Property rights under selective enforcement: How mining cadastres relate to conflict in low income countries

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Abstract

This paper examines how the legal status of 4505 mines in ten African countries relates to local conflict levels between 2000 and 2020. I argue and show with original data that property rights in the mining sector temper local conflict levels only if they are monitored by external stakeholders. If this is not the case, conflict levels reflect the design and enforcement of property rights in low income countries, which in turn reflect existing power relations that favor multinational corporations and politically connected actors.

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1 Introduction

Do mining licenses reduce the link between economically valuable minerals and local conflict? The relationship between increasing commodity prices for minerals and conflict events around mines extracting these minerals has been a subject of significant interest and concern among researchers, policymakers, and stakeholders. In countries with low state capacity, minerals fuel conflicts between state and non-state actors such as rebel groups (Berman et al. 2017; Collier and Hoeffler 2004), small-scale miners and industrial miners (D. Christensen 2019; Rigterink et al. 2023). One key factor that contributes to such conflict events is the gap between the legal (*de jure*) and actual (*de facto*) ownership over mines and the economic rents they create.

Improved documentation of ownership over assets can, in return, cause property rights gaps (Albertus 2021), which refers to the differences in the legal recognition and protection of property rights. Such gaps lead to disputes and tensions among stakeholders. Establishing property rights over mining activities could therefore lead to more conflict events than unregulated mining. Understanding the effects and mechanisms around property right gaps is crucial for comprehending the dynamics of contemporary mineral-fueled conflicts. Contests over mineral extraction are further exacerbated by climate change and the increasing demand for so-called "green" minerals in the supply chain of electronic consumer goods (Nguyen et al. 2021) and the economic importance of artisanal mining as supplementary income for farmers (Girard et al. 2022).

The legal status of mines in low-income countries has become increasingly important in recent years. Firstly, significant aid payments are contingent on building administrative capacities in mining cadastres to improve mining license documentation. Additionally, policies like the Dodd Frank Act section 1502 (hereafter DFA) reinforces ownership documentation for minerals known as the "3Ts" (tin, tantalum, and tungsten) by requiring companies to disclose their use of conflict minerals and ensuring that their supply chains are free from funding armed groups in the Democratic Republic of the Congo (DRC) and its neighboring countries. The implementation of the DFA caused an asymmetric shock to the economic value of property rights in the mining sector of the affected countries.

De jure ownership of T3 mines became increasingly useful, while the value of licenses for other commodities did not change.

Studying the relationship between commodity prices, mining licenses and conflict is a complex task. Firstly, the availability and reliability of data on mining activities and their legal status remain limited. Secondly, there are issues of endogeneity to contend with. The allocation of resources to formalize ownership over an asset class is typically influenced by factors such as economic wealth, state capacity, historical roots, or cultural norms. To address these challenges, this analysis examines mining licenses in the DRC and its neighboring countries, which face increased demand for property rights documentation over T3 and reduced costs to build up capacities in the mining cadastres, due to technological change and increasing aid to fund capacity-building efforts. In sum, these events caused exogenous variation in the provision costs and utility of mining licenses. By analyzing original and publicly available data from these cadastres, I overcome the issue of administrative constraints and study the full set of mining licenses affected by the DFA in countries with operating online cadastres in 2023.By triangulating the *de jure* status of mines and the sum of actual mining activities, I derive a novel and more granular measure of mining production sites. This measure covers the entire spectrum of mining activities, from artisanal to industrial mines.

The paper empirically examines the proposition that robust investment in property rights within the mining sector, demanded and financed by foreign actors, has the potential to mitigate increasing conflict levels if minerals become economically more valuable. Theoretically, investments in the administrative capacities of mining cadastres can improve the documentation of property rights, establish clear ownership frameworks, and foster stakeholder cooperation. These improvements should, in turn, lead to less local conflict near mines with licenses, as property rights become more transparent and easier to enforce.

However, I argue, and demonstrate with original data, that this is often not the case in settings with very low state capacity. In such contexts, mining licenses reduce local conflict only if independent actors enforce them. In the absence of institutional constraints, the most powerful actors in a market shape the design and enforcement of mining licenses. In resource-extracting low-income countries, such actors are multinational firms and domestic political forces.

Anecdotal evidence supports this argument. Mine privatizations at the end of the second Congo war caused conflicts between artisanal and industrial mining companies, as multinational firms received the exclusive rights to extract lucrative resources that had been extracted by artisanal miners before the privatizations (Gulley 2023). Gaps between the *de jure* and *de facto* status of mining activities are also documented for T3 mining in eastern DRC and its neighboring countries after the DFA began regulating these commodities. To export T3 without proper ownership documentation, miners use informal channels such as smuggling and relabeling the origin of minerals (Ojewale 2022).

Before presenting the analysis and its underlying data in detail, the following section elaborates on how property rights can help resolve existing mining-related conflicts and how political preferences influence the provision of such licenses. Next, I discuss how the DFA and technological innovations in mining cadastres provide a unique case to observe differently enforced property rights in low-state capacity settings. The final section concludes with the implications of the findings of this paper.

2 Theory: How property rights gaps relate to mining conflicts

The literature finds great potential in the establishment of strong and universal property rights. Scholars associate them with lower risks of expropriation (Besley and Ghatak 2010), higher firm value (Berkowitz et al. 2015), more investment (Goldstein and Udry 2008), and long-term economic growth (Acemoglu and S. Johnson 2005).

The potential of property rights to increase social welfare is particularly promising in the context of resource extraction, as this sector is not only economically crucial to many low-income countries but also relates to multiple types of conflict. Without exploring this mechanism in detail, early quantitative work conceptualizes mining conflicts between rebel groups and government actors (e.g., (Berman et al. 2017; Collier and Hoeffler 2004)). To observe exogenous variation in the economic value of mining activities, most studies in the mining conflict literature consider commodity prices as exogenous factors.

Empirical evidence supports these expectations (e.g., Galiani and Schargrodsky (2010) and Ho (2021)), but is limited to countries with sufficient levels of state capacity and domestic initiatives to establish property rights. Conducting a meta-analysis of 46 natural experiments, Blair et al. (2021) find that price changes for lootable artisanal minerals provoke conflict, while price changes for other commodities tend not to., on average, do not change conflict risks. Recent work points out that mining conflict often emerges between civil actors and industrial mines. D. Christensen (2019) finds that mining relates to conflict due to incomplete information – a common cause of conflict in industrial and international relations. This mechanism rationalizes why mining often induces protest instead of full-fledged battles between belligerents. The study suggests that transparency dampens the relationship between prices and protest. Rigterink et al. (2023) provide evidence that competition between artisanal and industrial miners is also an important source of natural resources-related conflict. They find that the impact of price shocks on violent conflict is roughly three times as large in locations with industrial mining where artisanal mining is feasible as in places with industrial mining but no potential for artisanal mining.

This raises the question of which incentives political leaders have to withhold property rights in the mining sector and maintain an inefficient allocation of resources, especially if foreign donors are willing to invest in administrative capacities to document mining licenses. Analysis of a similar question in the context of land reforms is sometimes facilitated by invokin the concept of "property rights gaps". Property rights gaps are disparities or inequalities in the legal recognition and protection of property rights among different individuals or groups within a society. These gaps occur when certain individuals or groups enjoy secure and enforceable property rights, while others, often marginalized or disenfranchised populations, have limited or insecure rights to own, control, or transfer property. Scholars of land reform find that property rights gaps are an important reason why land reforms often do not lead to the desired results (Albertus 2021). The literature offers two explanations for these gaps, beginning with weak state capacity. Even when foreign donors provide technical solutions for mining cadastres, maintenance and compliance enforcement of these registries is left to domestic bureaucracies. Where administrative capacities are missing, property rights are simply not awarded (Joireman 2007; Toulmin 2009). A second type of gap emerges if politically powerful actors deliberately tailor, award, or enforce property rights to enhance the prospects of their own political survival. Both democratic and authoritarian leaders have incentives to reward allies or exclude rivals (Hassan and Klaus 2023). In the context of resource extraction, property rights can regulate market access, investment incentives, and the probability of expropriation. Since property rights are irrevocable, leaders are incentivized to reward long-term allies rather than short-term supporters with legal recognition of mining activities. Finally, property rights gaps can help politically powerful mining companies protect their assets against other stakeholders. Recent empirical work on mineral conflicts highlights the importance of dynamics between large-scale miners (LSM) and ASM (Rigterink et al. 2023) or the local population (D. Christensen 2019).

Moving on to the institutional effect of property rights gaps, Winters (2011) stresses the importance of selective property rights enforcement as a way to enforce claims by powerful individuals such as oligarchs. Exclusive control over property rights plays therefore a crucial role in wealth defense and a way to maintain non-democratic rule over societies. Winters (2011) argues therefore that wealth defense, including exclusive access to property rights, is the core political dynamic and objective for all oligarchies.

To summarize, the literature finds a positive relation between the economic value of mines and nearby conflict, while it associates property rights with lower conflict levels as they make it easier to solve disputes and enforce the rule of law. This implies that newly established property rights over a mine should temper the link between commodity prices and conflict nearby mines extracting these commodities. Property rights gaps, on the other hand, might cause the absence of such moderating effects. Figure 1 summarizes the causal relation between the economic value of a mine, conflict and property rights.

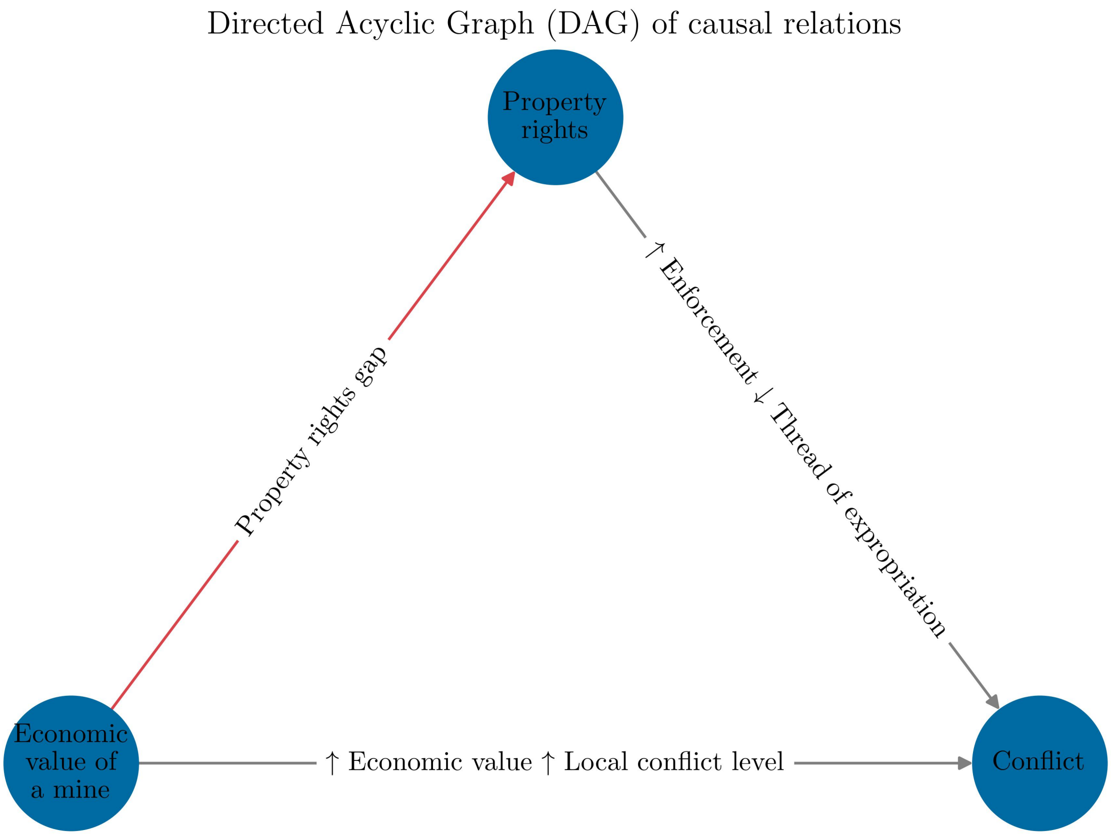


Figure 1: Directed Acyclic Graph (DAG) of the causal relations between the economic value of mining activities, property rights and conflict. If no property rights gap exists, moderate property rights local conflict levels. If they exist, they mediate the political or economic power of a mine its access to property rights. In this case depends the effect of property rights on local conflict on the political or economic characteristics of each mine.

A property rights gap moderates both the economic value of a mine and property rights local conflict levels. If they exist, mediate mine characteristics the access to and effect of property rights.

These gaps are state capacity- or deliberately created constraints that exclude some actors via access to rights or their selective enforcement. This implies that property rights have more characteristics of a club – rather than a public good. They cause welfare losses and also political spillovers. Such spillovers can become new reasons for conflict or welfare-inhibiting power-sharing mechanisms to maintain rule. Newly established property rights can influence local conflict levels in all directions and even increase local conflict levels if they create new channels for political influence and expropriation.

3 Context: The DFA and Its Effects

The issue of unclear property rights in the mining sector poses a significant challenge in the Democratic Republic of Congo (DRC) and its neighboring countries. While many large-scale mines (LSM) have operated since colonial rule, many sites are operated by small-scale, artisanal miners (ASM) who operate without any legal documentation. Disputes over access to resources exist between miners and political actors, as well as between ASM and LSM.

While the dynamics of these conflicts are heterogeneous, a particular instance of mining conflict receives a lot of attention among stakeholders in high-income countries. During and after the second Congo War (1998-2003), rebel military groups controlled ASM in the eastern Kivu region. These mines operate under devastatingly inhumane conditions and finance weapons purchases and more leading to the term "conflict minerals". In response, policies like the Dodd-Frank Act (DFA) require public companies in the U.S. to disclose their use of 3T minerals in their products and confirm that they are sourced ethically[1].

The DFA and the public debate around conflict minerals impose multiple types of costs to companies that trade or use of undocumented commodities that might be conflict minerals. For one, the United States Securities and Exchange Commission (SEC) can audit and fine companies found not to comply with the DFA. Additionally, links between companies and illicitly extracted conflict minerals can cause long-term reputation costs, especially for companies that sell consumer goods. As in other fields of public regulation (Malhotra et al. 2019), corporations sought to preempted the implementation of the DFA[2] with their own schemes for due diligence reporting, or formalized their sector before these practices received extensive international attention. For instance, Dell implemented a Conflict Minerals Program in 2008 (Dell Technologies Inc. 2008) and in 2009, Apple began to exclude companies from supply chain if they could not document that their T3 was

[1]Initially, the DFA also required due diligence reporting for gold. However, a substantial volume of gold is traded in unregulated, informal markets, so gold has been excluded from the due diligence requirements (Parker and Vadheim 2017) minerals.

[2]Following the US initiatives, entities such as the OECD, the Chinese Chamber of Commerce, and the European Union have passed similar regulations.

ethically sourced [3] (Apple Inc. 2019). However, as small-scale mining remains a crucial source of income for millions of people in the DRC and neighboring countries (Parker, Foltz, et al. 2016), a full embargo on conflict minerals has never been implemented.

Instead, donors finance and support efforts to formalize the mining sector in the affected countries and require due diligence reporting from private companies regarding the origin of the 3Ts they use. To provide the necessary administrative capacities to document ownership, mining cadastre systems not only record the beneficial ownership of mines, but also provide the administrative infrastructure for other bureaucratic tasks such as tax collection or environmental regulations. As a result, seven out of ten countries affected by the DFA now have publicly available online repositories of their mining licenses. Each country's decision about whether and how to formalize its mining sector with a cadastre is subject to domestic political processes.

When evaluating the effects of the DFA, scholars present a mixed picture. On one hand, the documentation of mine ownership has significantly increased in recent years. Today, a significant share of 3Ts is certified as "conflict-free". Unfortunately, the DRC's overall conflict level level has not fallen (Parker and Vadheim 2017). Qualitative evidence suggests that licensing schemes for formal property rights have introduced new avenues of political influence over the mineral supply chain (D. Johnson 2013), including mining certification fraud and cross-border smuggling (Ojewale 2022). This suggests that political alliances have become increasingly useful if one actor can provide legal documentation for the origin of 3Ts. The price of 3Ts without documentation of origin has dropped up to 80 percent compared to the world market (Carisch 2012). Transnational networks also play a crucial role in the second Congo War and subsequent conflicts (König et al. 2017).

These features make the DFA context an ideal case, for two compelling reasons. Firstly, the DRC and its neighboring countries extract both T3 and non-T3 minerals, enabling a comprehensive examination of the impact of the DFA on mineral-related conflicts and property rights enforcement. Secondly, the region has a long history of mineral-induced conflicts, with disputes over access to resources involving small-scale artisanal

[3] Based on the companies own definition of ethical extraction

miners and large-scale mining operations. The presence of such long-lasting conflicts provides valuable context for studying the effectiveness of heterogeneously established and enforced property rights.

4 Illustration: Property right gaps in the DRC

The formalization of the mining sector in the DRC and neighboring countries has resulted in multiple types of property rights gaps. This section illustrates two instances of these gaps.

The first instance of property rights gaps is situated in cobalt production in the DRC, the world's largest source of this commodity. Cobalt mining is closely tied to the extraction of other commodities, as its ores often oxidate with metals such as nickel and copper. While cobalt production had therefore been a byproduct of other mining activities, the global demand for cobalt grew 26-fold from 2000 to 2020 (Gulley 2023). This increased demand is driven by the use of portable electronics and electric vehicles (EV) in the transition towards clean energy (Nguyen et al. 2021).

This increasing demand presents mining companies operating in the cobalt sector with a trade-off. Since cobalt has been a byproduct, there has been hardly any exploration for untapped deposits globally for decades. New investments in industrial cobalt extraction therefore require a long implementation period. Existing cobalt large-scale mining (LSM) operations, primarily located in the DRC, face a high political risk [4].

To increase existing production capacities without the risk of long-term investment commitments, artisanal and small-scale mining (ASM) is useful, as it is neither capital- nor technology-intensive. As outlined in section 3, is cobalt not defined as conflict mineral and hence not regulated by the DFA. However, pursuing ASM without legal regulation poses the same reputational threat and might provoke external regulations, similar to the DFA.

[4] For instance, the DRC's first prime minister, Patrice Lumumba, tried to nationalize copper and cobalt mines that became Belgian private property after independence (Radmann 1978). During the second Congo War, all industrial copper-cobalt mining in Lualaba and Haut-Katanga stopped operating (Geenen and Cuvelier 2019).

To improve the *de jure* framework of ASM cobalt mining, multinational mining companies like Glencore cooperate with the central government of the DRC to formalize the sector since 2018 (Deberdt 2021). Today, Glencore and many other companies face allegations of large-scale corruption activities during the same period (Financial Times 2022; Lipton and Searcey 2022). These events suggest that large extracting firms and the former national DRC government designed the legal framework for LSM and ASM cobalt mining in ways that favor multinational firms. Figure 2 illustrates this legal setting. The satellite image shows the location of five LSM projects that are partly owned by Glencore. The cobalt ores in this region have a high degree of cobalt, making them suitable for ASM [5]. Between the 1960s[6] and 2005, hardly any constrains limited ASM operating in the region. Today, formal ASM licenses are awarded in the grey areas, while ASM in the actual mines is illegal. In contrast, multiple LSM licenses (not displayed in the figure) cover the entire area, including both ASM licenses and the actual industrial mining areas. Conflicts are documented between security forces and artisanal miners. Additionally switch former employees of the state owned companies into ASM after the mines got privatize(**faberArtisanalMiningLivelihoods**). Glencore claims that an average of 2,000 illegal miners enter their mines every day (Stans Bujakera and Aaron Ross 2019). In the present legal setting, ASM on land owned by multinational corporations itself is illegal and therefore not under the responsibility of these firms. The firms are for instance not liable if miners have accidents on the land they own. At the same time, ASM licenses for sites near the industrial mines enable ASM-mined cobalt to easily enter the supply chain which minimizes thread of additional regulation in the future.

A second example of property right gaps is the case of tantalum ASM in Northern Kivu, The export of tantalum is regluated by the DFA. Figure 9(a) plots awarded ASM production licenses and the actual locations of mines. The mines are located in the northern DRC, around 90 km to the border with Rwanda. The plot shows that only one of the fifteen mines within two $5km^2$ grid cells operated under an ASM license between

[5] The share of cobalt in ores determines the weight value ratio, and if this ratio is too low, ASM is not feasible

[6] During colonial rule, industrial cobalt mines operated in the region (Hance et al. 1961).

Figure 2: Satellite image of the Musonoi mines and the city of Kolwezi. The blue dots mark five large-scale mining pits that extract cobalt, including the Katanga pit displayed in Figure 4(a). The red dots mark cobalt processing plants. The grey areas mark ASM licenses.

1998 and 2023. Qualitative evidence documents mineral smuggling activities from the DRC into Rwanda (Ojewale 2022). This provides rent capture opportunities and political leverage to the central government of Rwanda, the DRC, and local groups like the March 23 Movement (M23), a rebel military group formed mainly of ethnic Tutsi. For instance, the DRC government can reward local militias that are its allies with mining licenses, which lowers their costs of exporting T3 minerals from mines they control. The Rwandan central government can increase its influence in the Kivu province by providing local militias such as the M23 access to T3 exports via Rwanda. This implies that, since DFA, ASM operations that do not have access to a formal license have become increasingly dependent on informal channels to export T3.

5 Measurement and Data: Mining activities and their legal status

This section outlines the methodology used to measure the effects of property rights on resource extraction in ten low-income countries, as outlined in section 2. To identify the causal relationship between the economic value of mines and property rights on conflict, two types of mining measures are needed: the location of relevant mining sites and the legal documentation of each site over time. To identify the location of ecomically import industrial mines, existing studies use proprietary datasets, but these ignore informal mines that may contribute significantly to a country's production capacities. Recent studies leverage geological characteristics to identify areas suitable for ASM (Girard et al. 2022; Rigterink et al. 2023), but do not localize unique mining sites or consider factors such as market access or labor availability in their measurement of ASM. This paper introduces a new approach to observing both mining activities and their legal status over time.

To measure the level of local conflicts, data from the Armed Conflict Location and Event Data Project (ACLED) (Raleigh et al. 2010) is used to measure of local conflict events. While ACLED has been criticized for underreporting (Van der Windt and Humphreys 2016) and imprecise geolocation (Eck 2012), it remains the most granular repository of data on expropriation- and conflict events, including , protests, and battles in Africa. König et al. (2017) show that their empirical findings on conflict in the DRC using ACLED data are still robust when they use the UCDP Georeferenced Event Dataset (Sundberg and Melander 2013) as outcome variable, which covers significantly fewer events.

Actual mining activities

To identify formal and informal mining sites, the Minerals Yearbook, volume III, published by the National Minerals Information Center at the United States Geological Survey (USGS), enables a first step. This publication provides a comprehensive overview of mineral resources available in each country, including their geological and geographical characteristics, production and trade statistics, and information on exploration and development activities. Individual formal mining sites are located, while ASM sites for specific commodities are aggregated on the district (adm2) or province level (adm1). To locate ASM sites more precisely, Yearbook data was linked with data from country-level datasets that list the locations of unique ASM mines. To observe the performance and ownership structures of mines, the data was also linked to three proprietary databases: Eikon Energy Screener, fDi markets, and Orbis. This approach significantly increased the sample size: a total of 4270 unique ASM and 235 unique LSM in the ten countries of interest. Figure 4(a) plots a single grid cell where LSM operates, while figure 9(b) plots two grid cells with ASM. Figure 5(a) plots the entire sample of mining activities. These data mapping efforts substantially expand the sample of observed mining activities. For instance, S & P Mines and Minerals, a commonly used resource for industrial mining activities, identifies only 82 unique mines in the DRC and its neighboring countries. I identified nearly triple this number. To my knowledge, no large-n study observes ASM activities on a unique asset level. Appendix 5 further disaggregates the comparison to S& P Mines, as documented by H. Christensen et al. (2022). The appendix also compares the sample to a USGS dataset from 2005, which Dreher et al. (2016) use to geolocate mining activities.

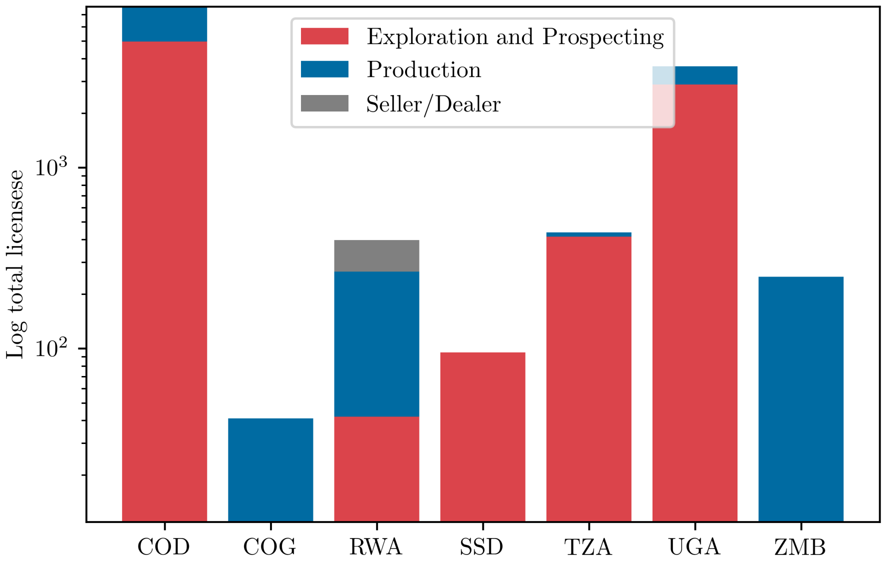
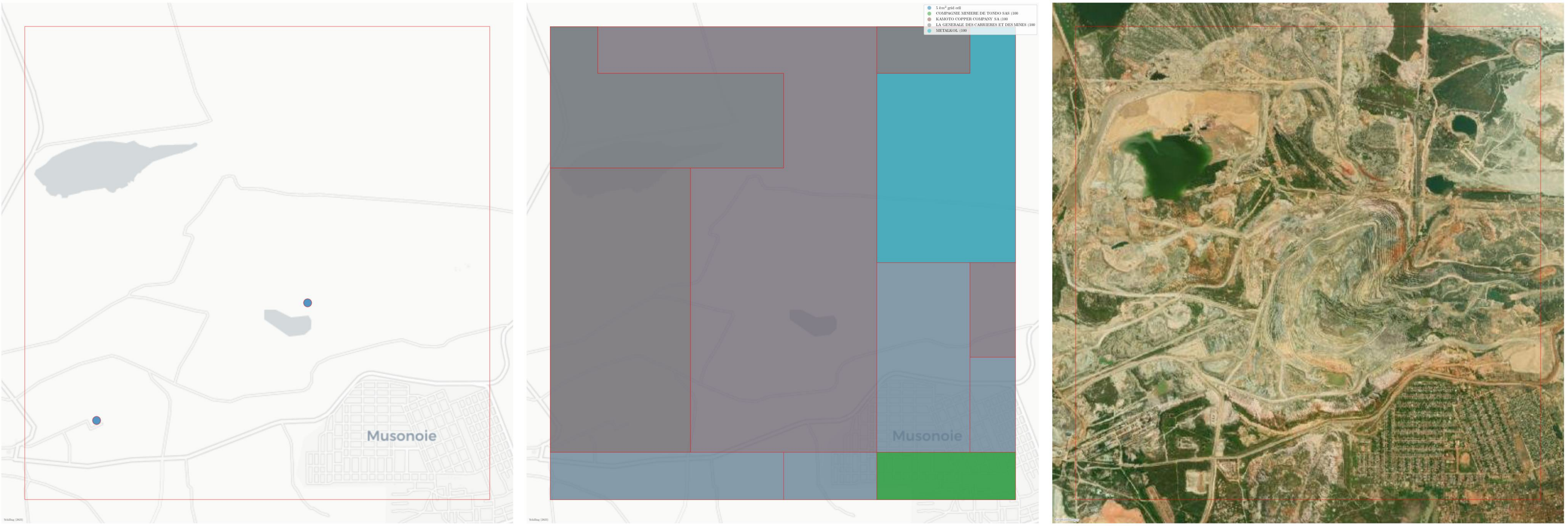


Figure 3: Total number of mining licenses per country with an online cadastre. Source: Author's estimates from analysis of national cadastres

Legal status of mines

To identify where property rights for mining activities have been defined, the mining cadastres of each country were parsed. Seven out of ten countries affected by the DFA publish their entire mining cadastres online. While these portals are public, the underlying data is unstructured and bulk download is not possible. To overcome this constraint, the framework Memorious was leveraged to scrape each mining portal. Even though the first mining cadastres went online in 2008, each portal also includes prior documentation of licenses in analog mining cadastres. This approach provides all formally-mined licenses since independence for each country. The exact legal definition and rights of each license type depends on the national judicial framework. Figure 3 plots the total number of each license type per country. Whether and how a country documents ownership structures over its mines is subject to its institutions and economic dependence. The analysis discusses selection into treatment in detail. Map 4(a) plots the location of mining activities for a single grid cell, while map 5(b) plots the locations of all mining licenses in the sample.

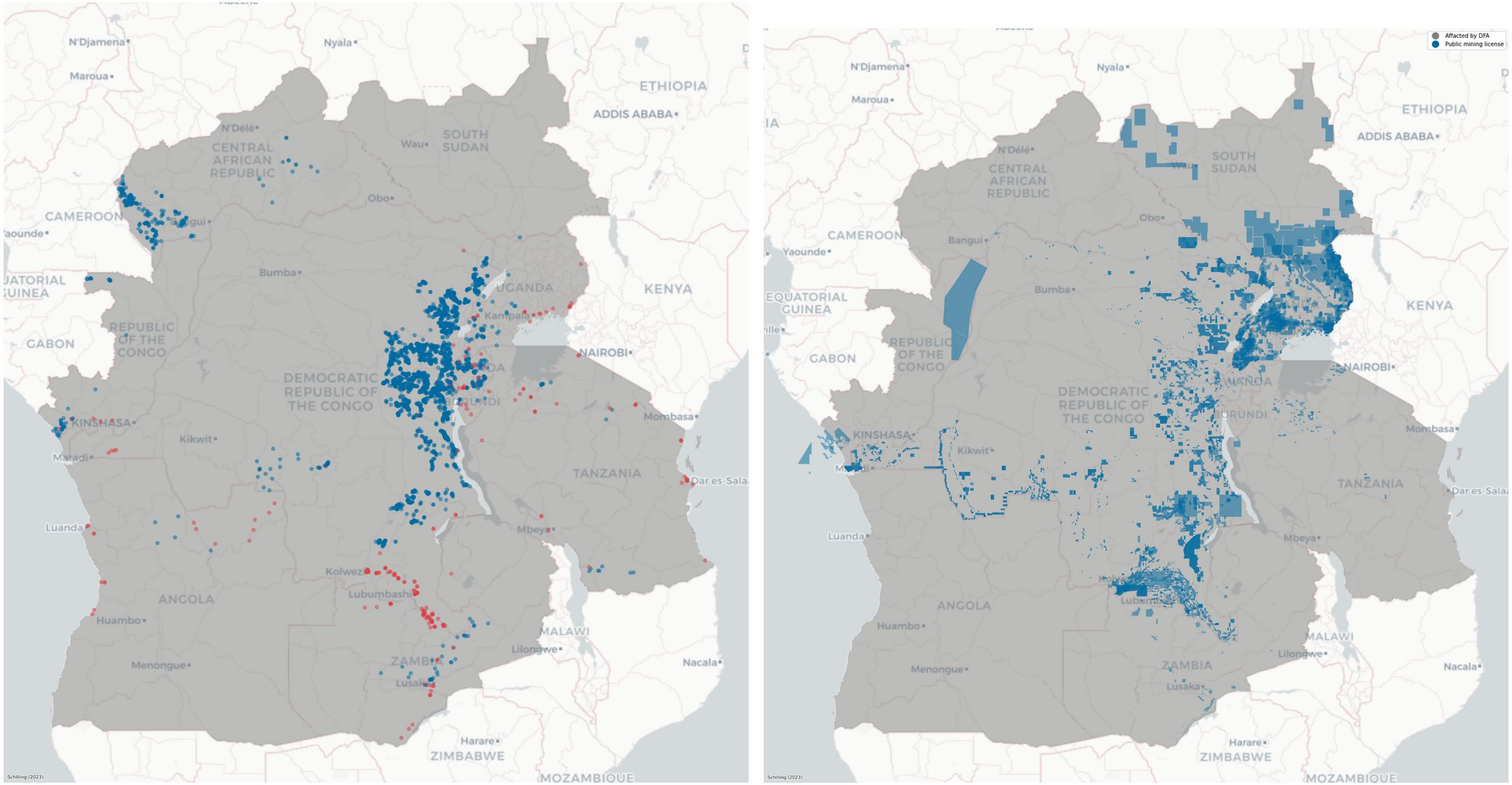


(a) Location of unique production sides on grid cell. Source: See main text

(b) Location of licenses. In total intersect 17 unique licenses with the grid sell. Source: See main text

(c) Satellite image of the cell. Source: Esri World Imagery

Figure 4: Production sites, mining licenses and satellite image of a single 5 km^2 grid cell with LSM. The displayed mines are called Katanga KOV Mine and Katanga KTO and extract copper and cobalt in the DRC. Katanga KOV produced 13.48 thousand tons in 2022 and is one of the world's largest cobalt mines. Both mines are run by the Kamoto Copper Company which is owned by the Swiss multinational Glencore (75%) and the state-owned Gécamines (25%) source. The awarded mining licenses in the cell are owned by four different entities and granted for the period 2002-2027. The first application for a license in this cell was filed in1999.



(a) ASM (blue) and LSM (red) mining sides

(b) Mining license locations

Figure 5: Location of artisanal or small-scale mining and large-scale mining (LSM) sides as well as mining licenses. The dark grey areas mark the territory of countries that are affected by Dodd-Frank Act section 1502 after 2010. Angola and the Central African Republic do not have mining registers that are available online. Burundi published only a static repository of mining licenses in 2014.

6 Identification

As outlined in Figure 1, the empirical strategy aims to determine the conditions under which mining licenses moderate the relation between price shocks and local conflict levels. The identification stragy relies on the comparison of $5km^2$ grid cells with different types of mining activities and licenses. This section details variations that occur across space, time, license-awarding institution, extracted commodity, and production scale. These variations enable consideration of the economic and legal heterogeneity of mining activities in the DRC and neighboring countries. While this rich data enables the separation of a mine's legal status from its economic characteristics, it makes the identification strategy somewhat complex. The primary focus of this identification approach involves a Difference-in-Difference estimation of the linear probability that a conflict event occurs in a grid cell in a given year. I distinguish between the legal, economic, and production characteristics of mines to delve into the marginal effects of formalization.

First, I leverage variation in world market prices for each commodity which are plausibility exogenous to the mines operating in the sample and compare mining licenses that are increasingly useful for exports after 2010 due to the DFA. Additionally, I distinguish between ASM and LSM mining, as these mines extract commodities at different scales. This paper also replicates the well-established finding that the increasing economic value of lootable minerals causes higher conflict levels (Berman et al. 2017; Blair et al. 2021), in greater detail than had been possible in studies that rely on less granular measurement of mining production sides and commodity prices. Additionally, I address potential observational selection issues. These could be caused by confounding factors that determine both a regime's decision to award mining licenses to miners in a grid cell as well as the local conflict levels.

Observational selection

In case only certain regimes award mining licenses, the present analysis builds upon a preselection into treatment. For instance, if only democratic regimes formalize their mining sector, changing conflict levels could be confounded by the effects of democratization rather than the licenses themselves. Since the DFA affected ten countries, the number of observations is too small for a reasonably quantitative finding of what determines country's decision to formalize its mining sector. Instead, I compare country-level descriptive statistics to explore the role of political and economic institutions. This includes political variables such as corruption, as well as export statistics of T3 and other minerals.

To observe institutional characteristics, I leverage the V-Dem score (Lindberg et al. 2014) for deliberative democracy, which focuses on how decisions are reached in a polity. Additionally, I consider the V-dem scores of political corruption which includes measures of six distinct types of corruption that cover executive, legislative and judicial corruption at different governance levels. I also consider the sub-measure 'executive corruption,' which asks how routinely members of the executive or their agents grant favors in exchange for illicit activities such as bribes or kickbacks. Like any measure of cross country intuitions, these measures need to be taken with a grain of salt as they face endogeneity issues and can not capture the full complexity of a country's political and social situation. Nevertheless, they display institutional patterns across countries and allow for statistical control over the establishment of mining cadastres.

Disaggregate legal status, economic value, and commodity type

To disaggregate each mine's legal status from its economic value, I apply a well-established measure of the economic value of mining activities. This approach leverages variation in world market prices for commodities to observe exogenous variation in the economic value of a mine and is often used in the mineral conflict literature. This assumption might be called into question, particularly when it comes to cobalt extraction, where the DRC provides up to 89% of the annual world supply. To validate the assumption that prices are indeed exogenous to the countries of interest, Appendix .1 examines the market power each commodity holds. To estimate commodity prices as accurately as possible, I consider the modal price ratio between value and weight of trade flows in the BACI trade statistics dataset (Gaulier and Zignago 2010). Compared to existing measures, this time series spans a larger time period. To validate this price measure, Appendix 7 compares this measure to prices in the spot market data from Bloomberg. Based on this comparison, I conclude that the BACI calculated price index provides the most comprehensive measure over time and correlates strongly with other, less comprehensive measures. Even though the global demand for cobalt has increased 26-fold since 2000, the world market prices of cobalt did not outperform other commodities, suggesting that even the DRC does not have enough political power to leverage its theoretical monopoly of the global cobalt supply.

While existing research estimates the economic value of each grid cell based on the modal extracted commodity, I consider the sum of T3, cobalt and copper (2C), gold, and diamond production for each cell. This approach allows for a more granular comparison of cells and distinguishes among the value of property rights over different commodity types. Furthermore, this measure accounts for geological clustering, which is important as many commodities are extracted at the same mine[7]. I compare T3 licenses to other types of mining licenses, i.e., I compare licenses to extract commodities that are regulated by the DFA to licences for commodities that are not.

Additionally, I distinguish between ASM and LSM as described in the measurement section 5 to control for the production scale of each mine. In sum, I derive four variables for economic value: DFA-regulated commodities that are extracted under ASM or LSM, and non-regulated minerals that are extracted under ASM or LSM. The total economic value of mining activities in each cell can be expressed with the following equation:

$$ECON_{it} = \sum_{c=1}^{C} ASM_c \times ln(P_{ct}) + LSM_c \times ln(P_{ct}) \tag{1}$$

Where ASM_c represents a dummy for an ASM of commodity c. Similarly captures LSM_c industrial production of commodity c. Next, $ln(P_{ct})$ captures the log of the world market price for commodity c in year t. DFA-regulated material includes T3 minerals, where c is tin, tungsten, or tantalum. To examine the relation between resource extraction, property rights and conflict across mining for different minerals, I group the economic value of mining activities for each cell in two dimensions: 1) ASM - LSM 2) DFA regulated

[7]Tungsten, tin, and tantalum as well as cobalt and copper are often extracted in the same mine.

Regulation	ASM	LSM
DFA	1589	24
non-DFA	2358	251

Table 1: Number of mines for each production type considered in the baseline regression. For each of these production sides I examine whether active mining licenses moderate the relation between the economic value of a mine and local conflict levels.

- nonregulated minerals. For each category, I consider the sum of each mining type operating within the boundaries of the cell and define a dummy for each category, if at least one mine is operating. Table 1 summarizes the number of mines for the four production types in a 2×2 matrix.

Estimation

Based on these considerations, I next examined how publicly documented property rights moderate the effects of mining activities on local conflict levels. I placed the proxy of economic mining value in each cell in interaction with a dummy variable that indicates whether the mine's territory lies within the scope of an active mining production license. Equation 2 expresses this relation:

$$P(CONFLICT)_{it} = \Gamma_i + \beta_1 Prod_{it} + \beta_2 Prod_{it} \times ECON_{itm} + \beta_3 ECON_{itm} + \omega_t + \epsilon_{it} \quad (2)$$

Where $Prod_{it}$ represents a dummy for any active mining license at cell i in year t. To account for spatial autocorrelation, I cluster the standard errors for both regressions using Conley (1999) and control for cell fixed effects Γ_i and year fixed effects ω_t. As each mining license's start and end dates are documented, each license treatment remains active until the license expires.

7 Results

As outlined in the identification section, I present two sets of results. First, I present descriptive statistics about the mining and country characteristics to explore which factors determine the establishment of a mining cadastre. Next, I examine the effects of mining licenses on the relationship between commodity price shocks and local conflict.

Descriptive statistics

Addressing the threat of observational selection, Table 2 displays the total amount of mining-related FDI, the first year a country received aid commitments related to mineral/mining policy and administrative management in the IATI database, the last year of an aid commitment project in this sector, the V-Dem scores for political and executive corruption, and the V-Dem deliberative democracy score [8]. As outlined in Section 6, I examine whether institutional characteristics confound both the decision to award mining licenses and local conflict levels. The table also indicates whether the country publishes a mining cadastre and whether this cadastre changes over time and intersects spatially with at least one mining production site. Additionally, Appendix 8 plots the annual T3 export for each country.

Combined, the data show a consistent trend. Countries that are affected by the DFA publish a mining register. Countries that do not export T3, including Angola, the Central African Republic, and South Sudan, do not publish a time-variant register. The only exception to this pattern is Burundi, which exports T3 but published only a static list of mining licenses nearly a decade ago. This implies a straightforward selection mechanism for the types of mining licenses observed in this study: If a country exports T3 and is therefore affected by the DFA, they publish mining licenses online, regardless of domestic institutional characteristics such as political corruption or degree of democratization.

[8] The sources of these data are fDi markets, the IATI database, and Lindberg et al. (2014)

Table 2: Country characteristics of DFA affected countries

iso3	Mining related FDI (mio. USD)	First mining aid commitment	Last mining aid commitment	Political corruption	Executive corruption	Deliberative democracy	Public mining cadastre	Δ Production license ∩ mine
AGO	293.1	Never	Never	52.9	69.8	4.5	False	False
BDI	317.9	2010	2017	57.6	43.1	9.7	True	False
CAF	0.0	2006	2018	69.1	56.8	8.1	False	False
COD	9619.0	2002	2022	67.4	78.8	7.2	True	True
COG	3364.4	2002	2017	79.5	92.7	11.1	True	True
RWA	318.3	2017	2018	48.4	49.3	8.7	True	True
SSD	0.0	Never	Never	9.5	9.7	0.7	True	False
TZA	3366.6	2001	2021	47.8	44.8	16.9	True	True
UGA	163.6	2003	2014	69.0	61.1	13.1	True	True
ZMB	9169.9	1995	2022	20.5	20.1	18.6	True	True

Notes: Descriptive statistics of all countries affected by the Dodd-Frank-Act (DFA) section 1502. Authors' computations from fDi Markets, International Aid Transparency Initiative and V-Dem. See main text for data sources and measuring scale.

Regression estimates

Moving on to the relationship between commodity prices and conflict, Figure 6 shows the regression predictions for changing commodity prices on the probability of local conflict

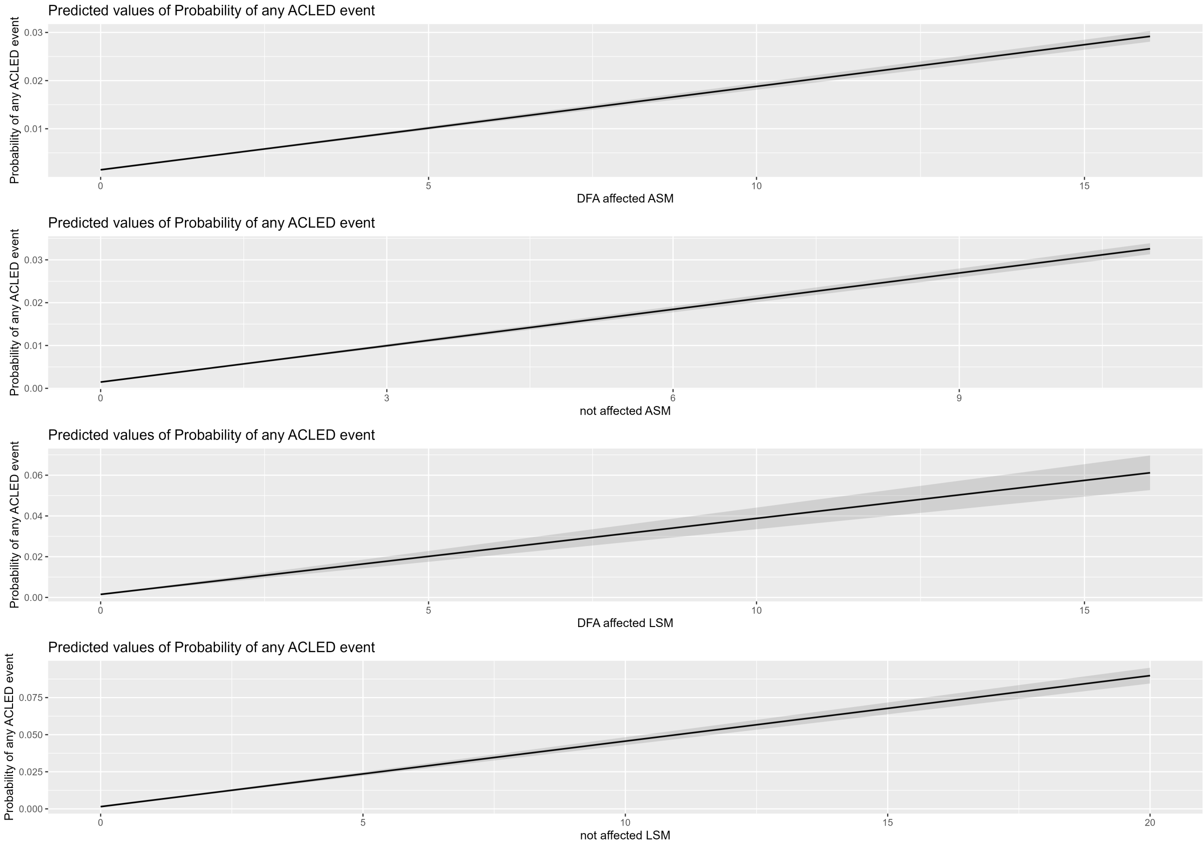


Figure 6: Linear regression of the log prices of extracted commodity on the probability of local conflict events across the four production types

events at the cell level for each of the four mining types, regardless of their legal status. The relation between changing commodity prices and conflict levels is positive across all four types of production sites. Yet, some heterogeneity exists. First, both the distribution and range of economic value proxies vary across the different mining types. This variation originates not only from different commodity price changes but also different location patterns across minerals and production types. For instance, ASM mines often extract all 3T minerals. As the measure considers the mining activities for each commodity type, it aggregates the price changes for each commodity of a production type. The effect size also differs, while all four types of economic activities increase the conflict levels in this linear model significantly at a p-level below 0.01, the coefficients vary from 0.0017 for ASM regulated by the DFA to 0.0044 for non-regulated LSM. The coefficient pattern suggests that price changes in DFA-regulated mines cause smaller increases in conflict levels and that the price-conflict link is stronger for industrial mines.

Next, I considered the role of mining licenses on the relation of interest. Table 3 reports the baseline results of the analysis. Each column examines the moderating effect of mining licenses on conflict for one of the four mining production types. As outlined in the identification strategy, the analysis separates commodities that need DFA-approved documentation of origin to be exported, i.e., T3, from those that do not. This reveals heterogeneity in the enforcement quality of mining licenses due to external monitoring. The first, fourth, sixth, and eighth rows display the coefficient for the relation between the economic value of each mining type and its local conflict potential. Across three of the four models, an increase in commodity prices corresponds to a significant increase in local conflict levels. Row two lists the coefficient for the direct effect of a mining license on local conflict level for each model. This includes cells that do not contain mining production but are legally covered by an active production license. The remaining rows interact the legal status of a mine with its economic value, distinguishing between DFA and non-DFA commodities as well as ASM and LSM mining. Columns 1) and 2) in table 3 show the results for commodities that are regulated by the DFA. Columnn 1) predicts that for artisanal T3 mines, a price shock larger than 45% of a standard deviation (SD) causes mines with a mining license to have lower levels of conflict than the same type of mine without a license facing the same price shock. This effect is even larger for mines that extract the same commodity on an LSM scale. For instance, column 2) predicts that for T3 minerals extracted by LSM, a price shock by one SD increases the probability of a conflict event by 0.0480 if the mine has a license. In contrast, the same type of mine without a license faces an increase of 0.0576. While these effects are small in absolute terms, they imply large changes in relative terms.

To present the effects more intuitive in percentages, a price increase of one SD with a license relates to a 1070% lower increase in the probability of conflict events compared to the baseline probability. For price shocks smaller than 45% for ASM or 11% for LSM, column 1) and 2) predict that DFA-regulated mines with a license face a larger probability of conflict events than the same type of mine without a license. Since the coefficients for price changes are larger than the coefficient of the interaction of prices × licenses, mining licenses will never fully mitigate the negative effect of price change in commodities that are regulated by the DFA in this model.

In contrast, mining licenses for commodities that are not regulated by the DFA do not temper conflict levels. Columns 3) and 4) document the regression estimates for this type of mining. In this specification, a non-DFA-regulated commodity's price increase of one SD is associated with 66% larger probability for a conflict event with a mining license than the same price increase without a license. The probability value in this case lays above on any established significance level.

In sum, these regression results support two main findings. First, the analysis confirms a well-established finding: the economic value of mines and conflict levels in their vacinity are positively related to each other. Using more granular measures of mining sites and commodity prices, this analysis shows that this relationship holds not only among large-scale mines but also smaller, informal mines that prior studies did not consider on an individual level. Second, property rights temper the effect of price shocks on local conflict levels if these rights are actually enforced and monitored. This implies overall heterogeneous effects of newly established property rights.

The clear utility provided by mining licenses for DFA-regulated minerals is that they reduce the likelihood of local conflict events. This finding holds for both LSM and ASM mines. In contrast, where mining licenses that are not regulated by the DFA do not provide such value. They are associated with higher levels of conflict than mines without ownership documentation.

The underlying mechanism of this heterogeneity is plausibly linked to a mine's dependence on political or bureaucratic entities. Due to property rights gaps, political or economic characteristics of mines mediate the effects of mining licenses on conflict levels. Miners who do not need to document their ownership are less vulnerable to political interference. When due diligence reporting becomes mandatory, miners with formal licenses are better protected from political interference. In contrast, miners without licenses are more dependent on political actors, as they need to find informal channels in order to sell their commodities abroad. In sum, these findings suggest that formalization and the DFA contribute to lower conflict levels for mines with access to property rights but increase conflict levels where license are not monitored by external actors.

Table 3: Effect of different mining actities on likelihood for conflict with or without Production license on a cell level 2000-2020. The baseline probability of a conflict evnt per cell in a given year is 0.00151

Dependent Variable:	P(any ACLED event)			
Model:	(1)	(2)	(3)	(4)
Variables				
DFA ASM	0.0072***			
	(0.0014)			
License	0.0019***	0.0017**	0.0014**	0.0016**
	(0.0007)	(0.0007)	(0.0006)	(0.0007)
DFA ASM × License	-0.0010**			
	(0.0005)			
DFA LSM		0.0159***		
		(0.0046)		
DFA LSM × License		-0.0046*		
		(0.0024)		
no DFA ASM			0.0037***	
			(0.0011)	
no DFA ASM × License			0.0006	
			(0.0011)	
no DFA LSM				0.0046
				(0.0029)
no DFA LSM × License				0.0002
				(0.0024)
Fixed-effects				
Cell level (333,719)	Yes	Yes	Yes	Yes
Year (21)	Yes	Yes	Yes	Yes
Fit statistics				
R^2	0.23508	0.23501	0.23504	0.23501
Adjusted R^2	0.19683	0.19676	0.19678	0.19676
Observations	7,008,099	7,008,099	7,008,099	7,008,099

Conley (9.2km) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

8 Conclusion

This paper highlights the importance of property rights gaps in the socio-economic utility of property rights, particularly in the context of resource extraction and local conflict. I argue that these gaps hinder efforts to formalize the mining sector in low-income countries and to reduce the level of conflict near the mines.

To test this argument, I introduce two novel data sets of mining activities and their legal status in ten sub-Saharan countries. Using a Difference-in-Difference design, the analysis shows that mining licenses reduce local conflict levels significantly only if their enforcement is monitored by external stakeholders. Global demand to document the origin of T3 minerals, initiated by the DFA, demonstrate that external monitoring can prevent some of the political influence over property rights and ensure that mining licenses reduce local conflict levels substantially. But the DFA also establishes new dependencies between miners and political actors, as T3 minerals need some sort of formal documentation prior to export. Miners without access to a mining license face therefore a large threat of political interference.

Can foreign stakeholders effectively oversee mining operations in low-income countries through regulatory mechanisms such as the DFA and mining cadastres? While the implementation of mining cadastres is comparatively cost-efficient, empirical evidence presented in this study underscores the indispensability of external oversight in ensuring the efficacy of mining licenses. It is challenging to provide a precise estimate of the total expenses associated with monitoring the origins of T3 minerals due to the multitude of governmental departments, corporate entities, initiatives, and non-governmental organizations involved in these monitoring endeavors.

Consequently, the findings in this paper call for further research aimed at comprehending the characteristics of mines that undergo formalization. An area of particular interest pertains to the interactions between multinational corporations, which dominate commodity extraction, and political actors in low income countries.

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.1 Market-power over global commodity

To ensure that commodity prices are exogenous to the actors in the sample, I examine in this section the market power of the DRC for the global cobalt production. If a single country dominates the global supply of a particular commodity, actors in the economy could set the market prices causing of endogenity. Across the minerals and countries in the sample, the market share of the DRC is by far the largest market share, making it the most likely case of a producer being a price setter in context of this study.

According to the USGS, the country accounts for roughly 70 % of the global market share. Cobalt is crucial for the global supply chain of lithium-iron batteries which face significant demand increase in recent years. In 2018 the government established the national agencia Enterprise Générale du Cobalt (EGC) the formal monolply to purchase and export cobalt.

However, despite this formal market dominance, the actual market power of DRC remains the defactovery limited. The major share of the fifteen production sides that extraction cobalt in the DRC are owned by Glencore, a multinational cooperation, approximately 30 % of the cobalt is extracted aritsanel. Yet, the no fully independent, economically relevant ASM sides are known . Instead the formal licenses of cobalt ASM are established in close proximity to LSM mining sides. The majority of domestic shareholder in cobalt industry are close to the ex president Kabliba (Deberdt 2021). Despite increasing demand, the global market prices did not increase substantially in recent years.

A Further heterogeneity of enforcement

The baseline identification shows that differences in the enforcement quality of mining licenses cause heterogeneity in their effectiveness to reduce conflict levels nearby mines. To examine differences in enforcement among licenses further, I disaggregate the licenses in two additional ways.

To do so, I replicate the baseline regression in Table 4, but split the sample into two periods: before the DFA became active in 2010 and after. This event did not impose a fully unpredictable event on the affected countries. For instance, the NGO Global Witness published their first report about the social issues of T3 extraction in 2005 (Lipsey 2005), raising awareness among policymakers and corporations. Columns 1) - 4) report the specification as the baseline regression for the post-period 2000-2009, while columns 5) - 8) report these specifications for 2009-2020 after the DFA became active.

This split reflects the main findings of the analysis, but most coefficients become statistically non-significant below a 10 % level. The direct relationship between commodity prices and conflict increased for ASM mines after the DFA became active (comparing column 1) and 5)), while the relationship turned negative for DFA-extracted commodities at an LSM level (column 2) and 5). While the coefficients of the mining licenses are non-significant for both the direct and interaction terms in all eight models, the direction of the coefficients reflects the main findings. After the DFA became active, active mining licenses mitigated the effect of price shocks to a large degree compared to similar mining types that are regulated by the DFA.

Table 4: Effect of different mining actities on likelihood for conflict with or without Production license on a cell level between 2000 and 2009 (column 1-4) and 2010-2020 (column 4-8).

Dependent Variable:				P(any ACLED event)				
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables								
DFA ASM	0.0029**				0.0087**			
	(0.0015)				(0.0040)			
License	0.0001	0.0002	0.0004	0.0004	-0.0002	-0.0003	-0.0007	-0.0002
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
DFA ASM × License	-0.0002				-0.0003			
	(0.0008)				(0.0006)			
DFA LSM		0.0062				-0.0516**		
		(0.0043)				(0.0260)		
DFA LSM × License		-1.19×10^{-5}				-0.0139		
		(0.0001)				(0.0104)		
no DFA ASM			0.0004				-0.0014	
			(0.0009)				(0.0014)	
no DFA ASM × License			-0.0024				0.0013	
			(0.0033)				(0.0013)	
no DFA LSM				0.0043*				0.0044
				(0.0025)				(0.0082)
no DFA LSM × License				-0.0019*				-0.0069
				(0.0011)				(0.0110)
Fixed-effects								
Cell level (333,719)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics								
# Year	10	10	10	10	11	11	11	11
R^2	0.32655	0.32654	0.32654	0.32654	0.30377	0.30377	0.30376	0.30377
Adjusted R^2	0.25172	0.25171	0.25171	0.25171	0.23414	0.23414	0.23413	0.23414
Observations	3,337,190	3,337,190	3,337,190	3,337,190	3,670,909	3,670,909	3,670,909	3,670,909

Conley (9.2km) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 5: Production sides per country, comparing my own ASM and LSM measure, to the S &P mines and minerals data and the USGS 20025 Compares USGS 2005 and 2018. USGS 2005 was collected by Dreher et al. (2016)

iso3	asm	lsm	S&P	USG 2005
AGO	5	17	10	13
BDI	58	20	0	9
CAF	225	0	0	0
COD	3365	87	36	0
COG	43	5	0	11
RWA	137	14	0	4
SSD	1	0	0	0
TZA	18	34	12	65
UGA	61	19	1	27
ZMB	34	79	23	113

A.1 Mining Licenses and production sides

B ASM in northern Kivu

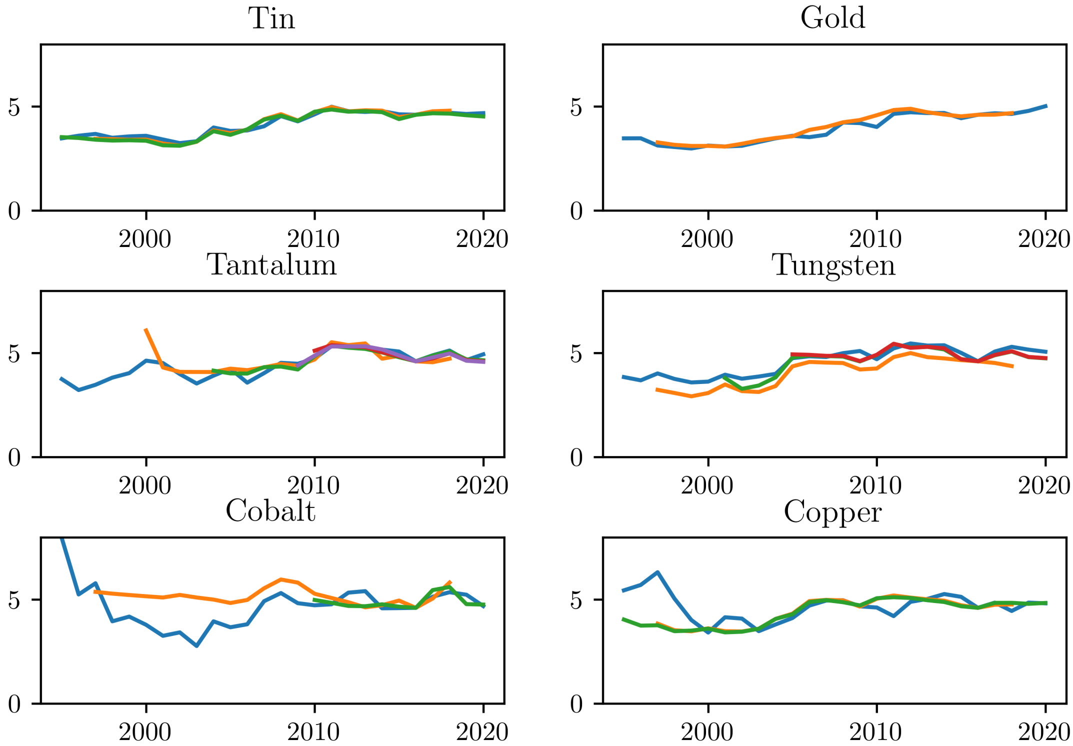


Figure 7: Commodity prices (ln, baseyear 2016) over time, comparing prices from Bloomberg (green, red and purple), BACI (blue), and metalary.com (orange). The Bloomberg data consists of the following prices indices: China Tantalum Concentrate Ta 205 30 % CIF, China Tantalum Metal 99.95 % FOB, China Tantalum Metal 99.95% Delivered US, Europe Tungsten APT 88.5 % In warehouse Rotterdam, China Tungsten APT 88.5 % FOB, LME TIN 3MO ($) UNF Comdty, LME COBALT SPOT ($) Comdty, LME COPPER SPOT ($) Comdty. The BACI prices index is the modular ration between quantity and value of all trade-flows per commodity type with at least one trade partner being affected by the DFA per year. Both BACI and metalary.com prices are deflated by prices real to 2016 and normalize by the natural log. This paper uses the BACI commodity prices for the analysis.

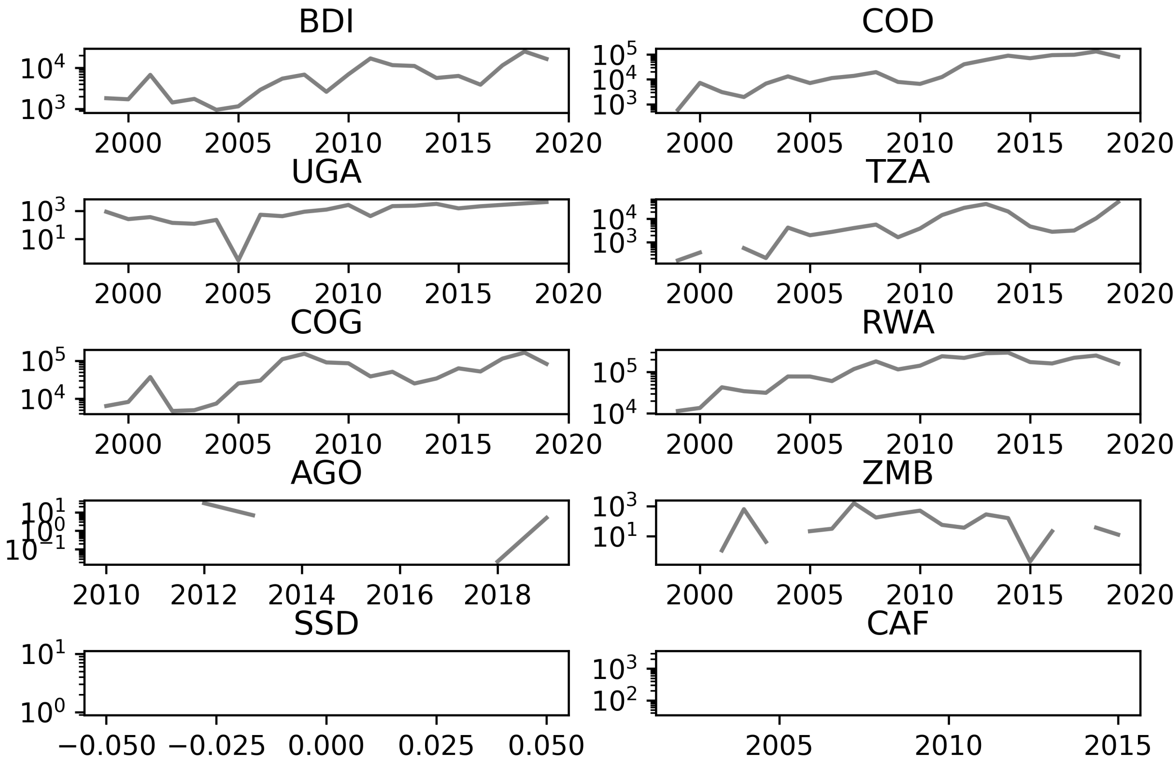
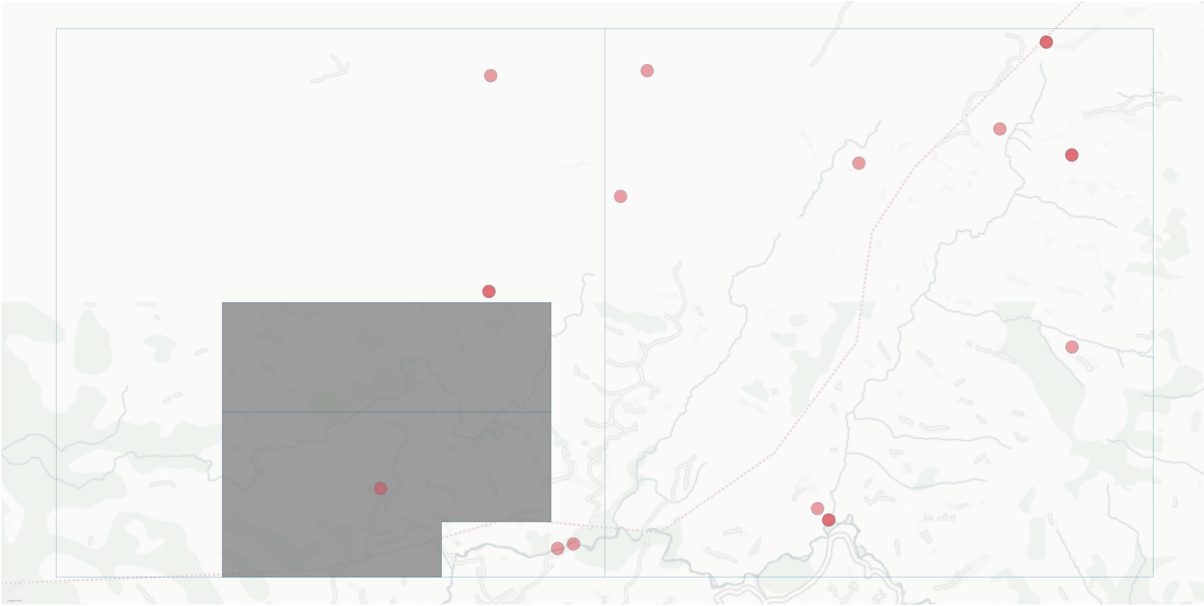


Figure 8: T3 exports per country 2000-2020 (data source: BACI)



(a) ASM gold and tantalum production, ASM licenses, and boundaries of two $5km^2$ grid cells at the border between North and South Kivu, DRC. The left cell is coded as ASM, regulated by the DFA with a license from 2017, while the right cell is ASM partly regulated by the DFA but without a license.

(b) Satellite image and ASM production spots

Figure 9: Example ASM production sites that are regulated by the DFA. The two grid cells are located around 90 km from Goma, the capital of the Northern Kivu province.