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Critical Minerals for Energy Transition and Sustainable Development in Africa

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Abstract

The ongoing energy transition from fossil fuels to renewable energies could have contrasting effects on African economies, particularly through increased extraction of metals critical to this transition. This paper describes the opportunities and challenges posed by the development of extraction of these metals. While Africa's share of global reserves and production is on the rise, it remains far from its potential. Factors such as lack of investment in transport and governance issues are likely to increase exploration and mining costs on the continent, and hold back the development of the sector. … /…

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Keywords: critical metals, critical minerals, energy transition, Africa

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. . . /. . . The expected increase in global demand for these critical metals could represent a major source of revenue for producing countries, as well as a diversification opportunity for net fossil fuel exporting countries, provided supply can adjust. The extraction of critical metals can only become a source of sustainable development if it is combined with appropriate fiscal and budgetary policies, controlled management of its social and environmental impacts, and the development of downstream value chains.

In Africa, the extractive sector has so far represented both a development opportunity and an expression of the "resource curse[1]". The "supercycle" of rising commodity prices until 2014 translated into increased growth and government revenues for Africa, which represented a promise of sustainable development. However, since 2014, in periods of falling or sharply fluctuating prices, the continent's heavy dependence on the extractive sector has fostered not only greater economic volatility, but also an increase in fiscal and external imbalances, generating higher risks of over-indebtedness. In the medium and long term, the "negative externalities", as well as economic and political distortions generated by the extractive sector may make more difficult in some countries a fair sharing of extractive rents and limited potential economic ripple effects of an essentially "landlocked" sector, hence delaying the achievement of the Sustainable Development Goals (SDGs, on the UN's 2030 agenda).

The ongoing energy transition from fossil fuels to renewable energies could have contrasting effects on African economies dependent on the extractive sector. It is likely to weigh heavily on the economies and finances of oil producers but also represents a new development opportunity[2] not only for the extractive sector, but also for the renewable energies sector, as Africa has comparative advantages in this area (Unctad, 2023). Demand and prices for the "critical metals"[3] essential to the energy transition are set to rise sharply between now and 2050. This paper aims to describe the opportunities, and challenges, posed by the extraction of these metals in Africa, particularly in comparison with the oil sector. While the sector of critical metals essential to the energy transition raises many environmental, social and governance (ESG) issues similar to those of the oil sector, it differs in one important aspect. By providing some of the conditions necessary for the development of renewable energies, it could help stimulate a catch-up in the energy sector, provided adequate public policies help materialize this new promise.

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[1] The natural resource curse refers to a set of difficulties specific to countries rich in natural resources (lower growth than others, greater inequality, etc.). See Jacolin and Vertier (2022) in the CMAF 2021 Report.

[2] The accumulation of sanitary, geopolitical and energy crises since 2020 has already stimulated investment in the mining industry in Africa (Gardes-Landolfini *et al.*, 2023).

[3] Metals are chimical elements that are part of the periodic table, while minerals are solid substances with specific crystal structure, and ores are rocks containing minerals. In this paper, we focus essentially on metals, but use both terms the terms “metals”, “materials” or “minerals” interchangeably.

1. In Africa, reserves and production of critical metals essential to the energy transition are increasing, but production potential is still far from being reached

A. Africa's growing importance in the global production of metals critical to the energy transition

Our analysis focuses on seven of the most important critical metals for Africa: cobalt, copper, tin, graphite, lithium, manganese and titanium[4]. This selection is based on the list of 27 critical metals identified by Miller *et al.* (2023) as playing an essential role in the energy transition, very similar to other lists established by the World Bank (2017), or Espagne and Lapeyronie (2023), among others. For each of these metals, we select those: i) with an African share of global production, according to *United States Geological Survey* (USGS) data[5], higher than 5% in 2022; ii) produced in several African countries; iii) included in the list of ten critical metals with the highest anticipated demand according to Miller *et al.* (2023); and iv) with sufficient production and reserves USGA data accuracy. Cobalt, manganese, graphite, copper and lithium cover all these criteria. Although excluded from the list of the ten metals with the highest anticipated demand, we extend our analysis to titanium and tin, produced in Africa for up to 35 % and 7 % of total output respectively in a large number of countries and with sufficiently reliable production data. The other metals produced in significant quantities in Africa (vanadium, chromium, tantalum and hafnium) are either only produced in a single African country (South Africa, for chromium and vanadium), are not included in the list of ten high-demand metals (tantalum and hafnium), or have incomplete USGS reserve data. According to USGS (2020), resources refer to a natural concentration of solid, liquid or gaseous material in a form and quantity such that its extraction is currently or potentially feasible. Proven or known reserves (referred to as "reserves" in this article) represent the proportion of resources that can be profitably extracted at the time of evaluation (even if the extraction infrastructure is not yet in place). They can be seen as an inventory of mining companies' capacity to supply a mineral they consider profitable to extract.

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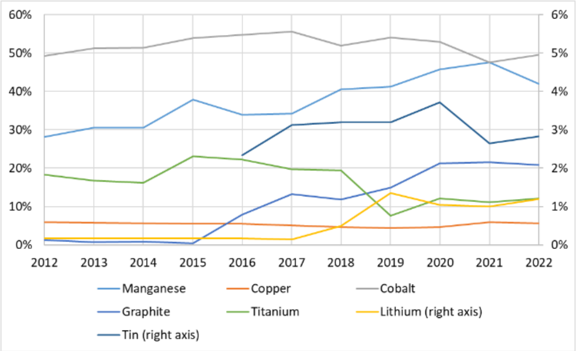
[4] All are metals, except for graphite, which is a crystalline form of carbon.

[5] For rare earth elements, we consider the amount of reserves, as production data are fragmentary; for lithium, we consider resource data, as the latter have a much greater geographical scope.

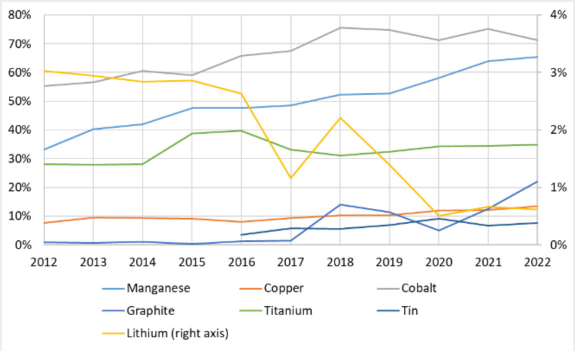
Overall, Africa's share of global reserves and production of these seven metals has risen sharply over the past decade (Charts 1 and 2). Between 2012 and 2022, global manganese reserves increased by a factor of 2.5, lithium reserves by 2 and graphite reserves by 4. Copper reserves have increased by 30% and cobalt by 10%. Production has also risen sharply, by 11% in ten years for graphite, 25% to 35% for manganese, copper and tin, and 85% for cobalt. Lithium production has increased almost fourfold. Africa's share of reserves rose sharply for manganese (from 30% to 40%) and graphite (from 0% to around 1.5%). Africa's share of world cobalt and titanium reserves is 50% and 10% respectively, but is tending to decline. In terms of production, Africa's share has increased since 2012 for almost all the metals considered, with the exception of lithium (for which data on African production is incomplete)[6] .

Figure 1. Africa's share of reserves of 7 critical metals



Source: USGS, authors' calculations

Figure 2. Africa's share of production of 7 critical metals



Source: USGS, authors' calculations

Africa thus boasts a large number of major producers of critical minerals essential to the energy transition, albeit distributed heterogeneously. In 2022, South Africa was the world's largest producer of manganese and third largest producer of titanium, Gabon the world's second largest producer of manganese, the Democratic Republic of Congo (DRC) the world's largest producer of cobalt, Mozambique the world's second largest producer of graphite and third largest producer of copper, and Madagascar the world's third largest producer of graphite.

In Africa, three-quarters of the metals critical to the energy transition are located in low-income countries, and the development of their exploitation represents a sustainable development challenge. An analysis of the distribution of natural resources in Africa (oil, other natural resources, identified critical metals) and by income level (low, intermediate) sheds light on three distinct challenges (Map 1). Countries producing fossil fuels (oil, coal, etc.) have benefited from a rise in per capita income, and are, with the exception of Chad and South Sudan, middle-income countries. Nevertheless, this rise has not necessarily translated into significant progress in economic and human development: in 2015, before the sharp drop in world oil prices, the human development index of oil-exporting countries worldwide overall remained lower than that of countries with an equivalent GDP per capita. Economic diversification into other mineral resources (particularly critical metals) is a major challenge for these countries, in order to offset the risks associated with the loss of

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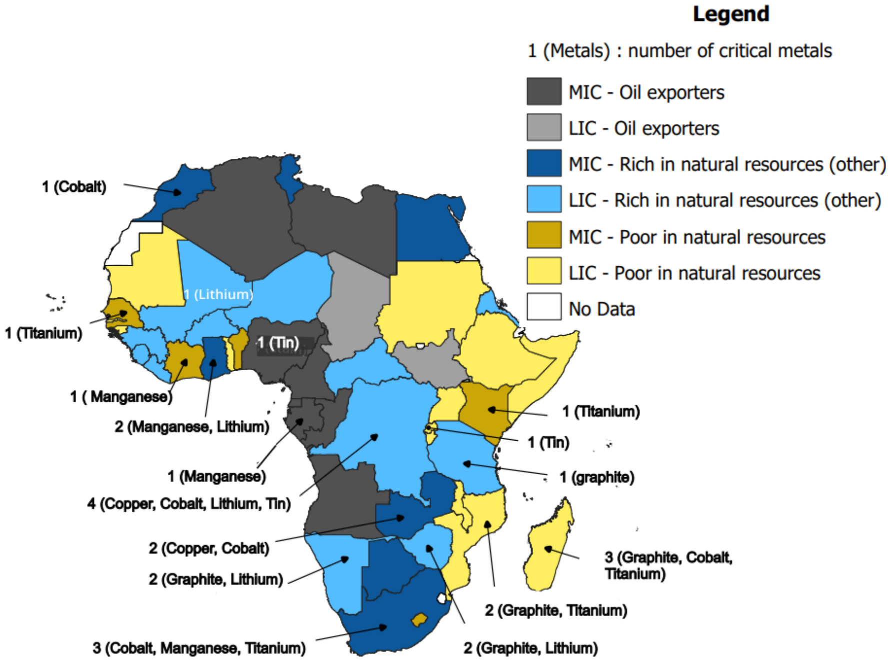
[6] These figures should be interpreted with caution, as they do not take into account informal mining, which is sometimes significant (e.g. cobalt in the DRC).

competitiveness of their oil sector (whose operating costs and greenhouse gas emissions are respectively 15% to 50% and 80% higher than the world average [McKinsey, 2022]), resource depletion or loss of value (risk of stranded assets). This is also the case for South Africa, a coal exporter whose foreign trade could suffer from a global energy transition (Le Goff and Vertier, 2023), but which has significant resources of various minerals. In addition, three-quarters of the countries producing metals critical to the energy transition, and more generally countries rich in natural resources (excluding oil), are low-income countries. This creates a strategic challenge: linking the exploitation of natural resources to the achievement of the SDGs. Finally, Eastern Africa is a singular case on the African continent, since, based on existing data, the region concentrates low-income countries that are poor in natural resources.

Map 1. Resource-rich countries by income level



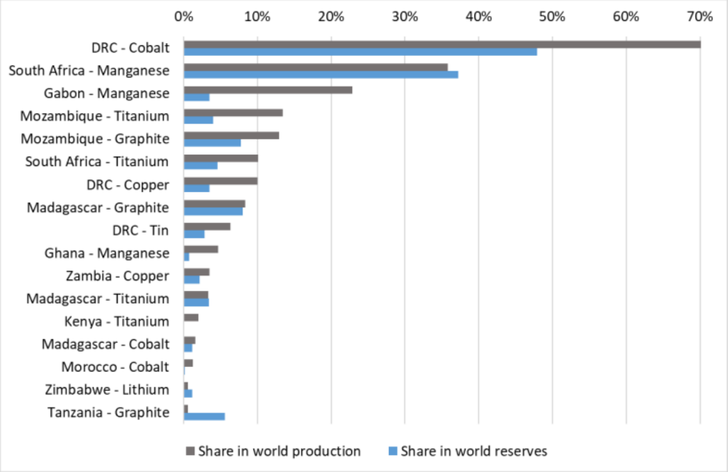
Source: USGS (2012-2022), IMF (2022).

Notes: LIC and MIC stand for low-income and middle-income countries respectively. Resource-rich SSA countries are defined according to the IMF classification (resource exports greater than 20% of total exports). For Northern African countries (not classified by the IMF), the categorization used is that of Mlachila and Ouedraogo (2017).

B. African metal deposits appear to have a shorter lifespan than elsewhere, reflecting a possible underestimation of the continent's reserves

While Africa's rise in global reserves and output of minerals critical to the energy transition is undeniable, the continent stands out from the rest of the world through a faster depletion of its reserves. In 2022, with rare exceptions, the shares of African economies in global production are well above their share in global reserves (Figure 3).

Figure 3. Share of world production and reserves in 2022



Source: USGS, authors' calculations.

This apparently faster depletion of reserves could reflect African specificities in terms of risks and returns from extraction projects (Khan *et al.*, 2016). Africa could be characterized by higher risks and costs, particularly before production starts, which could lead to an underestimation of reserves:

- Mining exploration expenditure is among the lowest in the world (S&P Global, 2022a), and is heavily concentrated in the gold sector (S&P Global, 2022b). Excluding the gold sector, spending on the continent's surface is lower than on other continents (Natural Resource Governance Institute, 2022), mainly due to incomplete geological studies (Schacherer and Kang, 2021);
- After a deposit is discovered, only a fraction of resources are exploited (45% on average worldwide according to Schodde, 2014), a fraction likely to be lower in Africa, particularly in conflict-affected or politically unstable countries;
- Depending on the type of metal, mining start-up lags can be longer in Africa than elsewhere, e.g. 19 years for copper compared with an average of 17 years (Schodde, 2014);
- The exploitation of small and medium-sized deposits can be hampered by the strong presence of major international mining groups, coupled with the fragmentation of small states, and an insufficient network of small and medium-sized enterprises and local technical capacity. This reinforces the isolation of the mining sector and the concentration of foreign direct investment (FDI) on the largest deposits (Africa Development Forum, 2023). International attractiveness issues (business climate, tax and regulatory incentives, etc.) are key for many African countries aiming at developing FDI;
- In the case of small and medium size deposits, small-scale, often informal and rural mineral operations play a particularly important role in Africa (World Bank, 2020), especially to foster employment. They also involve issues of surveying (Maus and Werner, 2024), rent capture

and taxation (through the formalization of its activities), as well as particularly high social and environmental costs (Merem *et al.*, 2018; Von der Goltz and Barnwal, 2019; Gittard and Hu, 2023; Goldblatt *et al.*, 2023)[7];
- Finally, the ability to mobilize budgetary resources from the mining sector may be lower than on other continents or than initially anticipated (Mihalyi and Scurfield, 2021). Fiscal resources from natural resources (including oil) account on average for only 38 % of the value of mining rents in Africa (Africa Development Forum, 2023), and this may be even lower for the mining sector. This limits the ability of local authorities to finance the transport and energy infrastructures needed to develop the mining sector.

2. Several factors are likely to affect the development of the mining sector in Africa

A. The quality of infrastructure and governance hinders exploration and development of African reserves

The development of critical minerals in Africa faces a number of constraints that are more prevalent than elsewhere, including bottlenecks linked to weak administrative capacity and uncertainties resulting from a less favorable business climate and poorer quality of governance (corruption, risks linked to capital flight).

While infrastructure plays a key role in economic development, particularly transport networks (Donaldson, 2018; Fiorini, 2021), the distribution of the latter in Africa is inefficient and spatially uneven (Graff, 2019; Fontagné *et al.*, 2023). Other types of infrastructure are crucial to economic development, particularly for mining. The inadequacy of electrical infrastructure, particularly in South Africa, is one of the factors of the decline in productivity (Le Goff and Vertier, 2023) and competitiveness of mining companies. This decline could be offset by the development of energy production sites close to extraction sites. The issue of infrastructure development appears all the more important as it seems to attract FDI (Armah, 2016), and thus makes it possible to finance the research and exploitation of critical minerals.

The interactions between mining investment and development have been documented in particular in the context of China's "New Silk Road", whose impact on African development remains an open field of debate. While the numerous investments by Chinese companies in infrastructure projects to facilitate the transport and exploitation of African minerals are likely to contribute to the continent's growth (Zhang, 2021), they would also strengthen Chinese control over metal production and accentuate the continent's economic dependence on this country (Ericsson *et al.*, 2020).

Governance and corruption issues are also major obstacles to resource exploration and development in Africa. Countries with weaker governance are less attractive to investors (Natural Resource Governance Institute, 2022) and corrupt public investments often result in higher costs and poorer infrastructure (Pattanayak *et al.*, 2020). For a given resource, higher levels of corruption or poorer governance translate into longer start-up lags. According to Khan *et al.* (2016), if governance indicators in low-income countries were to reach Latin America's, start-up lags would be reduced by three years.

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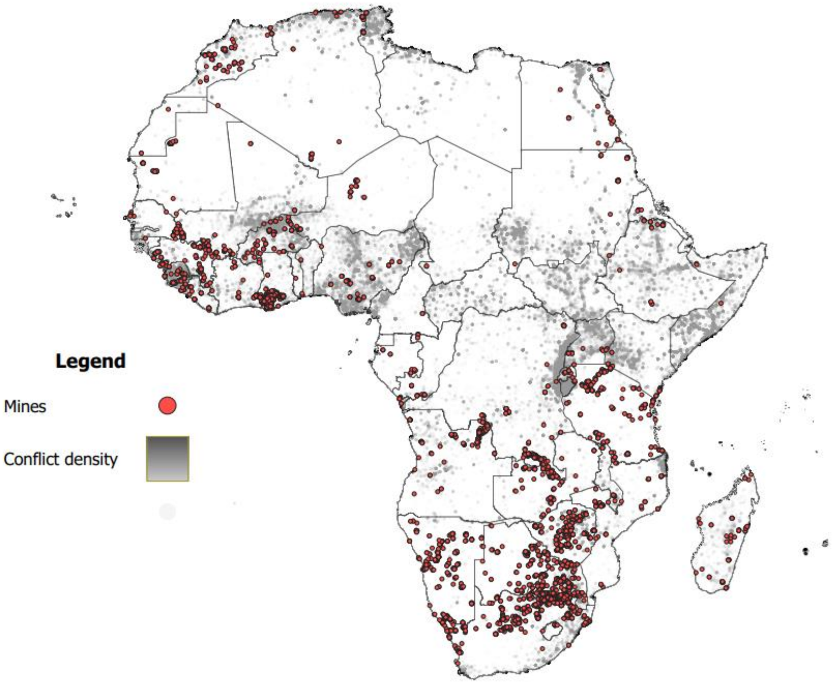
[7] In urban areas, the counterparts of these environmental and social costs are fast-growing electronics and metals recycling businesses (Moyo *et al.*, 2022).

Our analysis of geolocated mining data confirms the role played by governance in the location of mining operations. Drawing on the satellite database of Maus *et al.* (2022), which geolocates 4,917 mines in Africa (Map 2), we document, at the borders of African countries, a marked discontinuity in the number of mines, in favor of the country with the highest governance score, using a framework close to that of Cust and Harding (2021). For each pair of countries sharing a border, we calculate the distances to the border of mines observed in 2019 (see Map 3 for Guinea and Côte d'Ivoire). We then compare the density of observations on either side of the border. For each pair, observations from the country with the best average Polity score studied between 1965 and 1995[8] are placed to the right of the threshold, and observations from the country with the worst average Polity score between 1965 and 1995 are placed to the left of the threshold.

Map 2. Conflict density (1997-2022) and location of mines (measured in 2019, excluding oil and gas) in Africa



Sources: ACLED, Maus *et al.* (2022).

The identification of effects is based on a number of assumptions. First, it is based on the assumption that the natural resources present underground are exogenous to border lines. Africa is the continent with the highest proportion of "artificial" borders, with 80% following longitudinal or latitudinal lines (Alesina *et al.*, 2011). While a number of borders follow local geographic constraints, the probability that an ethnic group has faced partitioning does not depend on the presence of mineral resources (Michalopoulos and Papaioannou, 2016). Geographical and political characteristics appear uniformly distributed on either side of borders within the same ethnic group (Michalopoulos and Papaioannou, 2014). The second assumption is that there is no systematic measurement bias of mines on either side of borders (i.e. that the observed discontinuity is not a

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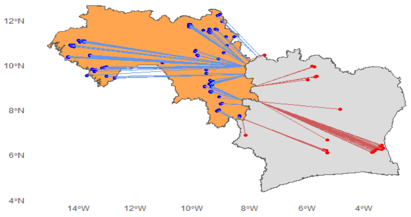
[8] The Polity score, calculated annually, ranges from -10 (most autocratic forms of government) to 10 (most democratic).

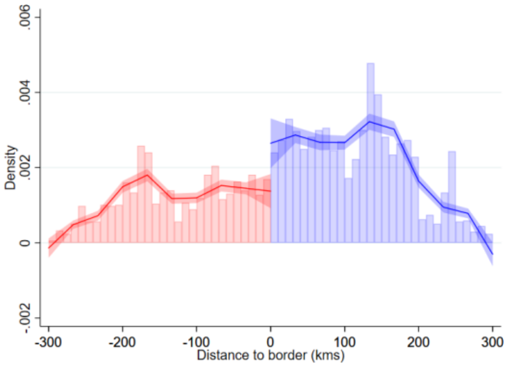
simple artifact linked to systematic differences in reporting between two countries). However, this risk is limited by the fact that our analysis is based on satellite data[9]. A final assumption is that there is no reverse causality, i.e. that the greater or lesser density of mines on the common border of two countries has no impact on the relative governance indices of these two countries. In an ideal configuration, we would only compare the locations of mines whose discovery or start-up took place after a pre-established date for calculating the Polity score[10]. However, we do not observe the opening date of these mines. We therefore choose to calculate the Polity score over a broad time range (to avoid capturing variations specific to a single year) and with an end date sufficiently distant from the date of measurement of the presence of mines (to take into account the often long lags for exploration and start-up)[11]. However, we cannot rule out the possibility that some mines may have been opened before the end-date of the Polity score calculation, which may result in biases with uncertain directions. We cannot rule out the risk that mines openings at the border have an impact on the governance of their countries (as discoveries of ore deposits have marked economic and political consequences, cf. Arezki *et al.*, 2017; Harding *et al.*, 2020), or on conflict with the neighboring country. It is however unlikely that it will systematically affect the Polity score differential between these two countries over the reference period.

Map 3. Distance to the border of mines in Guinea and Côte d'Ivoire in 2019



Note: the straight lines correspond to the distances from the mines to the border.
Source: Maus *et al.* (2022), authors' calculations.

Figure 4: Difference in mine density around borders in 2019



Note: Border density break by country pair (within each pair, the country with the best Polity score is to the right of 0, and the country with the worst Polity score is to the left of 0). 95% confidence interval. Estimated using the method of Cattaneo, Jansson and Ma (2018), with a polynomial of degree 3. The Polity score is calculated between 1965 and 1995. Data are aggregated by 10 km intervals.
Source: Maus *et al.* (2022), authors' calculations.

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[9] These data may include illegal mines. Maus *et al.* (2024) show that more than half the mines identified in their database are not listed in the S&P database, which is based on company reports. According to the authors, this may reflect unsatisfactory reporting of company declarations as much as the presence of illegal mines in satellite data, without any clearly identified regularities. Assuming that illegal mines are over-represented in weaker governance environments, if such mines are present in the satellite data, the result we obtain is likely to be biased towards zero, hence representing a lower bound on the sensitivity of legal operations to governance conditions.

[10] This is the approach taken by Cust and Harding (2021), who perform a discontinuity regression of the number of explorations according to distance from the border, placing on the right the observations from the country with the best governance score in 1965, and on the left the observations from the country with the worst score. Their data enable them to select only explorations carried out after 1965.

[11] Our approach differs from that of Cust and Harding (2021) in the method used. Their discontinuity regression approach involves generating a large number of randomly located fictitious observation points ("zeros") for which no mines exist, which is not necessary in our observation density approach.

In the baseline statistical analysis (Figure 4), in order to limit the above-mentioned biases, we implement various restrictions on the analysis sample. We consider a Polity score over the period 1965-1995, we consider only pairs of countries with an average Polity score difference of 2 (so that the countries considered have significant governance score differences), and each mine is used in only one pair of countries, where its distance to the border is closest. This amounts to studying 3,344 observations, for 38 country pairs and 38 distinct countries. In the Appendix (Figures A.1 to A.4), we show that the border discontinuity is robust to various alternative hypotheses (both in terms of the range used to calculate the Polity score, the minimum Polity score difference considered to select country pairs, and the polynomials used to estimate densities).

Finally, the exploitation of mining resources itself generates greater risks of corruption or violence than for oil resources, due to the greater potential for informal exploitation. This causal inference causally across the continent (Knutsen *et al.*, 2017, Berman *et al.*, 2017) can be observed in the above map on conflicts and mines locations (Map 2), particularly on the borders between DRC and Rwanda/Burundi, Burkina Faso and Mali, Algeria and Tunisia, or Sierra Leone and Guinea.

B. The response of African production to market prices suggests the presence of significant downstream cost effects

While the ability of the supply of critical metals to adjust to demand is a key issue in the global energy transition (Gardes-Landolfini *et al.*, 2023; Miller *et al.*, 2023), the price elasticity of metal supply is relatively poorly documented. While some contributions suggest higher profitability of mining projects in Africa once production has been initiated (Schodde, 2019, World Bank, 2020), notably due to weaker environmental and social regulations (Espagne and Lapeyronie, 2023) few studies document the reaction of metal supply to market price fluctuations (with the notable exception of Boer *et al.*, 2023)[12]. Such studies, in particular those documenting asymmetries with respect to upward or downward shocks, could nevertheless provide a wealth of information on the relative costs of the various actors and their ability to adapt their production to price variations. Raw materials production responses have been extensively studied in the case of the oil industry, through the notion of break-even point, which varies according to the producing country and the type of fuel extracted. For example, when oil prices fell in 2020, Nigerian independent producers, whose break-even points are higher than elsewhere, were at greater risk of having to cut back on investment and production (Cherif and Matsumoto, 2020), as were American producers of shale oil.

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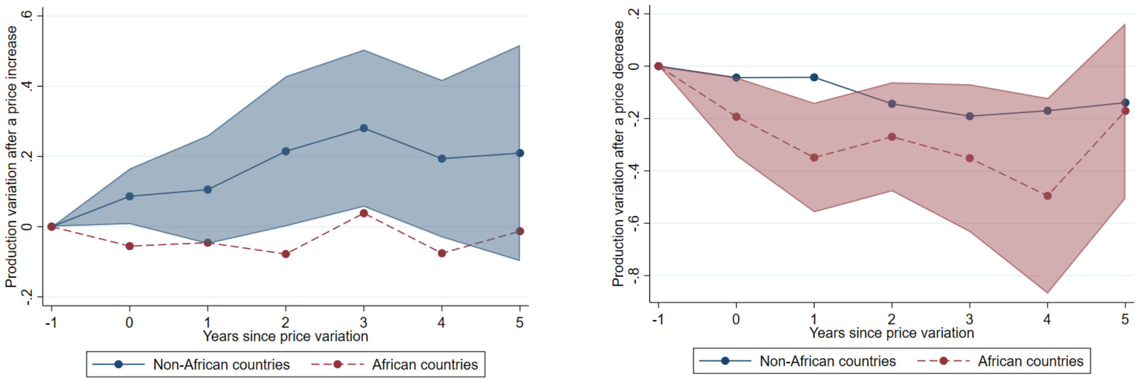
[12] More broadly, while the literature on the effects of commodity price shocks is large, contributions isolating the effects specific to metal prices are scarce (World Bank, 2021; Di Pace *et al.*, 2020).

Figure 5: Variation in output in response to positive and negative price shocks



a) Positive shocks > 15 %

b) Negative shocks > 8 %

Source: USGS, authors' calculations.
Note: effect expressed net of year, material and country fixed effects. Confidence interval at 90%. In panel a), positive shocks are dummy variables equal to 1 if prices have risen by more than 15% in the current year, and 0 otherwise. In panel b), negative shocks are dummy variables equal to 1 if prices have fallen by more than 8%, and otherwise.

We evaluate the response of production to past price variations, based on USGS data collected between 2012 and 2022 for our selected seven critical minerals. Using the local projection method**,** we regress, the variation in production between a year *t - 1* and different horizons ranging from *t* to *t + 4* on a variable indicating whether prices have increased or decreased between year *t - 1* and year *t*. Our working hypothesis is that only price shocks of significant magnitude are likely to induce variations in output (in other words, that the effects of price shocks are non-linear). To test this hypothesis, we insert price shocks as dummy variables, equal to 1 if the annual price variation exceeds a certain threshold, and zero otherwise. To capture possible asymmetric effects, we run two separate regressions based on a price decrease of more than 8% and a price increase of more than 15%[13] on the whole sample, and interact the price shock with a variable indicating whether or not a country belongs to the African continent. We isolate the effects specific to each material, country or year, by including fixed effects for each of these variables.

Differences in production responses to prices between Africa and other continents suggest greater cost effects in Africa (Figure 5). In the event of a significant positive shock, increases in production are statistically significant outside the African continent, with a maximum reaction time of around three years[14], while the African output does not react to the price shock. Conversely, in the event of a significant negative price shock, the African output declines in a statistically significant manner, with a maximum average lag of four years, while production on other continents appears less elastic to the shock (lack of statistical significance, see also Africa Development Forum, 2023). These results are still exploratory, particularly with regard to possible endogeneities. In particular, while our definition of shock is non-linear, it does not take into account the accumulation of shocks or their trends over time. Although it would be preferable to calculate shocks in deviation from a standard price level, calculated for example using a long-period trend (Cariolle and Goujon, 2016),

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[13] That is, respectively, the first and last quartile of annual price variations for the seven minerals studied between 2012 and 2022.

[14] These transmission delays reflect the existence of long decision chains leading to mineral production and significant costs of decreasing/stopping production (Fernandez, 2018). Response times to real price variations also vary widely by mineral: they reached almost eight years for copper after the 2004 boom (Natural Resources Governance Institute, 2022).

our analysis window is too short to be able to calculate such a price. Furthermore, our analysis does not take into account the role of capacity constraints, which introduce nonlinear effects in the firms' reactions to price signals (Boehm and Pandalai-Nayar, 2022). Nonetheless, we show in Figures A.5 and A.6 in the Appendix that our results are robust to alternative definitions of shocks. These additional results also suggest that, in the case of positive price shocks, the reaction gap between African and non-African countries is all the greater the larger the shock (output in African countries remains sluggish in all cases, but output in non-African countries rises more sharply if shocks are large). In the case of negative price shocks, the strong negative reaction of production in Africa seems to be observed even for smaller shocks (with the significance of the differences with non-African countries fluctuating).

Overall, these results suggest the existence of higher cost-effects in Africa[15], which can be translated into: i) upstream, higher risks of postponing exploration or bringing reserves into production, as many deposits in Africa remain under-exploited (Africa Development Forum, 2023); or ii) downstream, greater sensitivity of production to falling prices. Symmetrically, a rise in prices would also mean that fewer companies would be able to take advantage of it to increase investment or production. The short apparent lifespan of African deposits would therefore be more likely to reflect an underestimation of African reserves than a high production intensity.

3. Can critical metals help economic diversification and sustainable development in Africa?

A. Anticipated strong global demand for critical metals could generate substantial revenues for producing countries, provided that they can meet rising demand

Demand for critical metals is set to rise sharply over the next ten to fifteen years. According to assessments by Miller *et al.* (2023), in a scenario of zero net carbon emissions by 2050, global demand could increase more than fivefold for almost all critical metals by 2025, and more than twelvefold by 2040. Against this backdrop, it is worth asking whether critical metal rents essential to the energy transition could be a viable substitute for economies highly exposed to stranded asset risk.

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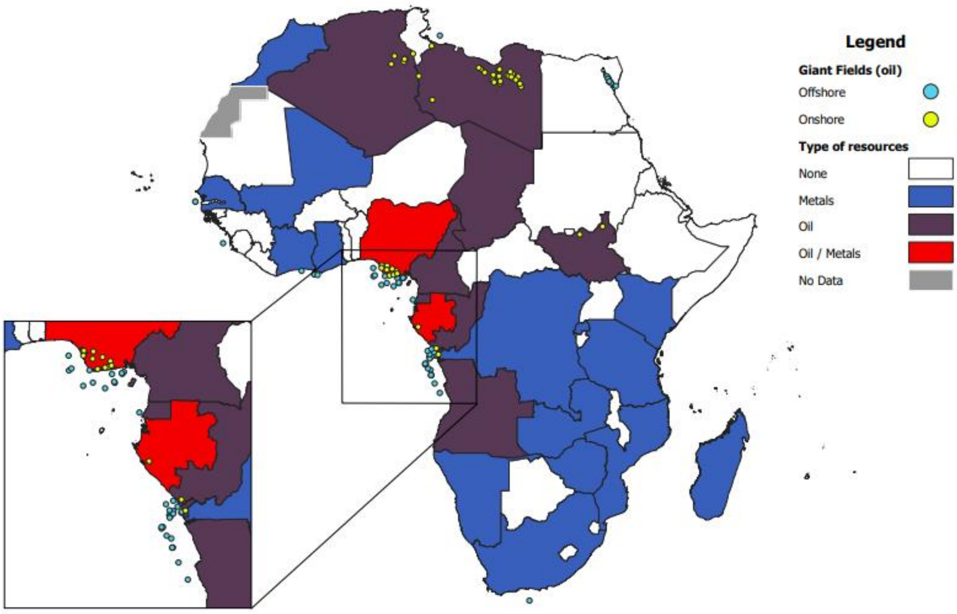
[15] If they differ from the estimates of a higher return on investment in Africa, several factors are likely to explain these discrepancies (different metal samples and time windows, different evaluation methodology).

Some oil-rich African economies also have significant mineral rents that are critical to the energy transition (Map 4[16]). Two countries stand out as both net oil exporters and producers of critical minerals: Nigeria (tin) and Gabon (manganese). Moreover, within these countries, the location of oil fields and of ores suggests a spatial differentiation between oil resources (which tend to be located offshore) and mineral resources (located inland), with potentially strong differences in terms of exploitation cost, isolation and regional development.

Map 4. Distribution of African countries by type of resource produced



Sources: IMF, USGS, Cust *et al.* (2021).

We assess the economic benefits to be expected from the exploitation of minerals critical to the energy transition, focusing on Gabon. Since the oil crisis of 2015-2016, Gabon's oil exports have stagnated at around 9 million tons in volume, representing between 3 and 5 billion USD (around 30% of current GDP), lower amounts than those seen in the late 1990s (around 15 million tons), or the first half of the 2010s (around 11 million tons). The peak value of exports was reached in 2011 (6.8 billion USD), reflecting both a high level of production and a high oil price. After fluctuating between 1 and 4 million tons until the mid-2010s, manganese exports rose sharply from 2017 onwards to reach almost 10 million tons. However, the associated values are much lower than those of oil exports (peaking at 1.3 billion USD in 2021).

The impact of manganese market development on economic activity will depend on the accelerating effects of manganese demand driven by the energy transition. Given the high degree of uncertainty surrounding these acceleration effects, we have selected two demand growth scenarios. In the first, demand growth follows the current trend, with no acceleration effect. In the second, we assume that demand growth in Gabon will be proportional to global demand growth in a carbon-neutral scenario by 2050 (based on the multiplicative orders of magnitude established by

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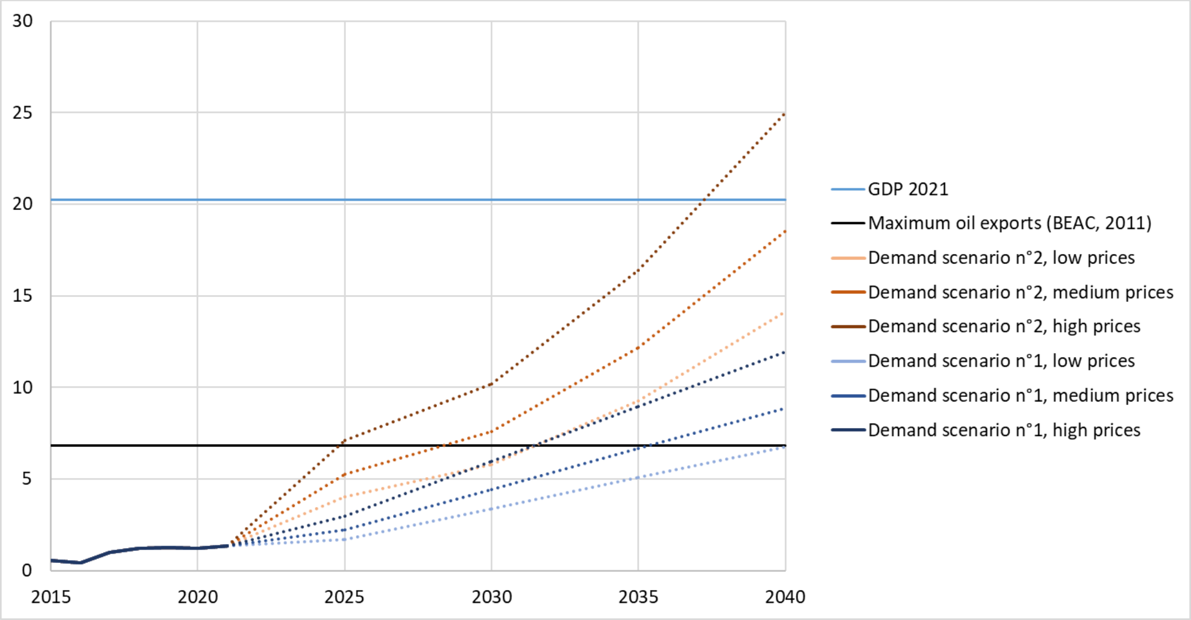
[16] This map does not take into account stranded asset risks related to the gas sector.

Miller *et al.* (2023)). These two scenarios imply different increases in world demand (a 6.5-fold increase by 2040 compared with 2021 in the first scenario, and a 12-fold increase in the second), and their plausibility is likely to depend on the credibility of the values of the estimated reserves[17] that condition the adaptation of supply to the increase in demand. We also use three price hypotheses: i) the lowest price observed between 2014 and 2021 (low price), ii) the average price observed over this period (medium price), iii) and the highest price observed over this period (high price)[18]. We compare each of these scenarios with the historical peak of oil exports (6.8 billion USD in 2011), and with the 2021 nominal GDP (20.2 billion USD).

Figure 6: Manganese export scenarios for Gabon
(in billions of current USD)



Sources: BEAC, World Bank, BACI, authors' calculations.

If Gabon's manganese exports continue to follow the trend observed since 2016, the revenues generated could reach the peak oil revenue by 2030 to 2040 (Figure 6). In a more dynamic export scenario[19], where Gabon instantly keeps pace with anticipated global demand for energy transition, manganese revenues could exceed peak oil revenue between 2025 and 2030. In this case, they could reach amounts equivalent to Gabon's current GDP shortly after 2035 (provided that prices correspond to the maximum prices observed over the 2014-2021 period, cf. demand scenario no. 2,

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[17] The latter were, according to the USGS, 13 times greater than annual production in 2022, a figure that may seem low in view of the scenarios proposed, and that should be interpreted with caution. According to these data, Gabon accounts for 2% of the world's reserves, while other estimates put the Moanda mine alone at 25%.
Source: https://www.jeuneafrique.com/1449784/economie-entreprises/pour-lapres-petrole-le-gabon-mise-sur-ses-mines/.

[18] The prices studied here correspond to the value of exports according to BACI divided by the volume of exports given by BEAC. These price assumptions do not include the effects on export prices of demand acceleration projections, or the effect of on-site reprocessing of manganese sought by Gabon.

[19] This scenario is however less likely in view of past dynamics and the length of the production cycle.

high price)[20]. These scenarios shed light on many possible paths for sectoral development. The promise of development in critical metals, and of economic growth for resource-rich countries, are predicated upon how current projections of medium- and long-term demand (and price) for critical metals will unfold, depending on future paths of technological innovation and on diversification of uses for these metals, which is still far from reaching that of hydrocarbon-derived products.

B. Critical metals: a source of sustainable development?

Beyond exports and associated revenues, and beyond the compensation for the anticipated decline in the hydrocarbon sector, metal production can help create sustainable wealth by contributing to the development of local industrial sectors, particularly that of renewable energies. Such economic diversification seems only possible under certain conditions.

As in the case of hydrocarbons, the first condition relates to the need to implement public policies addressing risks associated with the "natural resource curse". In addition to the risks already highlighted of political instability and conflicts linked to the appropriation of rents, the development of critical materials, as in the case of hydrocarbons, can result in lower growth and investment levels, particularly in Africa, the only continent to have faced a net loss of capital linked to the consumption and depreciation of its natural capital, particularly minerals (World Bank, 2021). Faced with these risks, an improved business climate, the promotion of stable regulatory frameworks (notably an even implementation of mining codes) as well as greater transparency and governance of the mining sector itself, notably through international coordination initiatives (Extractive Industries Transparency Initiative - EITI, Natural Resource Charter), are key to increase the attractiveness of African countries (Mejia and Aliakbari, 2023).

The quality of public finance management is an important factor in ensuring the optimal allocation of mining resources for sustainable development. The quality of macroeconomic policies (budgetary rules, strategies for investing resource revenues in human capital or non-resource productive infrastructure, etc.) is a central issue for the sustainable exploitation of critical metals, as in the case of other extractive activities (Jacolin and Vertier, 2022). Beyond the objectives of mobilizing fiscal and parafiscal revenues associated with rent-sharing during the exploitation phase, the development of critical materials requires upstream public policies. Such policies aim at assessing and limiting the collective public costs generated by the exploitation of these materials (increased water stress, pollution, impact on health, taking up of arable land), notably through environmental impact studies, and the inclusion of environmental clauses in the financing and contracting with mining companies. Public financial policy must also take into account risks of over-anticipating the rise of critical metals. These can lead to excessive and costly indebtedness, at non-concessional rates on Eurobond markets or collateralized by ore from mining and trading companies.

The final condition concerns the ability of African states to open up the mining sector to foster inclusive growth by capturing a greater share of the added value of critical materials in global value chains. This is particularly necessary as the employment content of critical metals mining declines and capital intensity increases with mechanization and digitization (Baskaran, 2022). In some countries, this opening-up of the sector may include targets for on-site processing of raw minerals. For example, Gabon's mining law (article 148) requires extractive companies to process

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[20] Another useful exercise would be to estimate the impact of projected increases in manganese production on budgetary resources, but data on manganese fiscal revenues are currently unavailable. As an indication, in 2022, oil budget resources corresponded to around 25% of oil exports (in value).

some or all of the minerals they extract locally. This also goes hand in hand with the local growth of renewable energies, whose complexity and development costs may require regional cooperation, as in the case of lithium (Goodenough *et al.*, 2021). This nexus between the mining sector and the local development of renewable energies appears crucial for Africa. This continent bears the high cost of greenhouse gas (GHG) emissions generated by the mining sector, but at this stage the associated gains mainly benefit developed and emerging countries. In the medium and long term, this joint development also seems crucial to limit the foreseeable dynamics of the continent's GHG emissions, resulting both from its demographic pressure and from a legitimate rise in the standard of living of African populations.

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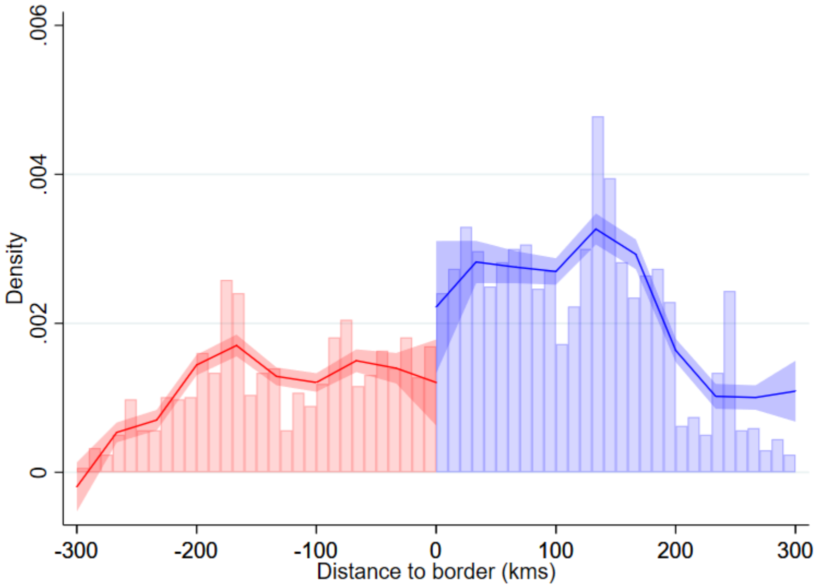
Appendix

Table A.1 - Critical metals in Africa

Minerals	Share of African countries, 2022 production (in %) [a)]	African producer countries (2012-2022)
Tantalum	72,8	Burundi, Democratic Republic of Congo (DRC), Ethiopia, Mozambique, Nigeria, Rwanda, Uganda,
Cobalt	72,1	South Africa, Madagascar, Morocco, DRC, Zambia
Manganese	65,5	Côte d'Ivoire, Gabon, Ghana, South Africa
Chrome	43,9	South Africa
Hafnium	35,0	South Africa, Mozambique, Senegal,
Titanium (Ilmenite)	34,8	Kenya, Madagascar, Mozambique, Senegal, South Africa
Graphite	22,1	Madagascar, Mozambique, Namibia, Tanzania, Zimbabwe
Copper	13,5	DRC, Zambia
Vanadium	9,1	South Africa
Tin	7,7	Nigeria, DRC, Rwanda
Lithium	5,0	Ghana, Mali, Namibia, DRC, Zimbabwe,
Tungsten	1,3	Rwanda
Rare earth elements (REE)	1,3	Burundi (nd), Madagascar (nd), South Africa, Tanzania
Niobium	1,0	DRC, Rwanda
Tellurium	0,6	South Africa
Aluminum	0	
Lead	0	
Silicone	0	
Magnesium	0	
Molybdenum	0	
Nickel	0	
Indium	0	
Zinc	0	
Cadmium	0	
Gallium	0	
Silver	0	
Neodymium	nd	nd

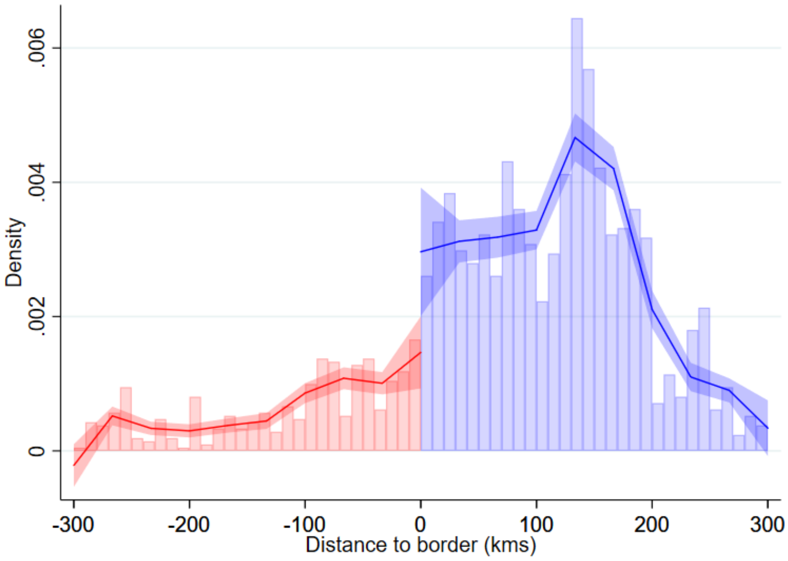
Additional results for border discontinuities

Figure A.1 - Difference in mine density around borders in 2019 – Alternative specification 1



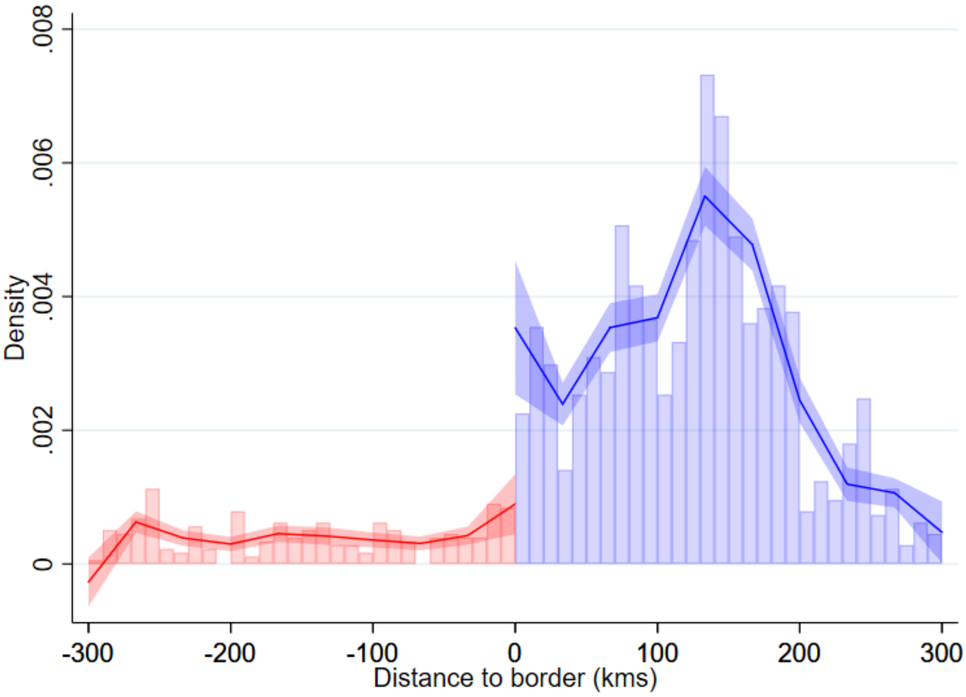
Note: Border density break by country pair (within each pair, the country with the best Polity score is to the right of 0, and the country with the worst Polity score is to the left of 0). 95% confidence interval. Estimated using the method of Cattaneo, Jansson and Ma (2018), with a polynomial of degree 4. The Polity score is calculated over the 1965-1995 period. Included country pairs have at least a Polity score difference of 2. Data are aggregated by 10 km intervals.

Figure A.2 - Difference in mine density around borders in 2019 – Alternative specification 2



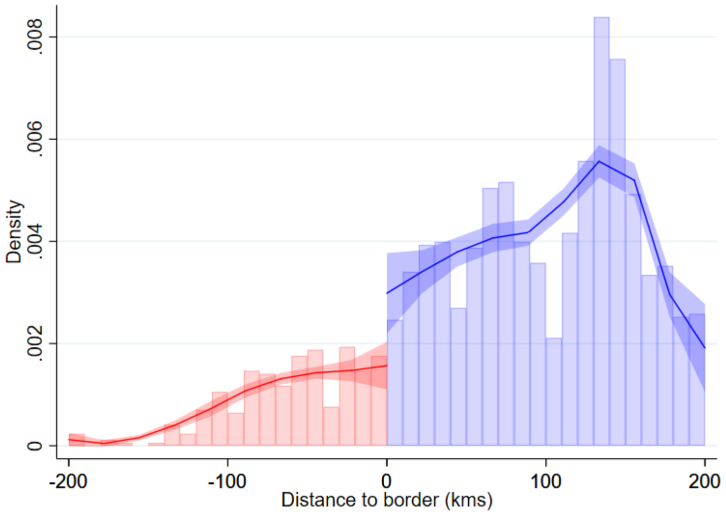
Note: Border density break by country pair (within each pair, the country with the best Polity score is to the right of 0, and the country with the worst Polity score is to the left of 0). 95% confidence interval. Estimated using the method of Cattaneo, Jansson and Ma (2018), with a polynomial of degree 3. The Polity score is calculated between 1965 and 1995. Included country pairs have at least a Polity score difference of 3. Data are aggregated by 10 km intervals.

Figure A.3 - Difference in mine density around borders in 2019 – Alternative specification 3



Note: Border density break by country pair (within each pair, the country with the best Polity score is to the right of 0, and the country with the worst Polity score is to the left of 0). 95% confidence interval. Estimated using the method of Cattaneo, Jansson and Ma (2018), with a polynomial of degree 3. The Polity score is calculated between 1965 and 1995. Included country pairs have at least a Polity score difference of 4. Data are aggregated by 10 km intervals.
Source: Maus *et al.* (2022), authors' calculations.

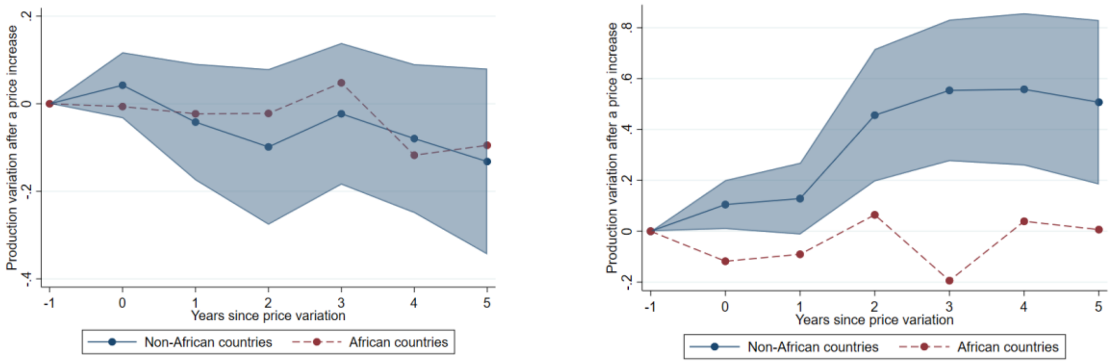
Figure A.4 - Difference in mine density around borders in 2019 – Alternative specification 4



Note: Border density break by country pair (within each pair, the country with the best Polity score is to the right of 0, and the country with the worst Polity score is to the left of 0). 95% confidence interval. Estimated using the method of Cattaneo, Jansson and Ma (2018), with a polynomial of degree 2. The Polity score is calculated between 1965 and 1975. Included country pairs have at least a Polity score difference of 3. Data are aggregated by 10 km intervals.

Additional results on production response to prices

Figure A.5. Variation in output in response to positive price shocks, for different shock thresholds

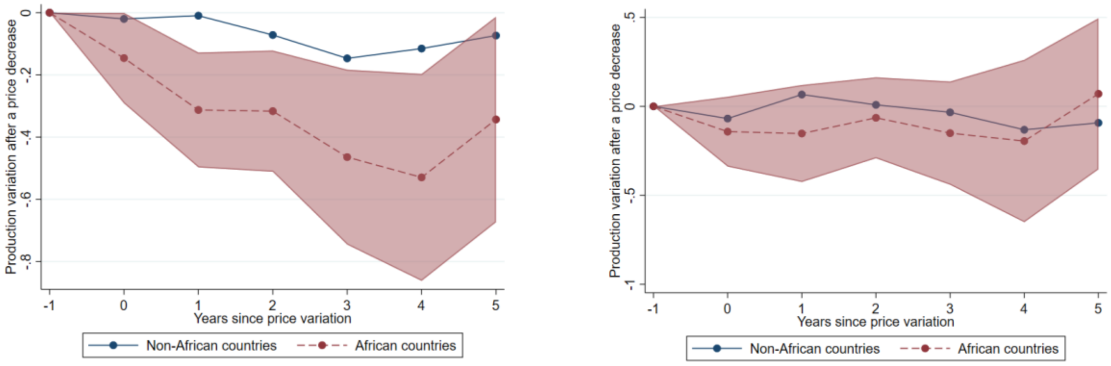


a) Positive shocks > 10 %

b) Positive shocks > 50 %

Note: effect expressed net of year, material and country fixed effects. Confidence interval at 90%. In panel a), positive shocks are dummy variables equal to 1 if prices have risen by more than 10% in the current year (corresponding to the first quartile of positive shocks) and 0 otherwise. In panel b), the threshold defining a shock is set at 50% (third quartile of positive shocks).

Figure A.6. Variation in output in response to negative price shocks, for different shock thresholds



a) Negative shocks > 5 %

b) Negative shocks > 20 %

Note: effect expressed net of year, material and country fixed effects. Confidence interval at 90%. In panel a), negative shocks are dummy variables equal to 1 if prices have fallen by more than 5% in the current year (corresponding to the first quartile of negative shocks) and 0 otherwise. In panel b), the threshold defining a schock is set at 20% (third quartile of negative shocks).

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Pascal

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