coal started to become a relevant factor for economic growth. We take this as a starting point.

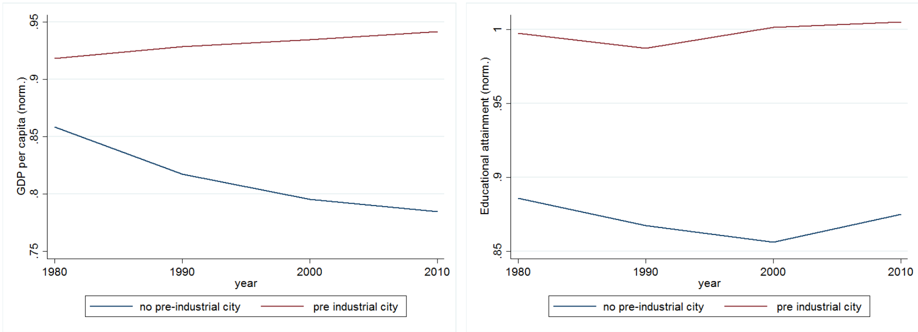
Figure 10 shows the difference in the evolution of GDP per capita and educational attainment between 1980 and 2010 within our group of coal regions, between those that contained a city with a population exceeding 5000 inhabitants in 1700 and those that did not. In each case, we show their respective performance relative to the respective national average. 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 nations 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.[9]

Following Glaeser's reinvention hypothesis, cities (and regions around them) that have reinvented themselves repeatedly in history might have become more resilient over time. Glaeser and Saiz (2004) find that human capital is especially important for cities that face adverse economic shocks regions. Testing the reinvention hypothesis they show

[9] One caveat here could 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.

Figure 10: Former coal areas and pre-industrial citydensity

(a) GDP per capita (b) Tertiary Education Share



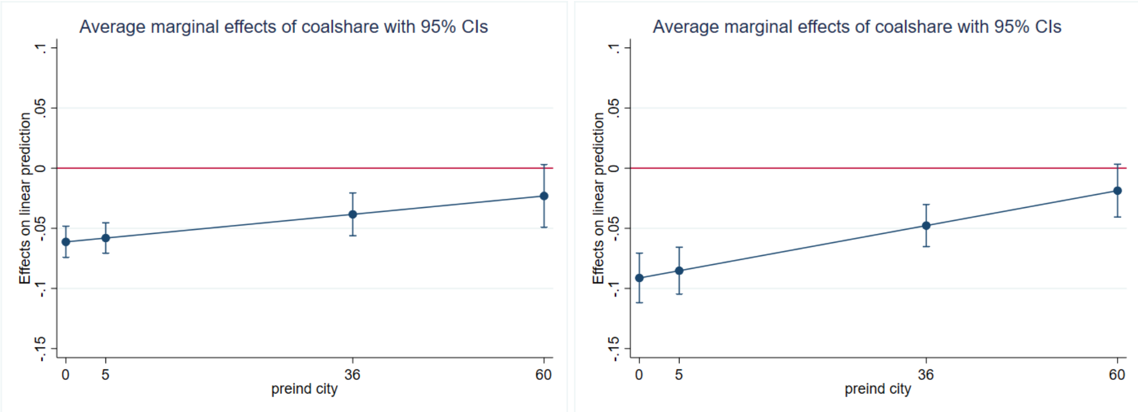
Notes: The figures show the deviation from respective country averages in terms of GDP per capita and tertiary education shares for coal regions. We distinguish between coal regions that contained at least one city with at least 5000 inhabitants (preindustrial city) and coal regions that did not (no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

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 display a higher initial skill level. Glaeser (2003) furthermore illustrates for the case of Boston how a strong skill-base enabled the city to re-invent itself multiple times in history.

A simple way to test whether and to what extent pre-industrial city density moderates the (direct and indirect) 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 educational 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 regions has a higher pre-industrial citydensity 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 of 36 people per square kilometer the negative effect of a one percentage point increase in coalshare is reduced by 60 percent $((-0.09 + (0.0015 * 36))/0.09)$. Next we add first and second nature geographical controls. 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 percent (=60) of the citysize distribution in 1700) as given by specifications with a full set of controls (OLS, left panel) and (IV, right panel). 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 experience no longer a statistically significant negative effect. In our preferred specification using the IV estimation, the effect for a former coal region with the average pre-industrial city density of 36 people per square kilometer is reduced by one half and still statistically significant.

Can we open the black box of pre-industrial city density and how it is related

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



(a) OLS (b) IV

Notes: Specifications with full set of controls as described in table A 4, col. 5 (OLS) and col. 6 (IV) in the appendix. Sources: see data appendix.

to human capital? First of all there might be a 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. 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. In particular, recent urban success has been defined by the shift out of manufacturing into knowledge intensive services. Third, regions with pre-industrial cities are likely to benefit from a tradition of local institutions such as schools and universities. We test for the presence of 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 populations density, industrial diversity, and the employment share in services. We proxy industrial diversity by constructing an Herfindahl index based on employment shares in six different sectors. The outcomes are measured in levels as of either 1950 or 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 these channels. Apparently, coal-regions regions with a pre-industrial urban centre had somewhat higher employment in services, a more diversified industrial structure 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

We started the paper with two main questions: how and when did coal, the pre-eminent fossil fuel of European industrialization, turn from a blessing to a curse? And what explains the puzzling persistence of the coal curse, long after coal mining stopped to be a sizeable economic sector? These questions and our answers to them have renewed relevance today. We showed that the turning occurred around 1960 and argued it was 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 Europe' 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.

Yet, what remained puzzling was the persistence of the shock. Why did coal regions fail to adjust, even decades after the "oil invasion" was over? In the second part of our paper, we exploited 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 could show that this indirect effect dominated, and actually did so from the 1990s onward. Hence, while coal mining became a negligible sector, coal regions continued to fall behind, because they failed to *expand* tertiary education fast enough. This left 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 a final part of our paper, we highlighted the very substantial heterogeneity between coal regions, related to their pre-industrial history: we showed 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 begged a host of 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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Appendix

Data Appendix

(to be completed)

Appendix Tables

Table A 1: Descriptive Statistics NUTS2 and NUTS3 sample

	NUTS2		NUTS3	
	no coal region	coal region	no coal region	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

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

Table A 4: Interaction effect: Educational attainment

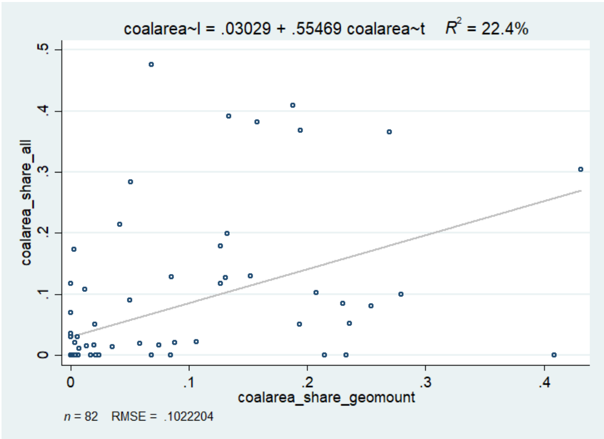
	(1)	(2)	(3)	(4)	(5)	(6)
coalshare	-0.03953***	-0.09039***	-0.03650***	-0.09130***	-0.06127***	-0.12442***
	(0.00589)	(0.00947)	(0.00558)	(0.01051)	(0.00662)	(0.01298)
preind city	0.00016***	0.00015***	0.00015***	0.00015***	0.00010***	0.00009***
	(0.00005)	(0.00003)	(0.00005)	(0.00003)	(0.00003)	(0.00003)
coalshare × preind city	0.00059**	0.00118***	0.00063**	0.00121***	0.00064***	0.00099***
	(0.00023)	(0.00020)	(0.00030)	(0.00021)	(0.00022)	(0.00020)
lnmeantemp			0.09298***	0.10599***	0.03458*	0.03714***
			(0.02305)	(0.01245)	(0.01840)	(0.01045)
lnrain			0.02474	0.04073***	0.05302***	0.06777***
			(0.01576)	(0.00867)	(0.01357)	(0.00794)
lncrop			0.01778	0.00824	-0.00928	-0.02661***
			(0.01082)	(0.00699)	(0.01107)	(0.00773)
mountain type			0.00038	0.00156	0.00104	0.00194*
			(0.00230)	(0.00125)	(0.00202)	(0.00113)
coast type			0.00222	0.00424***	0.00568***	0.00791***
			(0.00211)	(0.00112)	(0.00196)	(0.00108)
lndistharb					-0.00618***	-0.00664***
					(0.00204)	(0.00119)
capital					0.02983***	0.02077***
					(0.00832)	(0.00483)
lnpopden70					0.00592***	0.00874***
					(0.00186)	(0.00121)
uniden1945					-0.00021*	0.00033
					(0.00011)	(0.00023)
Observations	3355	3355	3355	3355	3355	3355
R-squared	0.76		0.77		0.81	
KP (F-stat)		125.43		108.32		86.98

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

Appendix Figures

Figure A1: Correlation between coalfields and carboniferous strata (NUTS2)



Notes: Coal abundance is measured as the percentage of land area covered by coalfields. In the IV-specification the percentage of land area covered by carboniferous strata is used as an instrument. All specifications include Nuts2 and time fixed effects. Robust standard errors are used. Population density as well as time interactions for a variety of geographical variables are used as controls.

Figure A2: Correlation between employmentshare in the mining sector in 1950 and existing coalfields

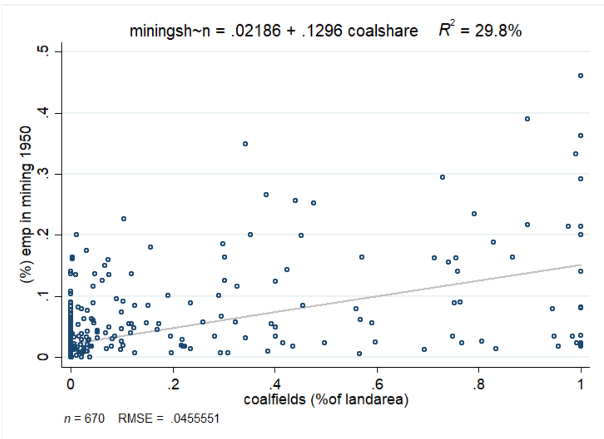
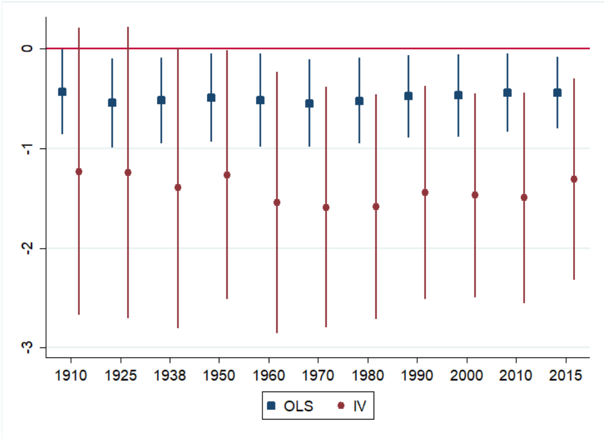
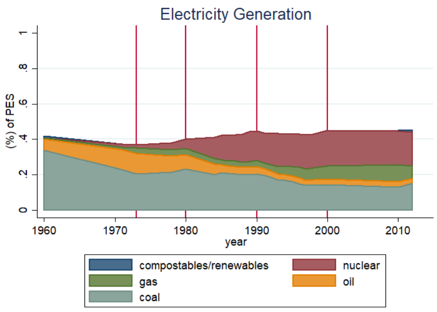


Figure A3: The effect of coal abundance on GDP per capita (alternative treatment dates)

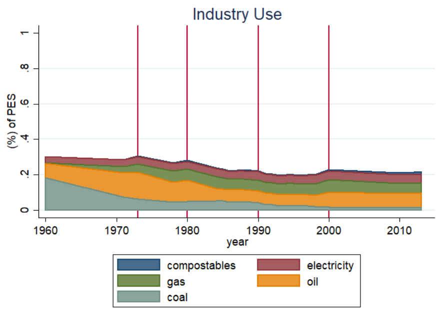


Notes: Coal abundance is measured as the percentage of land area covered by coalfields. In the IV-specification the percentage of land area covered by carboniferous strata is used as an instrument. All specifications include Nuts2 and time fixed effects. Robust standard errors are used. Population density as well as time interactions for a variety of geographical variables are used as controls.

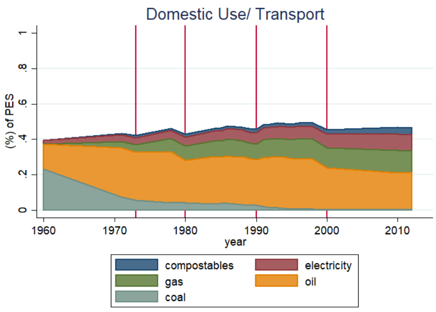
Figure A4: Energy use



(a)



(b)



(c)

Notes: Oil imports are measured as tonnes of hard coal equivalents aggregated for all five countries in the sample. Data is digitized from the Yearbooks Energy Statistics published by **the Statistical office of the European Communities** between 1950 and 1975, and later on published by **Eurostat**.