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Economic Consequences of Large Extraction Declines

Lessons for the Green Transition

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Economic Consequences of Large Extraction Declines: Lessons for the Green Transition*

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Abstract

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1 Introduction

Reaching net zero carbon emissions by 2050 requires a 80 percent reduction in global fossil fuel extraction compared with 2021 levels, according to the International Energy Agency (2022). Many countries could therefore experience a permanent contraction in their fossil fuel extractive sectors. What would be the macroeconomic impact?

A large body of literature emphasizes the negative impact of having a sizeable extraction sector on a country's economic growth, i.e., the resource curse, by weighing on the performance of manufacturing (see e.g., Frankel (2012) and Krugman (1987)) and on the quality of institutions (see Mauro (1995) and Lane and Tornell (1996)).

There is, however, a dearth of analyses on the macroeconomic effects of a reversal. It is an open question whether a decline in fossil production is detrimental or beneficial for countries' economic growth. Can the maladies identified by the resource curse literature during resource booms be reversed by shrinking the extractive sector? As climate policies and their effects on a specific country's extraction sector are uncertain, to what extent does anticipation or the lack thereof shape the effects of an extraction decline on economic activity, especially on the trade balance?

This paper sheds light on these questions by estimating the macroeconomic impact of large and persistent, exogenous declines in extraction activity. We study major transmission channels, the role of institutions, and compare the empirical results to a neoclassical model with and without full anticipation.

We collect a new data-set on the extraction of 13 commodities, including crude oil, coal, and metals, for countries worldwide starting in 1950. Using statistical and narrative approaches, we identify 35 episodes of persistent declines in extractive activity that are not correlated with other economic shocks hitting the economy at the same time. We set up a stylized classical small-open-economy real model to study adjustments to the extraction declines with and without anticipation. We use local projections to estimate the effects of these episodes on real output, the exchange rate, the quality of institutions, and the external and the domestic sectors.

The typical episode in our new data-set is a large and persistent decline in extraction activity: a 10 percent initial decline that accumulates to a 40 percent decline in the tenth year.

Local projection methods show that such a decline leads to a persistent decline in real GPD of six percent after about six years.

Both private and public consumption as well as investment fall in line with the decline in GDP. Consumption and the exchange rate, however, have a delayed reaction, inconsistent with full anticipation of the persistent fall in extraction and related revenues. The real exchange rate depreciates, eventually by about 20 percent, but not enough to stimulate a reallocation of economic activity towards other trade-able sectors such as manufacturing that could potentially offset the decline in exports. Empirical results, in fact, reveal significant negative spillover effects onto both the manufacturing and services sectors. Net exports fall in line with extraction.

The analysis finds heterogeneity of the effects across countries. This heterogeneity depends on their per capita income and the size of the mining sector relative to the economy. A large and persistent decline in extraction implies significantly larger declines in economic activity for low-income countries than for high-income countries.

Our results show that a decline in extraction activity does not improve the quality of institutions not even a decade after the shock. Theory stresses that increases in resource extraction diminishes long-term growth through rapacious rent-seeking (the voracity effect), negatively affecting the quality of institutions through political economy effects (as in Lane and Tornell (1996) and Tornell and Lane (1999)) and by increasing corruption (see Mauro (1995) and Leite and Weidmann (1999)). Our contribution to this literature is to show that there is no reversion of the deterioration of institutions after a decline in resource extraction. This suggests hysteresis effects and an asymmetric response of institutions to shocks: once institutions are damaged it is difficult to improve them. Stressing the relevance of good institutions, results also show that starting with higher-quality institutions can help to buffer the negative economic effects of persistent declines in extraction activity.

Our results also uncover negative spillover effects from the mining sector to the manufacturing and service sectors. The literature stresses that high resource extraction makes countries susceptible to the Dutch Disease. The real exchange rate becomes overly appreciated in response to positive commodity price shocks, causing a contraction of the tradable sector, especially manufacturing (e.g., Frankel (2012) and Krugman (1987)). We are the first to show that for the reverse case of decreasing resource extraction, the depreciation of the exchange rate does not stimulate a reallocation towards other tradable sectors such as the manufacturing sector, pointing possibly towards long lasting scars from resource boom. Since these sectors provide inputs and process outputs of the mining sectors, they are also negatively affected to an extent that more than offsets the potential benefits of the depreciation of the real exchange rate.

The initial share of the manufacturing sector in value added matters, though. Economies with a bigger initial manufacturing share fare better. This suggests that there are non-convexities in the tradable sector (i.e., sunk costs), favoring the intensive margin (existing exporting manufacturing firms) rather than the extensive margin (the establishments of new manufacturing firms).

We find little anticipation effects for extraction declines. This is in contrast to extraction booms, which are anticipated by large mineral discoveries and lead to an initial domestic saving-investment imbalance followed by the export boom as found in Arezki, Ramey, and Sheng (2017). It is, indeed, surprising how well a stylized classical small-open-economy real model can match qualitatively the empirical results once it departs from full anticipation. This is particularly the case, when the extraction decline is perceived as a series of temporary negative shocks that lead expectations of mining output to adjust slowly over time.

The paper runs a battery of robustness checks. Our results are robust to different specifications, the inclusion of various control variables and to using the synthetic control methodology. We also check for sensitivity to sub-samples and anticipation effects.

The main implication for policy makers is that the transition towards clean energy might be a challenge, especially for countries that rely on fossil fuel exports and are low to middle income. Countries will need to improve the quality of their institutions and policymakers should reduce climate policy uncertainty which may lead to a lack of anticipation, risking a more expensive adjustment process.

Our paper is to our knowledge the first to show that there are substantial impacts of declines in extractive activities at the macroeconomic level. It contributes to a broad literature on the resource curse (e.g., Sachs and Warner (2001) and Martin and Subramanian (2008)), as summarized in Brunnschweiler and Bulte (2008) and Ploeg and Venables (2012) that focuses on the macroeconomic effects of resource booms. This literature supports the theoretical prediction that higher resource extraction damages long-term growth (see e.g., Sachs and Warner

(2001), Feyrer, Mansur, and Sacerdote (2017), Allcott and Keniston (2018), Arezki, Ramey, and Sheng (2017), Cust, Harding, and Vezina (2019), and Harding, Stefanski, and Toews (2020)). There is a string of the literature that studies periods of resource busts, which is, however, focused on regional economic impacts (see e.g., Black, McKinnish, and Sanders (2005), Cavalcanti, Da Mata, and Toscani (2019), Watson, Lange, and Linn (2023), Jacobsen and Parker (2016), and Hanson (2023)).

Finally, our results can provide empirical benchmarks to an emerging literature on the impact of the clean energy transition on fossil fuel producing countries. This literature has mostly focused on the economic implications of stranded assets (see e.g., Ploeg and Rezai (2020)) and fiscal implications (see e.g., Mirzoev, Zhu, Yang, Zhang, Roos, Pescatori, and Matsumoto (2020)) so far.

The paper is structured as follows. Section 2 introduces our new data-set and explains how we identify the shock episodes. Section 3 presents the macroeconomic effects of these shock episodes based on simple plots. Section 4 introduces our theoretical framework and its results. Section 5 explains the empirical framework and Section 6 present the empirical results. Section 7 examines the relationship between persistent extraction declines and the quality of institutions. Section 8 provides robustness checks and Section 9 concludes.

2 Identification Strategy: Episodes of Exogenous Extraction Declines

The main concern when estimating the causal effect of a decline in extractive activity on macroeconomic variables is reverse causality and omitted variables. In particular, events that affect mining production may equally be correlated to GDP (or other variables) or, to put it differently, a decline in economic activity may have repercussions on mining output in the same year. To address this substantial issue, we build a new data-set consisting of fossil fuels and mineral extraction, mineral prices, and macroeconomic variables; then starting from a far larger set of candidate episodes, we identify 35, macro-economically relevant, exogenous episodes of declines in extraction output for 11 commodities across 30 countries using a narrative approach. These 35 episodes are plausibly unrelated to other development in the domestic economy or global activity and can, thus, be used to infer their causal effect on the country's macroeconomic variables.

2.1 The Dataset

We assemble data on mining (or primary) production of fossil fuels and metals, and identify episodes of sustained declines. We collect an unbalanced data-set for the 13 largest commodities in terms of their worldwide production value for 122 countries from 1950 to 2020. Please find the list of commodities and descriptions in Appendix A.

We combine annual data on the extracted quantities from different sources. We take historic primary production data for 11 commodities from Mitchell (2013) and include data on copper and lead production from the Federal Institute for Geosciences and Natural Resources (2012). The global historic production of metals is taken from U.S. Geological Survey (2012).

We take historical world prices of coal and metals from Schmitz (1979) and Schwerhoff and Stuermer (2019), and prices for oil and natural gas from BP (2022). We account for inflation by using the US consumer price index to deflate the commodity price data. We collect country-level data on macroeconomic variables including real GDP in local currency, nominal GDP, investment, private and public consumption, exports and imports, the real exchange rate (relative to the US Dollar), the current account and employment. We source the data from Feenstra, Inklaar, and Timmer (2015). We use data on real value added by industry from the United Nations (2022). Finally, we include measures on political stability and institutional quality from the Center for Systemic Peace (2022) following Acemoglu, Naidu, Restrepo, and Robinson (2019).

2.2 Large, Persistent, and Macro-relevant Extraction Declines

A candidate episode is any extraction pattern $\{Q_{t+k}\}_{k=0}^{T}$ over a given time window, $[t, T]$, for each country and commodity. To obtain a measure of its macroeconomic importance for each identified episode i, we compute the *average value of the extraction decline (ADV)* relative to the country's nominal GDP at the start of the episode:

$$ADV_i = \frac{1}{T_i} \frac{\sum_{k=1}^{T_i} \Delta Q_{t+k,i} P_{t+k,i}}{GDP_{t,i}}, \tag{1}$$

where Q and P are the production and price of the commodity considered and T is the duration of the episode.[1] The duration of an episode is defined as the number of years between the production peak (t=0) to the trough (t=T) where the trough is identified as the first year in which the fossil fuel sector operates at the new, permanent production level after the decline.

Episodes are initially selected using three criteria pertaining to the size, persistence, and macro-relevance of the decline in line with our objective to learn more about the potential impact of the energy transition: (a) The cumulative decline in the quantity of production is at least 20 percent from peak to trough; (b) after reaching the trough, the production level has to remain below its pre-shock level for at least 5 years; (c) the ADV is at least 0.05 percent. Criteria (a) and (b) isolate 154 episode, adding criterion (c) reduces that number to 70 macro-relevant episodes.

The value of the declines can be sizeable. The largest declines in terms of average revenue losses took place in oil, copper and gold production. Especially declines in crude oil production seem to come with large revenue losses of almost 20 percent of GDP on average (Appendix A shows the average size and duration).

2.3 Exogenous Extraction Declines

To identify episodes of extraction declines that are plausibly exogenous, we categorize them first by six different causes based on a narrative historical analysis (in the spirit of Romer and Romer (2010) and Ramey (2011) among others):

a. structural transitions (e.g. the breakdown of the Soviet Union) or wars,

b. global recessions,

c. policy changes affecting all domestic industrial sectors,

d. policy changes affecting only the mining sector,

e. depletion,

f. undefined causes.

[1] The ADV is closely related to the Net Present Value (NPV), which is used in empirical work on resource windfalls like in Arezki, Ramey, and Sheng (2017). We can not compute the NPV, because the duration of the exogenous declines is ex-ante uncertain and the discount factor could vary across countries and time.

Episodes in categories (d.) and (e.) are classified as exogenous since the driving factors are supposedly exogenous to (aggregate) domestic economic conditions and do not affect other sectors at the same time. In such cases, the most typical decline is either the result of a change in domestic policy specific to the commodity sector or depletion.

Domestic policy changes include the nationalization of mines or changes to the tax regime. For example, Guyana nationalized its bauxite mines in 1975. Subsequent mismanagement drove down their efficiency and resulted in large declines in production. An example for a tax change, is the sudden tax increase on bauxite mining in Suriname in 1974. This tax increase only affected bauxite mining but not other sectors. The levy led to a decline in bauxite mining by more than 30 percent over the next five years and a permanently lower production level thereafter. We exclude episodes during which policy changes are part of a broader change in economic policies (e.g., the nationalization of all mining industries and redistribution of land in Zimbabwe in 1999).

Exogenous production declines due to depletion encompass instances, when the quality of the deposit or reservoir deteriorates for geological reasons or due to missing investment. These two factors often interact with each other. In any case, the result is higher production costs, making production unprofitable and forcing the mine to close down. One example, is iron ore mining in Eswatini in 1975, where lower ore quality made mining unprofitable and resulted in fast declines in production and the subsequent closure of mines. Another example is Chad, where aging oil wells and declining reservoir quality led to higher production costs and made investment unprofitable after 2005.

Focusing only on the exogenous ones, leaves us with 35 episodes of large and persistent declines. Table 1 provides the summary statistics, while Appendix B lists all episodes with more details about their narrative.

Figure 1 shows the distribution of these declines over time. The occurrence of shock episodes is relatively evenly distributed and is unrelated to the global economic cycle.

	1 # of Decline Episodes	2 Decline of Extraction Quant. (% of Peak)	3 Decline of Extraction Value (Mil. USD)	4 Duration (Years)	5 Annualized Decline Value (% of GDP)
Bauxite	3	-50	-96	5	-1.9
Copper	3	-78	-619	13	-0.6
Crude Oil	18	-45	-10,000	9	-2.5
Gold	3	-52	-2,060	7	-0.4
Lead	1	-78	-11	6	-0.1
Natural Gas	2	-54	-4,480	6	-0.1
Nickel	1	-83	-98	7	-0.1
Iron	1	-78	-32	5	-1.7
Silver	1	-44	-14	8	-0.9
Tin	1	-65	-236	6	-1.2
Zinc	1	-99	-95	7	-1.1
Total	35				

Table 1: Summary statistics of the exogenous declines in extraction activity by commodity.

Notes: Column 5 (the average ADV) is the result of dividing column 3 by column 4 and the GDP at time $t = 0$ for every shock episodes.

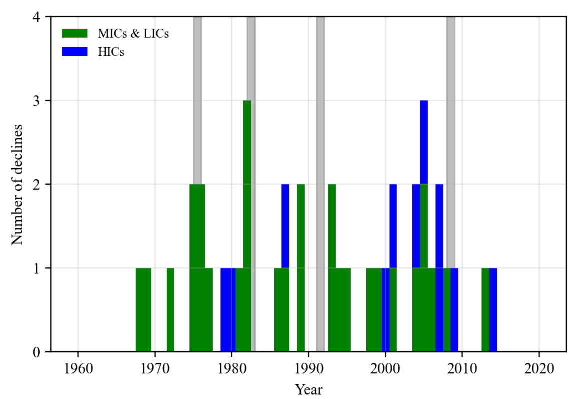


Figure 1: Distribution of extraction decline episodes over time.

Notes: MIC = Middle Income Countries, LIC = Low Income Countries, HIC = High Income Countries. The shaded areas represent global recessions as defined by Kose, Sugawara, and Terrones (2020).

2.4 Anticipation

Declining extraction activity due to lower ore quality but also due to policy changes could be anticipated, leading the economy to start the adjustment beforehand. Anticipation would bias our estimation results towards a smaller negative impact on aggregate output, because the regression would not capture the initial adjustment.

To assess the extent to which shocks were anticipated, we reviewed information on commodity production in Article IV consultation reports from the International Monetary Fund (IMF) and compared them to the actual extraction declines. These IMF reports aim at summarizing all relevant macroeconomic information based on discussions and information provided by the respective country's authorities, the private sector and IMF staff estimates. The biannual reports also typically provide a 5-year outlook for the economy and give guidance on macroeconomic and fiscal policies.

We find evidence that the initial decline in production was not anticipated in 24 decline episodes out of 29 decline episodes with Article IV Staff Reports (see Appendix B). The initial decline was fully anticipated in only four episodes. For one episode a staff report was available but the commodity production was not mentioned. There were no Article IV Staff reports available for the remaining six episodes. We keep the four episodes that were anticipated in the sample but check the sensitivity of our results to anticipation in Section 8.2.

We also conduct a detailed examination of revisions in commodity volume projections for the entire episodes for Chad and Gabon. We choose these countries, because they feature subsequent IMF Article IV consultation reports that cover the entire time of the episodes and the importance of oil production for their economies is among the five highest in the sample.

In both cases the detailed quantitative examination confirmed that extraction decline episodes were entirely unanticipated. In the case of Chad, the year before the decline started production over the next five years (2005-09) was projected to increase by 25 percent relative to the pre-episode peak (2005). This optimistic projection was more that 50 percent above the actual realized production during the period.

In the case of Gabon, the year before the decline started production over the next three years (1997-99) was projected to increase by 5 percent relative to the pre-episode peak (1997). By 1999 this initial optimistic projection exceeded lower realized production by 15 percent.

Once the decline episode was underway, the degree of anticipation of the persistent decline differed considerably for Chad and Gabon. In the case of Chad, one year into the decline episode (i.e., in 2006) the extent of the subsequent 5-year fall in commodity production was largely anticipated. Specifically, the projected fall was 72 percent of the realized decline in production volumes during 2006-10. In contrast, for Gabon we find that one year into the decline episode (i.e., in 1998) production was projected to return to the level of the pre-episode peak. Thus, the production fall was seen as fully transitory.

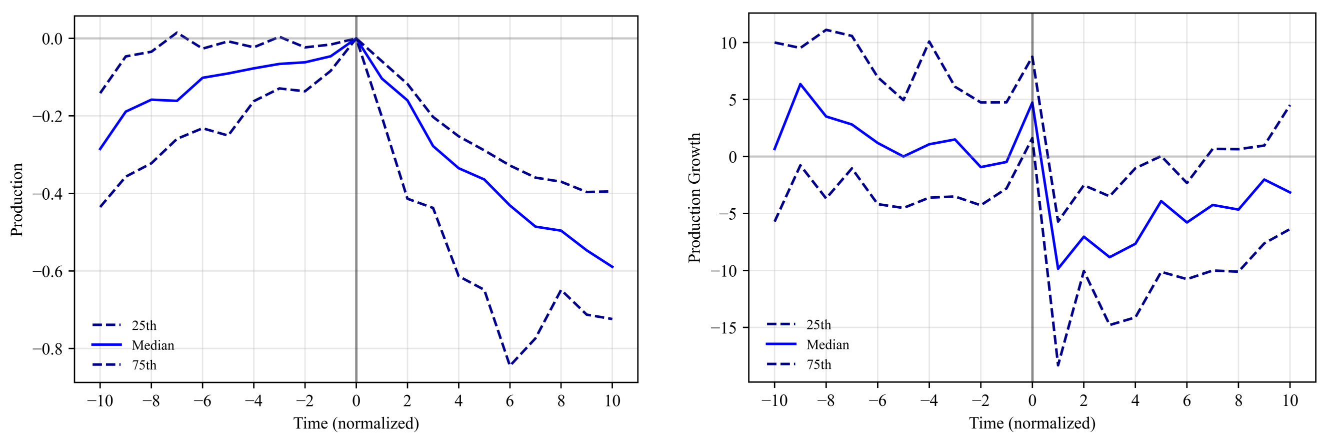
Overall, the in-depth exercise shows that the large and protracted production declines were entirely unanticipated a year before their start and exhibited varying degrees of anticipation after the declines were underway.

3 Extraction Decline Episodes: A Preview

Plotting the data of the 35 episodes gives an initial flavor of the relationship between declines in extraction and aggregate output.

3.1 Mining Activity

Figure 2 presents the episodes of extraction declines in log-deviations from peak production before the decline and in growth rates. Time zero is the year of peak production before the start of the decline, the time window ranges from 10 years before and 15 years after the shock.



(a) Extraction output relative to peak. (b) Extraction output growth (in %).

Figure 2: Exogenous declines in fossil fuel and mining activity.

Note: Time $t = 0$ corresponds to the peak of production and time $t = 1$ is the first year with a negative production growth rate. We normalize the log-level of production relative to the median at time zero. We present the 25th and the 75th pointwise percentiles for every horizon.

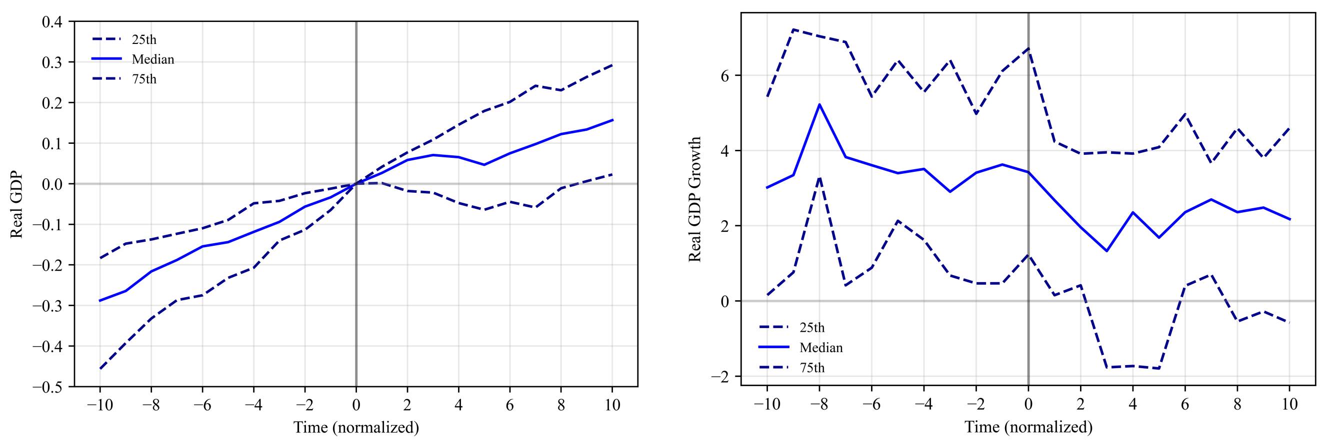
The exogenous declines have a median duration of 7 years in our sample. We measure duration from the first year of declining production after the peak at $t = 0$ to the saddle point at the permanently lower level of production. The mean duration is quite similar with 8 years. There are still some further declines in the years after up to the fourteenth year (see Figure 2a).

The path of the extraction declines follow a convex function with a median growth rate of -9 percent per year during the first ten years. Afterwards production declines at a median growth rate of -3 percent.[2]

The declines in our sample are skewed towards the lower end of the distribution. The gap between the 25th percentile and the median increases after the peak with a skewness factor of 2 after year zero indicating the presence of a few, very large negative production shocks. A summary of all 35 declines is provided in Appendix B.

3.2 Economic Activity

Figure 3a shows a substantial shift in the median real GDP in response to declining mining activity. The log-level of real GDP declines persistently, as the median does not return to its pre-shock trend even after 15 years. Accordingly, the growth rate of GDP is also persistently depressed for 15 years.



(a) Real GDP in levels.

(b) Real GDP growth (in%).

Figure 3: Real GDP in levels and in growth rates during the 35 episodes of extraction declines.

Notes: Time $t = 0$ corresponds to the peak of production and time $t = 1$ is the first year with a negative production growth rate. We normalize Figure 3a relative to the median at time zero. We present the 25th and the 75th pointwise percentiles for every horizon. The growth rate and the level do not necessarily correspond to the same country at every point in time, as the composition of the median and percentiles can differ between levels and growth rates.

[2] As the number of observations naturally declines for a longer duration due to closed mines or missing data, the softening decline rate of production after year ten is mainly driven by a survivor bias of longer, permanent declines.

4 Theoretical Framework

To interpret the empirical findings, we introduce a stylized two-sector model with tradable and non-tradable goods in a small open economy. In a simple endowment open economy, the response to an unexpected fall in tradable goods is linked to the shock persistence and its anticipation. According to the permanent income hypothesis, agents optimally smooth consumption in response to negative transitory shocks, decrease their consumption permanently by the full shock size in response to persistent negative shocks. As the majority of the extraction decline episodes seemed to not have been fully anticipated, this section compares the model's results for a shock that matches the typical extraction decline in the data, with and without perfect anticipation. We highlight how the lack of anticipation can delay the economic adjustment and lead to lower GDP and welfare even in the absence of other frictions.

4.1 Model Setup

Consider an economy populated by identical agents who maximize their lifetime utility U, defined over a sequence of an aggregate consumption basket C_t

$$U = \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{\sigma} - 1}{\sigma} \right], \tag{2}$$

where $0 < \beta < 1$ is the subjective discount rate. The specified utility function exhibits a constant intertemporal elasticity of substitutions, $1/(1-\sigma)$. Consumption consists of tradable and non-tradable goods aggregated by the CES function

$$C_t = \left[(1-\gamma)(c_{N,t})^{\frac{\eta-1}{\eta}} + \gamma (c_{T,t})^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{3}$$

with home bias γ and η capturing the substitutability between tradable and non-tradable goods. The prices of the two goods are P_T and P_N, respectively. It is, thus, possible to define a price index

$$P_t = \left(\gamma^{\eta} P_{N,t}^{1-\eta} + (1-\gamma)^{\eta} P_{T,t}^{1-\eta} \right)^{1/(1-\eta)}, \tag{4}$$

household demand functions

$$C_{N,t} = \gamma \left(P_{N,t} / P_t \right)^{-\eta} C_t, \tag{5}$$

and

$$C_{T,t} = (1-\gamma)\left(P_{T,t}/P_t\right)^{-\eta} C_t. \tag{6}$$

We define all prices, P_N/P and P_T/P, in terms of the tradable good $p_t = \frac{P_{N,t}}{P_{T,t}}$.

There are two productive endowment sectors in the economy: a commodity (tradable) sector and a non-commodity (non-tradable) sector. For simplicity, non-tradable output is kept constant while tradable output is any exogenous process defined on the positive domain

$$\{y_{T,t}\}_{t=0}^{+\infty}. \tag{7}$$

The domestic tradable sector can be thought of as a mining sector producing an intermediate good y_T that is exchanged in the world market at a given price for the internationally traded good c_T; given the small open economy assumption both prices can be assumed as given, which, in turn, implies that the terms of trade is exogenous (and assumed to be constant and unitary, for simplicity).

The flow budget constraint is given as follows:

$$B_t = (1+r_t)B_{t-1} + y_{T,t} + p_t y_{N,t} - c_{T,t} - p_t c_{N,t}, \tag{8}$$

where B_t are net foreign assets at the end of period t and p_t can be interpreted as the real exchange rate with prices of the tradable good set as the numeraire. Market clearing implies that

$$c_{N,t} = y_{N,t}. \tag{9}$$

To close the model, the interest rate in the small open economy is set equal to the world interest rate, which is assumed to be in a steady state so that world interest rate equals the inverse of the discount factor:

$$r_t = r^* = \beta^{-1} - 1. \tag{10}$$

Finally, the economy's GDP is defined as

$$Y_t = p_t y_{N,t} + y_{T,t} \tag{11}$$

and the trade balance is

$$TB_t = Y_t - pc_{N,t} - c_{T,t} = y_{T,t} - c_{T,t}. \tag{12}$$

4.2 Model Results

In relation to the empirical analysis, it is instructive to compare two model scenarios. In the first scenario the empirically motivated exogenous and persistent decline in extraction output is fully anticipated as of $t = 0$. In the second scenario, the same extraction decline is implemented in the model as a sequence of transitory annual extraction output decline shocks. In a given period k, the extraction decline from $k-1$ to k is taken from data, but in all subsequent periods, i.e., from $k+1$ onward, extraction output is assumed to reverse to its $k-1$ level; i.e., $E_{t+k}[y_{T,t+k+j}] = y_{T,t+k-1}$ for $j \geq 1$.[3]

To solve the two model scenarios, we set the discount rate $\beta = 0.95$ and the intratemporal elasticity of substitution $\eta = 6$. The initial steady state net foreign asset position is set to $B_{-1} = 0$. The value of the home bias γ is calibrated such that the share of the extraction sector in total output matches the 20 percent share observed in the data in the initial steady state. Finally, for the exogenous output decline in the extraction sector we rely on empirical estimates for the 35 extraction episodes, reported in Appendix F. The sequence of extraction declines is reported in top left chart of Figure 4, which summarizes the results of the two model scenarios.

In the first scenario, labelled "permanent shock", an anticipated persistent decline in mining (tradeable) output leads to an immediate fall in consumption and a depreciation of the exchange rate. The price of non-tradeable goods declines relative to the price of the internationally traded good as the country becomes poorer. This leads to a surplus in the trade. Savings increase to smooth out the consumption impact of the anticipated future decline in mining output. After an initial fall, the decline in real GDP traces the decline of the mining sector and its trajectory is more gradual than the fall in consumption. However, consumption converges to the new steady state by falling less than GDP, as the increase in the net foreign asset position results from transitional surplus in the trade balance.

[3]While not fully consistent with rational expectations, this scenario is motivated by the lack of anticipation for extraction output declines in data (see Section 2.4). It can be rationalized by assuming a mining output process to be perceived as $y_{T,t} = \theta_t + \epsilon_t$ with $\theta_t = \theta_{t-1} + \eta_t$ unobservable, where ϵ and η are unobservable white noise, and the Kalman-gain evolves as $K_t = (y_{T,t-1} - \theta_{t-1|t})/(y_{T,t} - \theta_{t-1|t})$ converging to 1 in the new steady state.

In the second scenario based on the transitory shock series, the representative consumer smoothes consumption by borrowing abroad. This induces a trade deficit but mitigates the decline in consumption. A sequence of negative unanticipated shocks, thus, leads to a partial consumption adjustment resulting in a smoother decline in consumption and output. Both eventually decline more than in the perfectly anticipated case. This is for two reasons: 1) the exchange rate depreciates only gradually and 2) the trade balance initially deteriorates. Eventually, the decrease in the net foreign asset position forces a decline in tradable consumption.

To sum up, the two model simulations reveal three key differences. First, the model predicts a trade surplus in the case of full anticipation, but a trade deficit in the unanticipated case driven by a sequence of transitory shocks. Second, in the case of a fully anticipated decline, output adjusts more gradually than consumption and vice versa for the sequence of transitory shocks. Finally, the real exchange rate depreciation is gradual and persistent under the sequence of transitory shocks.

In the next sections, we will test how our model predictions compare with the results from the empirical analysis.

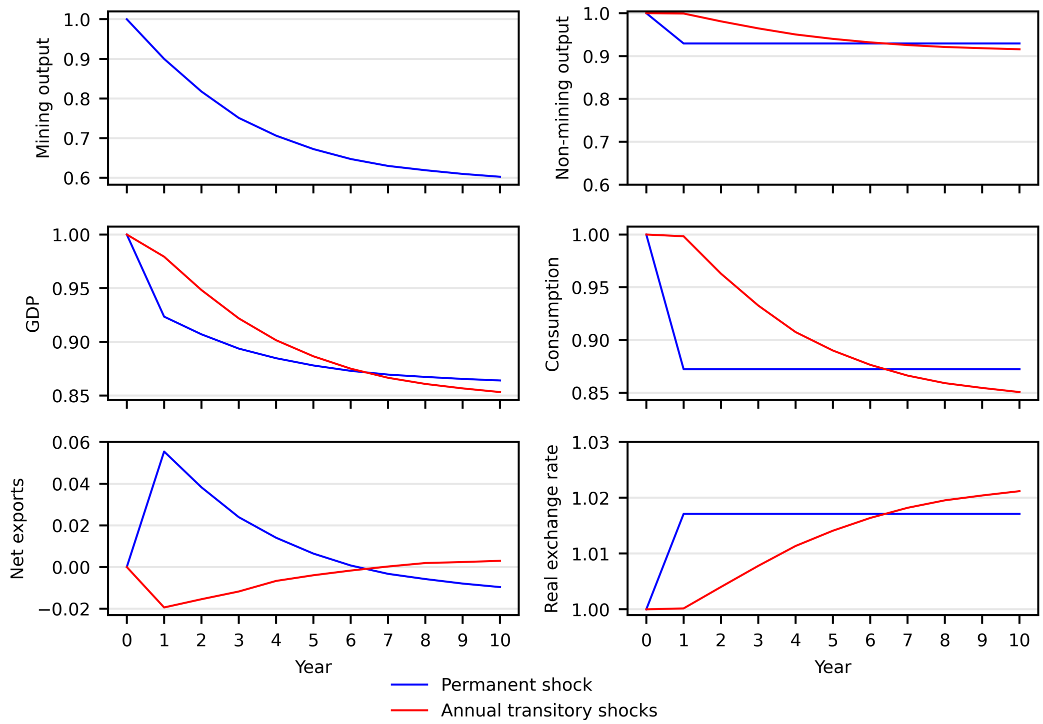


Figure 4: Effects of a fully anticipated permanent output decline compared to the effects of a sequence of transitory negative shocks to mining output.

5 Empirical Framework

For each commodity- and country-specific time series i, with $i \in \Omega_X$, a binary dummy variable, δ_{it}, takes the value of 1 if the year is part of a decline episode and 0 otherwise, where Ω_X is the set of episodes classified as exogenous in our previous section. We then estimate a first-stage regression:

$$\Delta q_{it} = \alpha_i + \beta_i \delta_{it} + u_{it}, \tag{13}$$

where Δq_t is the percentage change in extraction for episode i at year t. While we could assess the effect of the binary dummy on the macroeconomic dependent variables directly, creating a time series based on a first stage regression allows us to calculate the effects of different sizes of production shocks. At the same time, we remove the noise related to fluctuations in production. We consider the percentage change in production as the dependent variable to circumvent any issue of non-stationarity.[4]

[4]The first stage gives the following estimated coefficients $\hat{\beta} = -s/(1-s)(\bar{\Delta q} - \bar{\Delta q}^\star)$ and $\hat{\alpha} = \bar{\Delta q}^\star - \hat{\beta}$, where s is the frequency of years of production declines over the length of the sample, $\bar{\Delta q}$ and $\bar{\Delta q}^\star$ are the average changes in output in the overall sample and during the decline episode, respectively. The fitted values are $\bar{\Delta q}^\star$ during each episode.

We use the fitted values from the first stage, $\Delta\hat{q}_{it}$, in a local projection exercise on the macroeconomic variables in line with Jordà (2005) and Stock and Watson (2018). We estimate the following equation as a baseline:

$$y_{t+h,i} - y_{t-1,i} = \alpha + \beta^h \Delta\hat{q}_{t,i} + \sum_{j=1}^{p} \Gamma_j^h y_{t-j,i} + \sum_{j=1}^{p} \Pi_j^h \Delta\hat{q}_{t-j,i} + \psi_n + \phi_t + u_{t+h,i} \tag{14}$$

The left-hand side represents the deviation of the log-dependent variable from its initial value. We interpret the results as cumulative percentage deviations to a shock in year t over the horizon h. The fitted values from equation 13 are denoted as $\Delta\hat{q}$. We include $p = 3$ lags of the dependent variable and the shock series as regressors to deal with auto-correlation following Montiel Olea and Plagborg-Møller (2021). We add country fixed effects ψ_n to account for structural differences across countries as well as time fixed effects ϕ_t to control for global price movements and other common global factors to our baseline. We cluster standard errors around every shock.

6 The Impact of Extraction Declines on Aggregate Output

6.1 The Typical Dynamics of Extraction Declines

The typical initial production shock is assumed to be a ten percent decline, which matches well the median extraction decline observed in our sample during the first year(see Figure 2). The initial shock has a persistent effect. The persistence of the shock is estimated, in our sample, using the following specification (see Section F):

$$\Delta\hat{q}_{t+h,i} = \alpha_A + \beta_{A,h} \Delta\hat{q}_{t,i} + e_{t+h,i}; \text{ with } h = 0, \ldots, 10. \tag{15}$$

After the initial decline, extraction continues to decrease to an average accumulated decline of 40 percent after ten years. The typical episode is, thus, a 10 percent initial decline that accumulates to 40 percent after ten years. We will use it to assess the impact of the extraction declines on the variables of interest (see Figure 5) in the next sections.

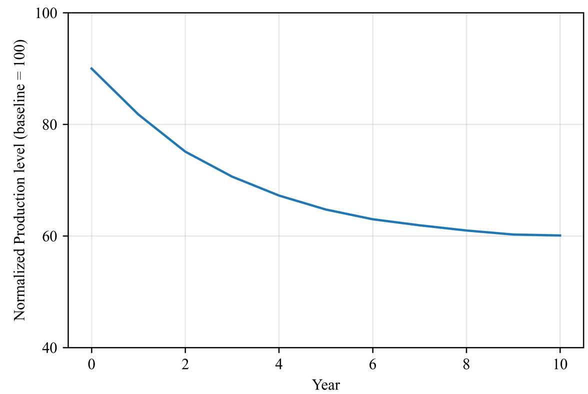


Figure 5: The accumulated extraction decline of an initial 10% drop in production growth accumulates to a 40% decline after 10 years.

Notes: The production decline is based on the estimated persistence of declines in our sample (as further described in Appendix F) and matches the initial ten percent decline of the median decline episode observed in Figure 3b during the first year.

6.2 Baseline Results

During a typical extraction decline episode, real GDP falls significantly, relative to pre-shock trend, with a peak effect of seven percent after ten years (Figure 6). [5]

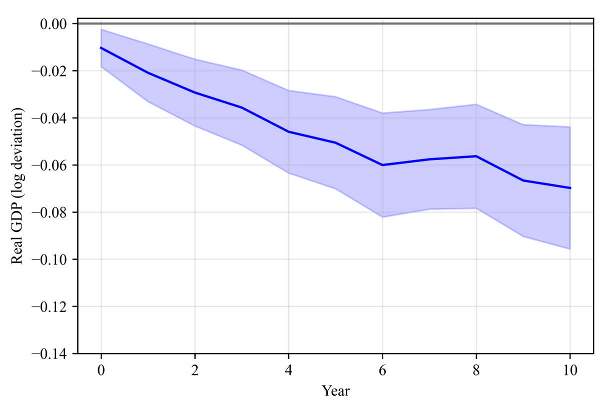


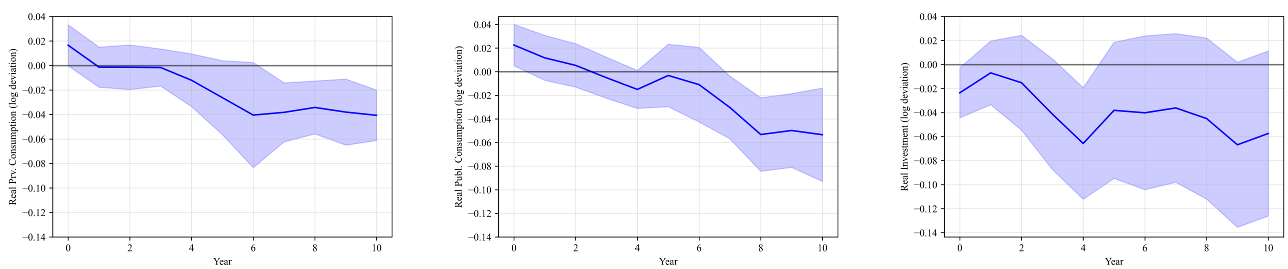
Figure 6: Impulse response function of real GDP to a shock episode.

Notes: The responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the beta coefficients from equation 14. The shaded area reports 90 percent confidence intervals.

[5]We use the GDP accounting identity, $Y_t = C_t + G_t + I_t + (X_t - M_t)$ to compare the relative size of sectoral drivers with the overall GDP response. We weight each sector by its respective average share of GDP in the sample. We find that the sum of point estimates, $4.1\% * 0.54 + 5.3\% * 0.16 + 5.8\% * 0.2 + (8.7\% - 3.5\%) * 0.1 = 4.8\%$, is smaller than the total GDP response of 6.9%. The difference, however, is not statistically significant. Such departure in point estimates is likely to be caused by sector share differences across countries, while the impulse response functions provide unweighted averages.

We further analyze the real GDP response by looking at its domestic and external components, comparing results against the model. Domestically, both, real private and public consumption respond with a delay of four years to the decline and fall to levels that are -4% and -4.5% lower, respectively. The lagged responses suggest that agents misinterpreted the initial fall as an isolated one-off event and plan to smooth their consumption over time. Only as the decline worsens and extraction activity stays persistently at a lower level, consumption is eventually adjusted to a permanently lower level, as predicted under the perfectly anticipated case. Likewise, real investment responds with a delay. The response, however, remains insignificant over the the majority of the ten-year horizon. [6]

Overall, our results suggest that consumers and policymakers reacted in line with a series of temporary negative shocks rather than fully anticipating the entire decline in extraction output. They seem to underestimate the shock persistence and, thus, smooth aggregate effects sub-optimally.



(a) Real Prv. Consumption (b) Real Publ. Consumption (c) Real Investment

Figure 7: Impulse response functions of domestic sector variables to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the beta coefficients from equation 14. The shaded area reports 90 percent confidence intervals.

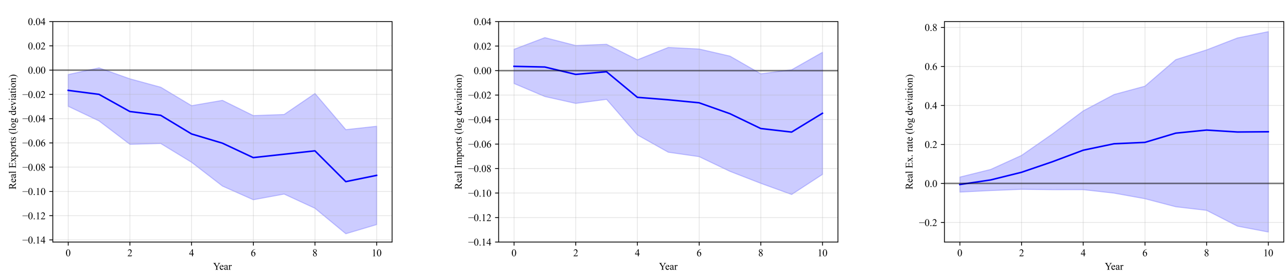
The external sector also plays an important role during the episodes. Real exports show an immediate fall, accumulating to a decline of 9% after ten years (Figure 8a). Real imports respond with a four-year lag and with a peak decline of 3.5% that remains insignificantly different from zero over the ten year horizon. Consequently, declining extraction activity is accompanied by a deterioration in the trade balance. Three forces are at play. First, since

[6] We also assess employment responses as shown in appendix G. Employment falls slightly in response to the shock and is only statistically significant between the six and eighth year horizon. The muted response could be driven by the high capital intensity of the sector. At the same time, employment data for low and middle income countries is not reliable, which may introduce an attenuation bias.

extraction sector output is mostly exported (directly as primary commodity or indirectly transformed into secondary commodities), the decline in mining output reduces export volumes. Second, the lagged response in consumption translates into a delayed decline in real imports. Third, possibly because of the lack of full anticipation, consumption does not decline enough, supporting demand for imports and inducing an increase in borrowing, which in turn allows the trade balance to worsen. This helps to mitigate the decline in consumption.

The real exchange rates should play the role of a shock absorber. It depreciates persistently by approximately 20 percent after four years and remains at its lower level thereafter, even though the response is not precisely estimated (see Figure 8c). The depreciation indicates that the economy becomes poorer, as the price of the non-tradable output declines relative to the price of the fossil fuel. At the same time, the decline could potentially limit the fall in exports by stimulating non-mining exports and re-allocating resources towards other tradable sectors. Our results suggest, however, that the induced reallocation channel is too weak to reverse the negative consequences of the mining decline. Moreover, countries under fixed exchange rate regimes will face strong devaluation pressures in response to large and persistent declines in mining sectors.

Overall, the comparison of empirical and theoretical results suggests that governments and firms probably misjudged the impact and persistence of declines in extraction activity. The delay in responses indicates that agents either perceived shocks to be transitory or learned slowly as the decline in the extraction sector unfolded.



(a) Real Exports (b) Real Imports (c) Real Ex. Rate

Figure 8: Impulse response functions of external sector variables to a shock episode.

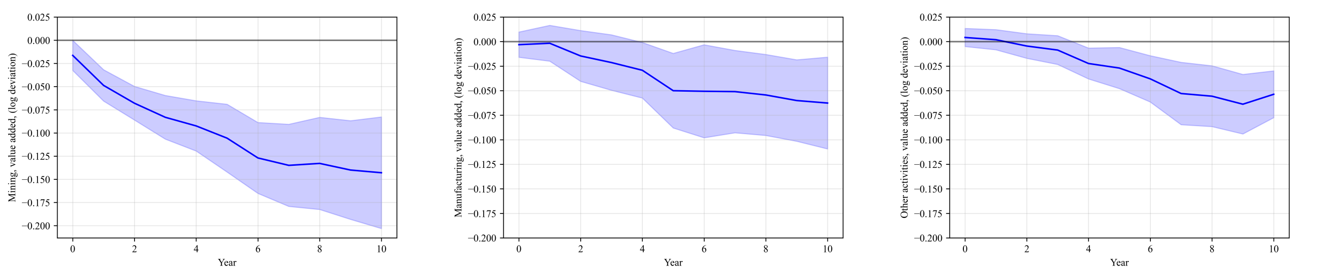
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the beta coefficients from equation 14. The shaded area reports 90 percent confidence intervals.

6.3 Effects Across Industries

We decompose the real GDP response by industry. Figure 9 displays the response for the three largest sectors in our sample, namely mining, manufacturing and services. The mining sector drops by 2% at the time of the shock, $t = 0$, and falls by 14.5% after ten years. The convex decline mimics the fall in production shown in Figure 2a. Moreover, the immediate drop in mining at time $t = 0$ provides an explanation for the corresponding drop of real GDP on impact.

The manufacturing and service sectors react with a lag of three years each. Their value added falls by 6% and 5.5%, respectively. As domestic aggregate consumption and investment react with a similar lag, the lag in the response of manufacturing and service is in line with a domestic demand-driven channel.

An additional explanation is that manufacturing and services are likely related to the extraction sector both in terms of inputs of machinery and business services, respectively. Both sectors react with a lag as mining output gradually falls over several years in most episodes. The decline in extractive activity, in fact, may have spillover effects on these industries, reflecting its large footprint on the economy that goes beyond its simple output share.



(a) Mining,value added (b) Manufacturing, value added (c) Services & others, value added

Figure 9: Impulse response functions of real value added (in constant 2015 local currency units) by sector to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40 percent over ten years. The point estimates are based on the beta coefficients from equation 14. The shaded area reports 90 percent confidence intervals. The IRFs of the remaining sectors are shown in Appendix J.

6.4 Heterogeneity Across Countries

We test for potential heterogeneity in responses across countries by augmenting the local projection with multiple interaction terms for per capita income and mining sector size. We also control for the share of the manufacturing sector in total output and institutional quality.

Income and Mining Sector Size Effects:

As a first exercise we control for the heterogeneity in the shock size and interact the decline in quantities with the share of the value added of the mining sector in total value added MS_i averaged over the 10 years preceding each episode:

$$y_{t+h,i} - y_{t-1,i} = \alpha + \beta^h \Delta\hat{q}_{t,i} + \gamma^h(\Delta\hat{q}_{t,i} * MS_i) + \theta^h MS_i + \sum_{j=1}^{p} \Gamma_j^h X_{t-j,i} + \psi_n + \phi_t + u_{t+h,i}.$$

Figure 10 shows the response for small and large mining sectors corresponding to the 10th and 90th percentile in our sample—that is, a mining share of 2.5% and 58%, respectively.[7] Countries in our sample with a relatively small mining sector experience relatively muted declines of 3.7% in real GDP after ten years. For countries with large mining sectors the decline is significantly larger with an average 15.3% fall in real GDP after ten years. The impact of the share of the mining sector, however, is less than proportional, since doubling the mining share increases the impact on real GDP on average by only about 40 percent.[8]

[7] To give a sense of proportion, mining accounted for 1.2 percent of value added in 2019 in the U.S., while for a primary commodity importer such as Italy mining and quarrying account for about 0.2 percent of value added.

[8] It is possible that a bigger mining sector might also be more diversified across commodities.

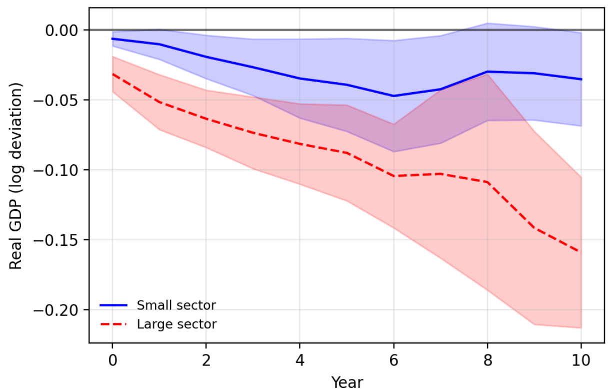


Figure 10: Impulse response function of real GDP interacted with the size of the resource sector to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the coefficients from equation 16. The shaded area reports 90 percent confidence intervals.

We assess the impact countries' different income levels on GDP responses. We include an interaction term between the shock series and a binary dummy I_n that indicates the country's per capita income level. The binary dummy variable takes the value of 0 for high income and 1 for middle and low income countries based on the country classification by the World Bank (2022). The interaction term allows us to assess the additional shock effect for different income levels.[9] We run the following augmented local projection:

$$y_{t+h,i} - y_{t-1,i} = \alpha + \beta^h \Delta\hat{q}_{t,i} + \gamma^h(\Delta\hat{q}_{t,i} * I_n) + \sigma^h(\Delta\hat{q}_{t,i} * MS_i) + \rho^h(\Delta\hat{q}_{t,i} * I_n * MS_i) \qquad (16)$$
$$+ \theta^h MS_i + \sum_{j=1}^{p} \Gamma_j^h X_{t-j,i} + \psi_n + \phi_t + u_{t+h,i}$$

Figure 11 shows that the declines in mining activity are particularly detrimental for low-income countries with large mining sectors.[10] While the income level plays a relatively minor role for countries with small mining sectors, the impact on GDP is especially pronounced for low-income countries with large mining sectors.[11] In response to a decline in extraction of 40%

[9]Note that since I_n is constant over time, we do not include it as a separate regressor as it is captured by the country fixed effects. We further move all lagged controls into X.

[10]Note that the small sector size corresponds to a 10th percentile in our sample (5 percent for HICs and 2.5% for LICs) and the large sector size is defined by the 90th percentile in our sample, which equals 58% for HICs and 50% for LICs.

[11]Appendix H displays the response under a further linearity restriction implying a linear effect of the sector

after ten years in a sector that makes up about 58% of aggregate value added, real GDP in low-income economies falls by 30%. This compares to a 10% decline in high-income countries.[12] The initial impact is stronger in high-income countries (with a large mining sector). Three years after the shock, instead, the ranking flips and the difference becomes pronounced over time, suggesting that low income countries are not able to cushion the detrimental effect on aggregate output as much as high income countries. This may indicate the lack of means to stabilize or transform the economy away from resource-linked activities or could point the role of institutions (see Section 7).

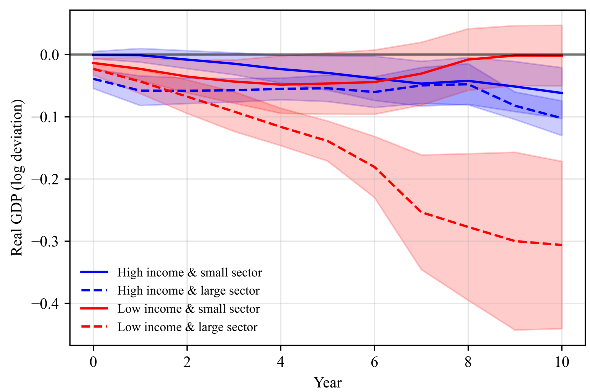


Figure 11: Impulse response function of real GDP interacted with per capita income and sector size to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the coefficients from equation 16. The shaded area reports 90 percent confidence intervals.

Manufacturing Sector Size Effects:

We estimate the effects of the shock episodes on real GDP controlling for both the mining and the manufacturing share of value added. As the mining sector declines and the exchange rate depreciates, resource reallocation towards non-mining export sector may be able to buffer the shock impact. When controlling for manufacturing sector sizes, data availability becomes a limiting factor. In particular, the value added of manufacturing sectors is available for only 25 shock episodes. Given the small sample size the statistical power falls substantially, especially when controlling for multiple interaction terms. In order to maintain a high level of statistical power, we control for mining and manufacturing with a mining-manufacturing sector ratio

size on real GDP.

[12]There are 11 high and 24 low-income countries in the sample (see appendix B).

$MR_i = \frac{MS_i}{Manf_i}$ in the following regression:

$$y_{t+h,i} - y_{t-1,i} = \alpha + \beta^h \Delta\hat{q}_{t,i} + \gamma^h(\Delta\hat{q}_{t,i} * MR_i) + \theta^h MR_i + \sum_{j=1}^{p} \Gamma_j^h X_{t-j,i} + \psi_n + \phi_t + u_{t+h,i}$$

Figure 12 shows the real GDP response for countries with small and large mining sectors relative to the manufacturing sector. The results indicate that a larger manufacturing sector can buffer the shock to extraction. The small mining-manufacturing ratio corresponds to the 10th percentile in our sample and represents a mining sector that is 30% as large as the manufacturing sector. The large mining-manufacturing ratio corresponds to the 90th percentile in our sample and represents a mining sector that is eight times as large as the manufacturing sector.

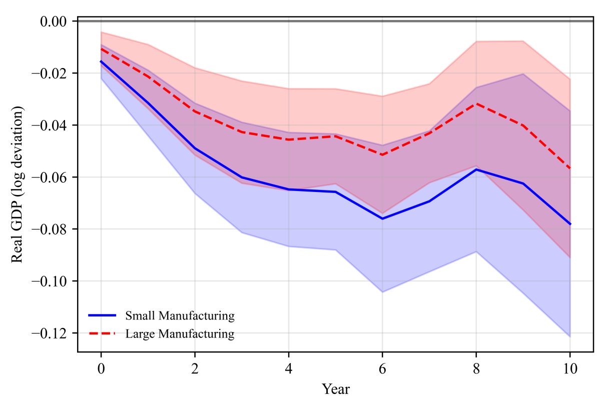


Figure 12: Impulse response function of real GDP interacted with the mining sector and the manufacturing sector share of value added to a shock episode.

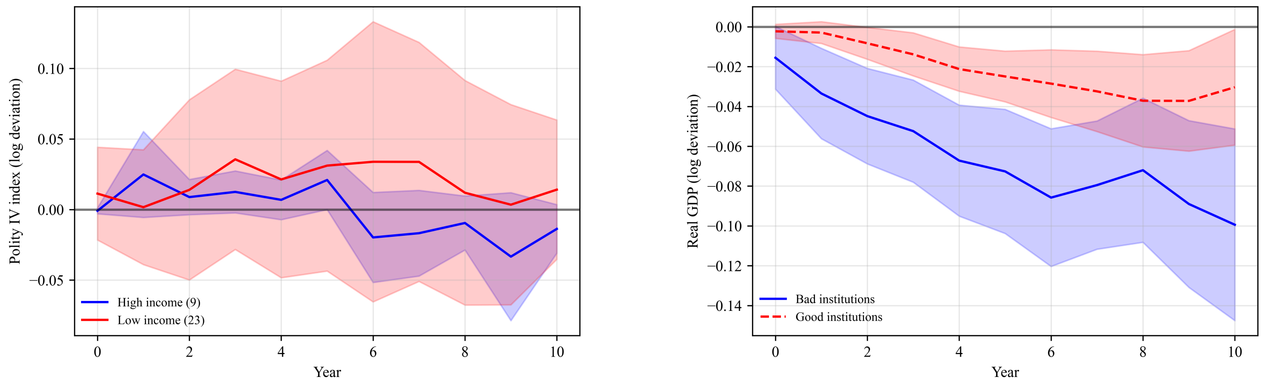
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

7 The Role of Institutions

An extensive literature highlights that resource booms lead to a deterioration in the quality of institutions, negatively affecting other sectors of the economy. In the reverse case, does a decline in extraction lead to better institutions or is there a legacy effect from rent seeking? To test this hypothesis, we follow Acemoglu et al. (2019) and use a data-set on institutional quality from the Center for Systemic Peace (2022) as a dependent variable in Equation (14).

We find that persistent declines in extraction do not cause improvements in institutional quality in neither high nor low-income countries (see Figure 13a). The impact is statistically insignificant from zero. This means that there is a potential asymmetry, if institutions were damaged during the resource boom, a decline in extraction is not enough to improve them. Once institutions are damaged they are hard to fix.

We also investigate whether the quality of institutions before the extraction decline can affect the economic impact of such a decline. This could explain why high income countries, having on average better institutions, fare better during extraction declines. We include the variable for institutional quality as a separate interaction term in Equation (14). Figure 13b shows the effects of the extraction decline episodes accounting for different levels of institutional quality. Five years after the shock, the difference in real GDP between countries with high and low institutional quality is about 5 percentage points. While a democratic country with high institutional quality (i.e. an indicator of 10) experiences a decline in real GDP of 2.5%, an autocratic country with bad institutions (i.e. an indicator of -10) exhibits a decline of 10% after ten years. Finding an explanation for this is beyond the scope of the current paper. It is possible that higher institutional quality leads to a more diversified economy or to more promptly enact structural policies to address the shortfall in mining output and revenues, including fiscal revenues. Our results suggest that institutional quality, used as a proxy for the ability to cushion negative effects with public policy, plays a role in determining the impact of the declining fossil fuel extraction effects on the economy.



(a) Institutional quality

(b) Real GDP and institutional quality

Figure 13: Impulse response function with the institutional quality indicator (-10 to 10) to a shock episode.

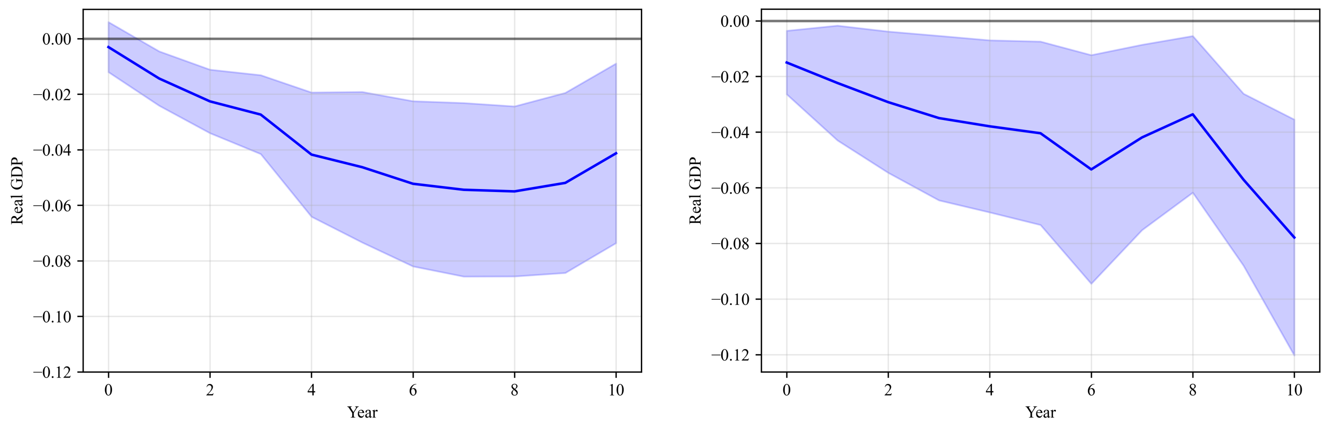
Note: Figure 13a shows the impulse response of institutional quality to a shock episode accounting for the income per capita level. Figure 13b shows the impulse response of real GDP to a shock episode accounting fr the institutional quality level. Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

8 Robustness

8.1 Sub-Sample Analysis

Our results are robust to sub-samples of shock episodes: one that includes all non-oil shock episodes, and one with the oil shock episodes only. Figure 14 shows the impulse response of real GDP to the shock episodes in the two sub-samples, respectively. In both cases, the shock consisting of a 40% decline in extraction after ten years causes a real GDP slow down of between five and six percent after six years. While the impact levels off for all commodities ex. oil, the negative impact becomes even more pronounced based on the oil shock episodes only after 10 years.

We also check the robustness of our results for excluding one of the 35 declines episodes at a time. This allows us to investigate whether the results are driven by particular decline episodes. The results in presented in Appendix I show that they are robust to this sensitivity check.



(a) Real GDP (excl. oil and gas shocks)

(b) Real GDP (only oil and gas shocks)

Figure 14: Impulse response functions of sub-sample Real GDP to a shock episode.

Notes: Figure 14a is based on 15 decline episodes in metals and Figure 14b is based on 20 decline episodes in oil and natural gas. Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

8.2 Anticipation Effects

To assess the potential differences between anticipated and unanticipated extraction decline episodes, we run the local projection exercise including a binary dummy for anticipation. Figure 15 shows that anticipated declines lead to an insignificantly smaller response in point estimates over the 10-year horizon than for the unanticipated ones. This suggests that even the anticipated episodes are hard to predict. This leaves little time for the economy to adjust before the shock is realized. This seems a substantial difference with the initial stage of the resource curse where, after large mineral deposits are discovered, the increase in resource extraction is much more predictable as in Arezki, Ramey, and Sheng (2017).

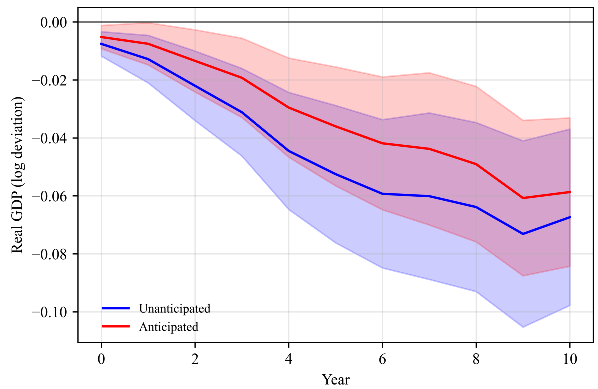


Figure 15: Impulse response functions of GDP interacted with a dummy for anticipation to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals. We include 27 shock episodes in this local projection, 24 are unanticipated and four are anticipated. There is no data available for the remaining seven.

8.3 Long-Term Results

Impulse response functions for a longer time horizon show that the impact on real GDP is quite persistent. After twenty years, real GDP is still 4% lower due to the decline in extraction. The persistence indicates that there is no reversed resource curve even 20 years after the initial shock.

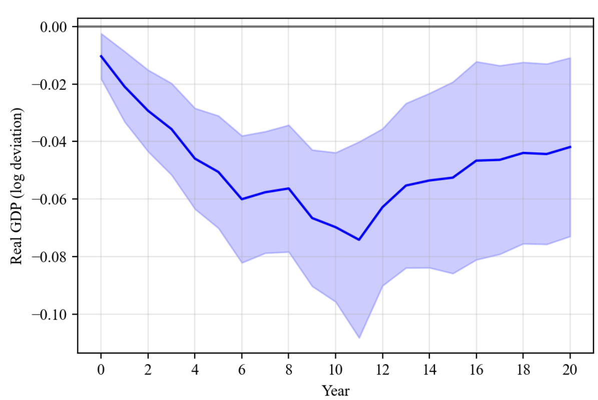


Figure 16: Average impulse response of real GDP over 20 years to a shock episode.

Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The point estimates are based on the coefficients from equation 3 with a horizon of 20 years. The shaded area reports 90 percent confidence intervals.

8.4 Synthetic Counterfactual Method

We employ the synthetic counterfactual method (SCM) by Abadie, Diamond, and Hainmueller (2010). While local projections provide us with an average prediction for shock responses via IRFs, synthetic counterfactuals works complementary by allowing us to summarize the shock response on an country-average and case-by-case basis.

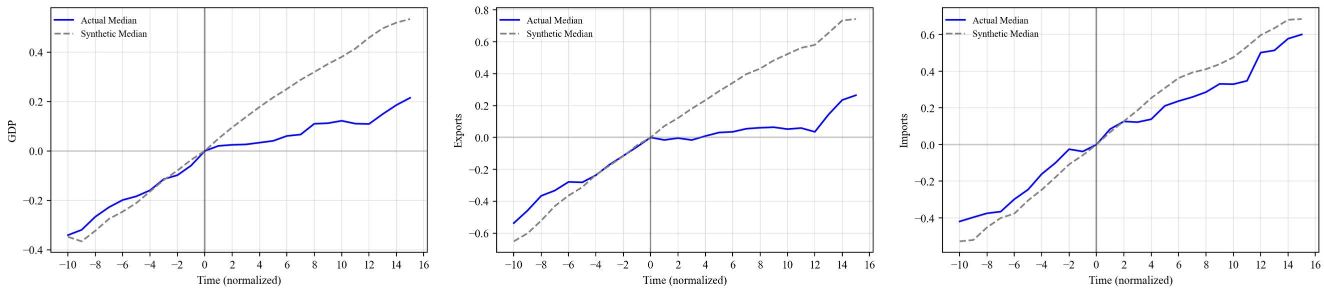
The synthetic control method estimates the impact of an intervention by comparing the actual evolution of a variable for a country to the development of the same, aggregate variable in a synthetic control group.[13] This is particularly helpful when a suitable single control does not exist. Instead, the method employs a combination of all countries worldwide that are not affected by similar shocks at that time and that are similar to the treated economy along some dimensions (e.g. also a producer of the same commodity or similar levels of GDP). The synthetic counterfactual drawn from this pool for each treated economy represents a weighted average counterfactual of control countries that together mirror the development of the recipient in the pre-shock episode.

To summarize the results across the whole sample, we use the difference between the synthetic and actual development to measure the median effect over time. To ensure that this gap is based on a well-fitted counterfactual, we trim the observations to only include countries with a root mean square prediction error (RMSPE) below the 75th percentile. Appendix E showcases the country-specific SCM results based on one shock episode.

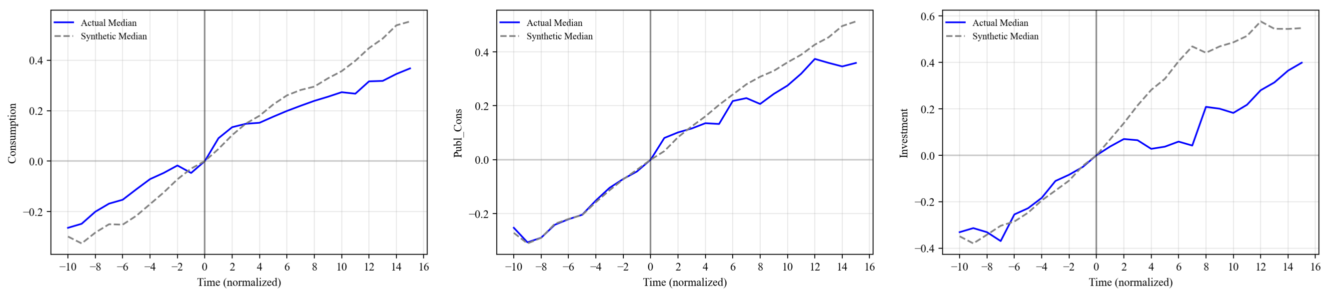
The results summarized in Figure 17 confirm our previous findings. Median real GDP decreases by approximately 15 percent after six years relative to the synthetic counterfactual.[14] The decline in real GDP is matched by the difference in declines between real exports and imports over time. Employment deviates from its synthetic counterfactual with a lag of six year before it returns to its counterpart in year 14. Real consumption falls, however, less so then real GDP. Interestingly, investment declines just as much as GDP. However, it is important to mention that the overall fit of investment in the SCM may reduce the reliance on its estimates.

[13] See Appendix D for more details on the estimation equations.

[14] In comparison, GDP in Figure 3a is about 13 percent lower than its linear trend after six years.



(a) Real GDP (b) Real Exports (c) Real Imports



(d) Real Prv. Consumption (e) Real Publc. Consumption (f) Real Investment

Figure 17: Actual versus synthetic counterfactual medians over time.

9 Conclusion

This paper is the first to empirically examine the macroeconomic effects of persistent contractions of fossil fuel and other mine production. Based on a new data-set on the extraction of 13 different minerals for 122 countries worldwide starting in 1950, we identify 35 episodes of large and persistent declines in extractive activity that are exogenous to a country's macroeconomic activity.

Using local projects methods, we find that declines in extraction activity lead to a significant and persistent negative effect on real GDP. The real exchange rate depreciates slowly and not enough to offset the decline in exports. This leads to a deterioration of the trade balance. Private and public consumption fall but with a lag. There are, in fact, significant, negative spillover effects of declining extractive activity on the manufacturing (and service) sectors. Results are qualitatively consistent with a classical small-open-economy model, in which agents learn only slowly about the persistence of the shock over time.

Results show significantly larger impacts for low-income countries when controlling for the sector size. This suggests a greater ability of high-income countries to buffer the detrimental effects on economic activity. A possible explanation is that high income countries exhibit on average better institutions, which could mitigate the impact of the extraction decline. Declines in extraction seem to not improve the quality of institutions, possibly perpetuating the negative impact of the resource sector even after the resource sector looses importance.

Our findings suggest that enhancing climate policy certainty at the global level would enable a smoother transition for countries that heavily rely on fossil fuel exports. Such certainty could provide incentives to initiate an early and gradual adjustment to the declining extraction of fossil fuels. Therefore, it is vital for policymakers to provide clear and consistent signals so that fossil fuel production declines are well anticipated.

Our paper and the new data-set suggest several potential areas for future research. For example, one could empirically study to what extent specific institutions and policies mitigated some of the macroeconomic effects of the extraction declines in the historical episodes. In addition, a broader data-set could examine the impact of the decline in extraction activity on the fiscal accounts. Such an analysis could shed light on the extent to which declining extraction activity affects government revenues, public spending priorities, and overall fiscal sustainability.

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Appendix

A Summary Statistics: Entire Data-set

Commodity	# of Decline Episodes	Decline of Extraction Quant. (% of Peak)	Decline of Extraction Value (Mil. USD)	Duration (Years)	Annualized Decline Value (% of GDP)
Bauxite	10	-69	-47	6	-3.4
Brown Coal	2	-76	-6	7	0.0
Copper	17	-80	-226	9	-3.8
Crude Oil	21	-47	-8290	6	-19.4
Gold	9	-50	-379	5	-1.7
Hard Coal	11	-77	-113	5	-0.2
Lead	30	-75	-25	9	-0.1
Natural Gas	7	-60	-6080	7	-0.5
Nickel	3	-46	-49	3	-0.5
Iron	14	-79	-55	5	-1.5
Silver	10	-64	-24	9	-0.2
Tin	11	-85	-22	11	-0.4
Zinc	9	-60	-153	6	-0.2
Total	154				

Table 2: Summary of episodes of declining extraction activity by commodity (in averages).

Note: Columns 2 and 3 show the average total decline over all the years of each episode. Column 4 shows the average duration of the episodes. Column 5 (the average ADV) is the result of dividing column 3 by column 4 and the GDP at time $t = 0$ for every shock.

B Summary Statistics: 35 Extraction Decline Episodes

1 Country	2 Commodity	3 Year	4 Duration (Years)	5 ADV (% of GDP)	6 Reason	7 Anticipated
Kuwait	Oil	1979-1982	4	23.3	Policy change	No
Brunei Darussalam	Oil	1979-1981	3	13.5	Policy change	NA
Chad	Oil	2005-2014	10	4.1	Depletion	No
Suriname	Bauxite	1974-1977	3	3.8	Policy change	NA
Gabon	Oil	1997-2002	6	3	Depletion	No
Brunei Darussalam	Oil	2006-2018	13	2.35	Depletion	No
Eswatini	Iron	1975-1979	5	2.2	Depletion	NA
Equatorial Guinea	Oil	2012-2019	8	2.2	Depletion	No
DR Congo	Zinc & Copper	1988-1994	7	1.9	Depletion	No
Guyana	Bauxite	1975-1982	8	1.7	Policy change	NA
Norway	Oil	2003-2013	11	1.5	Depletion	Yes
Zambia	Copper	1988-1994	7	1.5	Policy change	No
Jamaica	Bauxite	1981-1986	5	1.3	Policy change	No
South Africa	Silver, Lead & Gold	1994-2001	8	1	Depletion	No
Trinidad and Tobago	Oil	2006-2019	14	1	Depletion	No
Bolivia	Tin	1981-1986	6	0.7	Depletion	No
Syria	Oil	2003-2010	8	0.7	Depletion	No
Indonesia	Oil	2000-2007	8	0.5	Depletion	No
Fiji	Gold	2004-2007	4	0.5	Depletion	No
Mexico	Oil	2004-2009	6	0.5	Depletion	No
Peru	Oil	1985-1991	7	0.4	Depletion	No
Zimbabwe	Nickel	1998-2004	7	0.4	Policy change	No
Tunisia	Oil	2007-2017	11	0.3	Policy change	No
Denmark	Gas	2008-2013	6	0.3	Depletion	Yes
South Africa	Gold	1970-1975	6	0.3	Depletion	No
Denmark	Oil	2004-2019	16	0.2	Depletion	No
United Kingdom	Oil	1986-1990	4	0.2	Depletion	Yes
Myanmar	Lead	1973-1976	4	0.2	Depletion	NA
Tunisia	Oil	1992-2001	10	0.2	Depletion	Yes
Netherlands	Gas	2013-2019	6	0.2	Depletion	NA
United Kingdom	Oil	1999-2015	16	0.2	Depletion	No
Nicaragua	Copper	1968-1978	11	0.2	Depletion	NA
Zambia	Lead	1988-1994	7	0.1	Depletion	No
Australia	Oil	2000-2006	7	0.1	Depletion	No
Philippines	Copper	1981-2002	21	0.1	Depletion	No

Table 3: Summary of the 35 episodes of exogenous extraction declines.

Notes: Countries sorted by the estimated value of the extraction decline as share of GDP (ADV). Anticipation indicates whether the initial decline was anticipated in IMF article IV consultation reports. There are no reports for 6 out. In the case of the Netherlands, natural gas production was not discussed.

C Model: First-Order Conditions

This appendix provides the first-order conditions for the two-sector model as well as its calibration. Equation (17) shows the intra-temporal Euler equation relating the choice between non-tradable and tradable consumption to their relative price p with home bias γ as well as the substitutability between non-tradable and tradable goods η. Equation (18) shows the inter-temporal Euler equation relating current consumption to future consumption via their relative price r and the discount factor β.

$$\left(\frac{c_{T,t}}{c_{N,t}}\right)^{\frac{1}{\eta}} = p * \frac{\gamma}{1-\gamma} \tag{17}$$

$$\left(\frac{c_{T,t+1}}{c_{T,t}}\right)^{\frac{1}{\eta}} = \beta * (1+r) \tag{18}$$

D Synthetic Control Methodology

Following Abadie and Gardeazabal (2003), let y_{it} denote the observed variable of interest with the set of determinants Z_{it}, where i denotes the shock ($i = 1$ corresponding to the treated country and ($i = 2, \cdots, N$ to the control countries) at time $t \in [-10, \cdots, T]$. The synthetic counterfactual is a weighted average of y_{it} (with $i = 2, \cdots, N-1$ and $t < 0$) computed to match y_{1t} accounting for the determinants Z. The set of weights is $W = (w_2, \cdots, w_{N+1})$ with $w_i \geq 0$ for $(i = 2, \cdots, N-1)$ and $\sum_{i=2}^{N-1} w_i = 1$. Assuming no anticipation effects of production shocks, the synthetic counterfactual $\sum_{i=2}^{N-1} w_i y_{it}$ equals the treated country y_{1t} during the pre-shock episode as follows

$$\sum_{i=2}^{N-1} w_i y_{it} = y_{1t},$$

where

$$\sum_{i=2}^{N-1} w_i Z_{it} = Z_{1t}.$$

The optimal vector of weights W^* solves

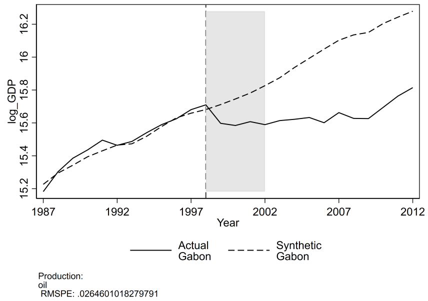
$$\min(S_1 - S_C W)' M (S_1 - S_C W),$$
$$\text{s.t. } w_i \geq 0$$
$$\text{and } \sum_{i=2}^{N-1} w_i = 1,$$

where S_1 is the vector $(k \times 1)$ of the treated country characteristics (k) in the pre-shock episode, S_C is the vector $(k \times N)$ of the same variables for the control nations and M is a $(k \times k)$ symmetric, semi definite matrix measuring the relevance of the variables included in S_1 and S_C. W^* minimizes the squared error of the pre-shock distance between the vector of the treated country variables and the vector of the synthetic control variables.

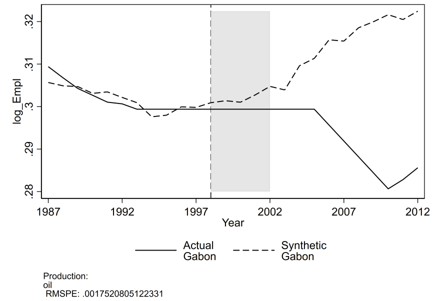
E Synthetic Control Method Example - Country Results

We use Gabon as an example for a by-country analysis. The synthetic counterfactual for GDP is based on a weighted average of eight countries that are also oil producers and together mimic both, Gabon's pre-shock oil production as well as real GDP.[15] Appendix E shows that real GDP drops by 16 percent after two years compared to the counterfactual. The gap between actual and synthetic GDP widens to a peak size of 52 percent after eleven years.

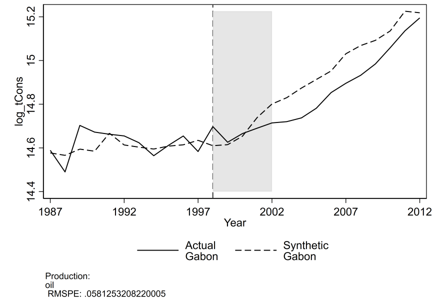
[15] The weighted countries are: Angola, 8.1%; Ecuador, 18.8%; India, 29.4%; Iran, 5%; Italy, 18.9%; Saudi Arabia, 0.9%; Thailand, 15.1% and Vietnam, 3.7%.



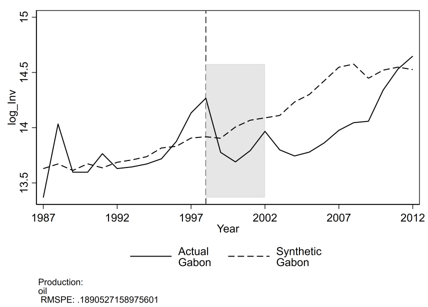
(a) Real GDP



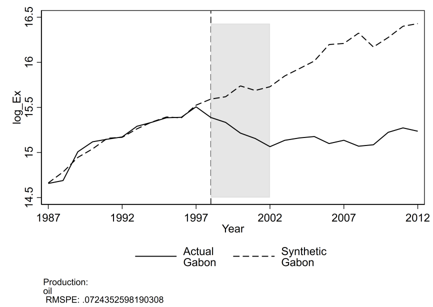
(b) Employment



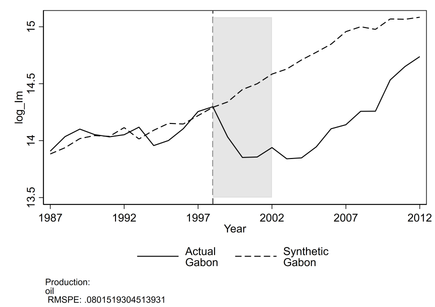
(c) Real Consumption



(d) Real Investment



(e) Real Exports



(f) Real Imports

Figure 18: Synthetic counterfactual for Gabon.

Note that the shaded area shows the duration of the oil production shock.

F Estimated Shock Persistence

Following Caselli, Grigoli, and Sandri (2022), we estimate the persistence of shocks in our sample based on the following specification:

$$\Delta\hat{q}_{t+h,i} = \alpha_A + \beta_{A,h}\Delta\hat{q}_{t,i} + e_{t+h,i}, \tag{19}$$

with the fitted shock series of extraction declines $\Delta\hat{q}$ at time t, horizon h, and commodity-episode i, the coefficient for the constant α_A, the autocorrelation coefficient β_A^h and the regression residual e. Figure 19 illustrates the corresponding shock persistence underlying the local projection based on the coefficient β_A^h. The y-axis reports the unit of the auto-correlation coefficient. A shock at time t tends to persist throughout subsequent years with an average duration of eight years.

We can iteratively define the baseline production level, $Y_t \equiv Y_{t-1}\Delta\hat{q}_{t+h,i}$, to accumulate the shock persistence to display the decline of the (trend) production level over time by

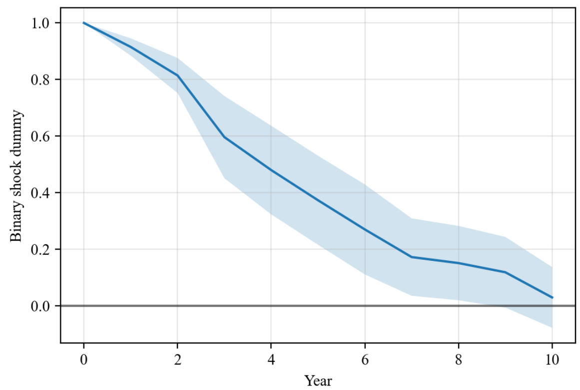


Figure 19: Estimated persistence (auto-correlation) of the binary shock dummy.

multiplying the β_A^h coefficient iteratively with :

$$Y_{t+h} = Y_{t+h-1} * (\beta_{A,h} + \alpha_A) = Y_{t-1} * (\beta_{A,h} + \alpha_A) * \cdots * (\beta_{A,0} + \alpha_A) \tag{20}$$

where Y_{t+h} is the extraction level over the horizon h, β_A^h is the auto-correlation coefficient of the shock from Equation (19).

G Employment Response

This chart shows the average impulse response of the employment rate to the shock episodes. The employment rate is defined as the number of employed people in the labour force (i.e. older than 15 and younger than 65) over the population. The data is not reliable for many of the middle and low-income countries in our sample.

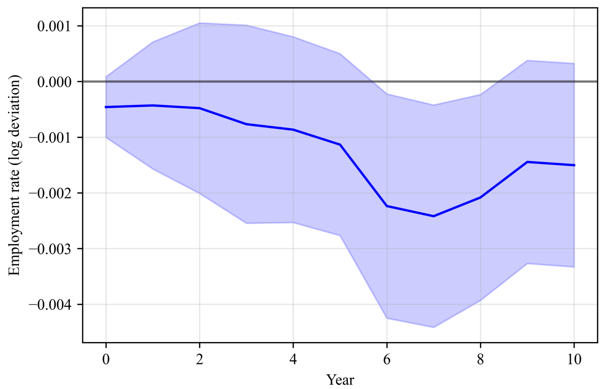


Figure 20: Impulse response functions of the employment rate to a shock episode.
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

H Linearity Restriction

This chart displays the impulse responses for real GDP when restricting the effect of the sector size as shown in the following equation:

$$y_{t+h,i} - y_{t-1,i} = \alpha + \beta^h \Delta(\Delta\hat{q}_{t,i} * MS_i) + \sum_{j=1}^{p} \Gamma_j^h X_{t-j,i} + \psi_n + \phi_t + u_{t+h,i}$$

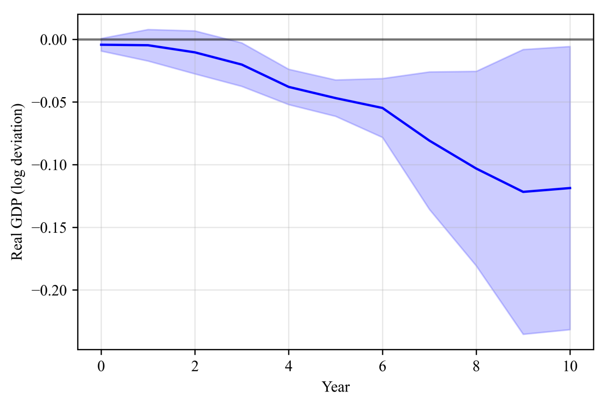


Figure 21: Impulse response function of real GDP to a shock episode with linearity restriction.
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

I Sub-Samples

This chart shows the impulse responses for real GDP excluding one shock episode at a time.

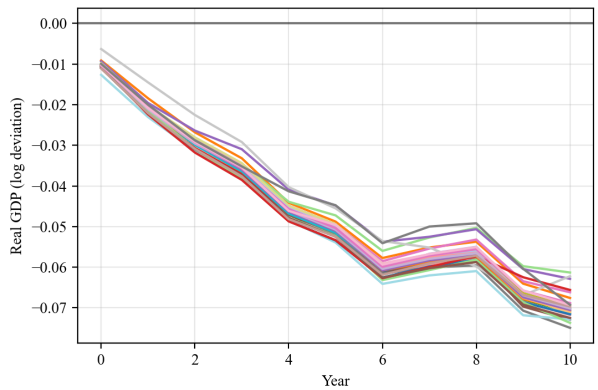
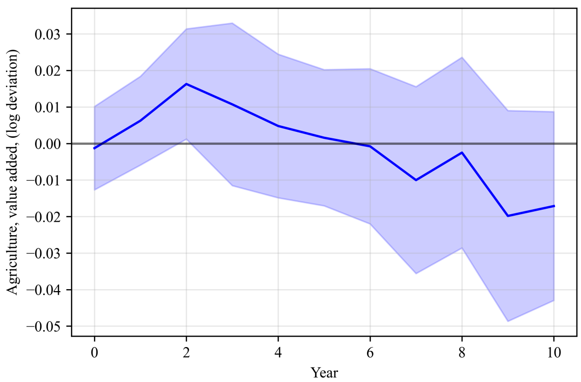
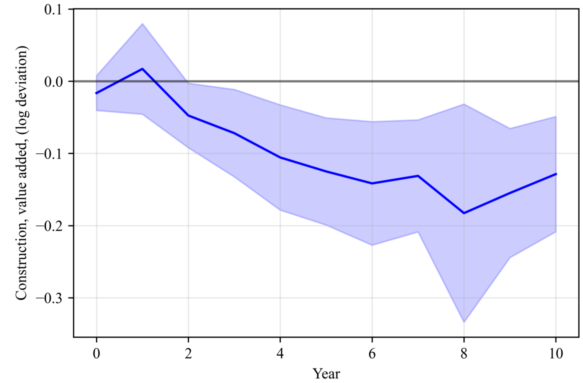


Figure 22: Impulse response functions excluding one decline episode a time.
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

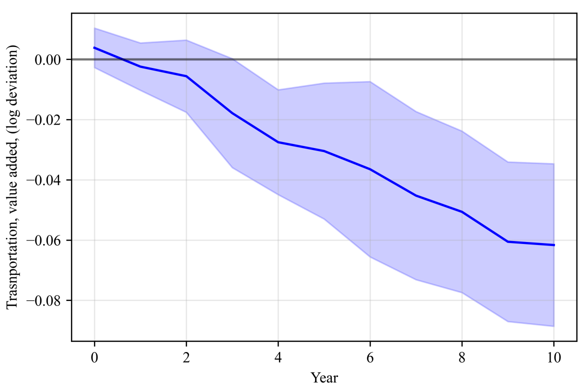
J Industry Specific Analysis



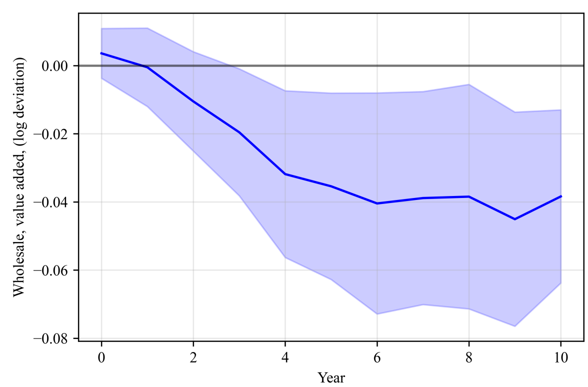
(a) Agriculture, value added



(b) Construction, value added



(a) Transportation, value added



(b) Wholesale, value added

Figure 24: Impulse response functions of real value added by sector to a shock episode.
Notes: Responses are generated using a shock episode normalized to an accumulated exogenous extraction decline of 40% over ten years. The shaded area reports 90 percent confidence intervals.

PUBLICATIONS

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