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

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Introduction

Do legal mines cause less conflict than informal ones? Research has shown that resource extraction is often associated with various types of conflict, particularly in low-income countries. The issue of conflict is further exacerbated by climate change, as the global demand for mining commodities continues to rise and artisanal and small-scale mining (ASM) becomes increasingly important for the livelihoods of many individuals [1]. For decades, donors and scholars have advocated for property rights in low-income countries and have provided financial support to establish them. When properly enforced, mining licenses can create investment incentives, reduce transaction costs, and minimize the risk of expropriation. However, the effectiveness of these licenses depends on the rulers and bureaucracies in place, who may prioritize political survival and personal access to rents over the efficient allocation of resources. Despite significant efforts to enhance administrative capacities in the mining sector of low-income countries, little is known about how these investments relate to non-market strategies and local conflict levels.

This paper aims to empirically examine the proposition that robust investment in property rights within the mining sector, demanded and financed by foreign actors, has the potential to mitigate conflict over valuable resources such as minerals. Specifically, I consider the role of property rights as a moderating factor between the economic value of a mine and its level of local conflict. 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 lower levels of 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 due to non market strategies. In such contexts, mining licenses only reduce local conflict if they are additionally enforced by independent actors. In the absence of such actors become the design, enforcement and quality of

[1] ASM helps to supplement or even replace agricultural incomes during droughts. Currently, the livelihoods of 130 to 270 million people depend on ASM (Girard et al. 2022)

mining licenses subject to non-market strategies that powerful actors carry out. If the potential for local grievances is particular high, can mining licenses even increase the levels of local conflict in the short term. To observe exogenous variation in the level of foreign enforcement over mining rights, I study the effects of Section 1502 of the Dodd-Frank (DFA) Act. This US legislation requires the documentation of origin for tin, tungsten, and tantalum (T3) minerals[2] in the Democratic Republic of the Congo (DRC) and its neighboring countries. The legislation compels companies in the electronics sector to document the origin of these minerals in their supply chain.

Qualitative evidence suggests for instance that smuggling and the forging of traceability documentation for T3 minerals by politically connected actors in the DRC and Rwanda increased after the DFA became active in these countries (Ojewale 2022).

Studying the effects of property rights empirically is a challenging task, particularly in low-income countries. Firstly, access to administrative data is often 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 property rights that were documented due to exogenous events, namely shifting types of aid payments and technological innovations. These two factors enabled the countries in my sample to formalize their mining sector with online mining cadastres at very low costs from the 21st century onwards. 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. To observe not only legally registered mines but also actual extraction sites, I combine georeferenced data sources to derive a novel and more granular measure of mining production sites. This measure includes a wide range of production scales, from artisanal to industrial mines.

The primary argument presented in this paper is that mining licenses only increase the costs of non-market strategies if they are awarded and enforced by sufficiently strong

[2]Gold was initially included in this list, but its due diligence reporting is practically impossible due to its large informal market (Parker and Vadheim 2017)

domestic institutions or foreign actors. If this is not the case, provide mining licenses even more potential for non-market strategies. For instance, selective property rights can give rise to new causes of conflict, such as competing property claims between the legal owner of a mining license and defacto operating miners within the boundaries of the license.

In the context of the DFA, mining licenses for T3 minerals are monitored and enforced via the influence of foreign companies, while licenses for other minerals are regulated solely by domestic institutions. To maintain their power, domestic rulers have an incentive to strengthen their personal grip on the mining sector rather than provide universal access to and enforcement of rights. This incentive creates mechanisms that resemble what Albertus (2021) refers to as "property rights gaps" in land reforms. In other words, varying levels of political influence among mining stakeholders result in selective enforcement and access to licenses, even if administrative capacities improve the documentation of ownership rights. Such selective enforcement can give rise to new causes of conflict and maintain non-democratic types of rule such as oligarchies (Winters 2011).

My empirical analysis supports this argument. In my baseline regression, I find that T3 mining licenses weaken the positive relationship between price shocks and local conflict levels. In contrast, licenses that are not subject to the DFA have no effect or even increase the likelihood of conflict events. Using more granular data, these findings also confirm existing research: The economic value of an extraction site is positively related to the probability of conflict events near a mine.

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 such licenses are influenced by political preferences. 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 by discussing the cases to which the findings of this paper apply.

Theory: How property rights gaps relate to mining conflicts

The literature finds great potential in the establishment of strong and universal property rights. Scholars attribute 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 Johnson 2005). Empirical evidence supports this perspective (e.g., Galiani and Schargrodsky (2010) and Ho (2021)), but is limited to countries with somewhat sufficient levels of state capacity and domestic initiatives to establish property rights. The potential of property rights 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.

Conducting a meta-analysis of 46 natural experiments, Blair et al. (2021) find that price changes for lootable artisanal minerals provoke conflict, while commodity price changes, on average, do not change conflict risks. Recent work points out that mining conflict often emerges between civil actors and industrial mines. 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 it is 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. Addressing a similar question in the context of land reforms, the term *property rights gaps* refers to the 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 on land reforms find in property rights gaps an important reason why land reforms often do not lead to the desired results (Albertus 2021). The literature provides two potential explanations for these gaps. The first one is weak state capacity. Even if foreign donors provide technical solutions for mining cadastres, domestic bureaucracies still need to maintain these registries and enforce compliance. If 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 in the interest of their own political survival. To maintain their political power, 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, or the probability of expropriation. Since property rights are irrevocable, leaders have an incentive 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 work highlights the importance of conflict dynamics between large-scale miners (LSM) and ASM (Rigterink et al. 2023) or the local population (Christensen 2019).

Moving on to the institutional effect of property rights gaps, Winters (2011) highlights the importance of selective property enforcement as a way to enforce property 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, property rights 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 become a club rather than a public good. This causes not only welfare losses but also political spillovers. Such spillovers can be new reasons for conflict or power-sharing mechanisms to maintain rule. Property gaps moderate the effects of mining licenses on conflict, especially under weak or selective enforcement. 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.

Context: The Dodd-Frank Act Section 1502 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 been operating since colonial rule and are arguably more established than their national governments, there are also many mines that operate as artisanal or small-scale miners (ASM) without legal documentation.

One instance that highlights the social costs of these weak property rights is the second Congo War from 1998 to 2003, during which military groups gained revenue by controlling ASM in the eastern Kivu region. These mines operate under devastating and inhumane conditions and finance armed conflicts, leading to the term "conflict minerals." While the conflict in the eastern DRC has multiple causes, the issue of conflict minerals has gained significant attention among stakeholders in high-income countries. In response to these social issues, the Dodd-Frank Act of 2010, specifically Section 1502 (hereafter referred to as DFA), requires public companies in the U.S. to disclose their use of tin, tungsten, tantalum(3Ts)[3] in their products and determine if they are sourced ethically.

The DFA and the public debate around conflict minerals imposed multiple types of costs to companies that trade or use conflict minerals without documentation the origin of these commodities. For one can the SEC audit and fine companies that do not comply with the DFA. Additionally imposes a link between companies and illicitly extracted conflict minerals a sustainable reputation costs, especially for companies that sell consumer goods.

As in other fields of public regulation (Malhotra et al. 2019), preempted corporations the implementation of the DFA[4] with their own scheme of due diligence reporting beforehand. For instance, Dell implemented a Conflict Minerals Program in 2008, Apple excluded the first companies from its T3 supply chain in 2009 due to missing documentation.

However, due to the fact that small-scale mining remains a crucial source of income for millions of people in the DRC and neighboring countries, a full embargo on conflict minerals has never been implemented.

Instead, donors have financed and supported 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, bilateral and multilateral donors have financed and supported the creation of mining cadastres. These cadastre systems not only document 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. The decision of whether and how each country formalizes its mining sector with a cadastre is subject to domestic political decisions.

When evaluating the effects of the DFA, scholars present a mixed picture. On one hand, the documentation of mining ownership has significantly increased in recent years.

[3] As mentioned in the Introduction, the DFA initially also required due diligence reporting for gold. However, since gold has a substantial informal market that is not regulated by Dodd-Frank it is excluded from the due diligence requirements (Parker and Vadheim 2017).

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

Today, a significant share of 3Ts is certified as ”conflict-free” minerals. Unfortunately, these efforts have not reduced the overall conflict level in the DRC (Parker and Vadheim 2017). Qualitative evidence suggests that licensing schemes for formal property rights have introduced a new avenue of political influence over the mineral supply chain (Johnson 2013), including mining certification fraud and cross-border smuggling (Ojewale 2022). Transnational networks also play a crucial role in the second Congo War and subsequent conflicts (König et al. 2017). 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).

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. To insulate the effect of property rights in the mining sector, two types of measures are needed: The location of relevant mining sides and the legal documentation of each side over time. To oberve the former, existing studies use proprietary data sets to identify the location of industrial mines (e.g.Berman et al. (2017) and Christensen et al. (2022)). While these measures capture economically important extraction sites, they ignore informal mines even if they contribute significantly to a country's production capacities. Addressing this constrain, recent studies combine remote sensing and geological data (e.g. Girard et al. (2022) and Rigterink et al. (2023) to identify areas that are suitable for extraction. These measure define areas suitable for ASM, but do not localize unique mining sides or consider factors such as market access or labor availability in their measurement of ASM. This paper introduces therefore both a new observational approach to observe formal and informal mines as well as mining licenses over time.

As the main dependent variable, I use data from the Armed Conflict Location and

Event Data Project(ACLED) (Raleigh et al. 2010) as a measure of local conflict events. This measure documents on very granular measure of conflict events, including expropriation, protests and battles.

Actual mining activities

To identify formal and informal mining sites, I utilize as first step the Minerals Yearbook, volume III, published by the National Minerals Information Center at the United States Geological Survey (USGS). 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. Formal mining sites are located individually, while artisanal and small-scale mining (ASM) sites for specific commodities are aggregated on district (adm2) or province level (adm1). To disaggregate ASM further, I merge the Yearbook data with additional data sets for each country, which list the location of unique ASM mines. The references for these additional data sets are listed in Appendix **??**. Compared to existing measures, this approach increases the sample size significantly and list a total of 4270 unique ASM and 258 unique LSM in the ten countries of interest. Map 3(a) plots the location of mining activities for a single grid cell, map 4(a) plots the locations of the entire sample. Appendix 5 compares this measure to data from the proprietary database S & P mines, as documented by Christensen et al. (2022) and minerals aswell as the USGS data friom 2005 using data from Dreher et al. (2016)

Legal status of mines

To identify property rights for both ASM and LSM, I parse the mining cadastres of each country. While these portals are public, the underlying data is unstructured and does not allow for bulk download. To overcome this constrain, we[5] leverage the framework memorious to scrape each mining portal. Even though the first mining cadastres went online in 2008, each portal includes existing paper-based documentation of mining licenses.

[5]The data scraping of mining licensees is joint work with Alan Jones

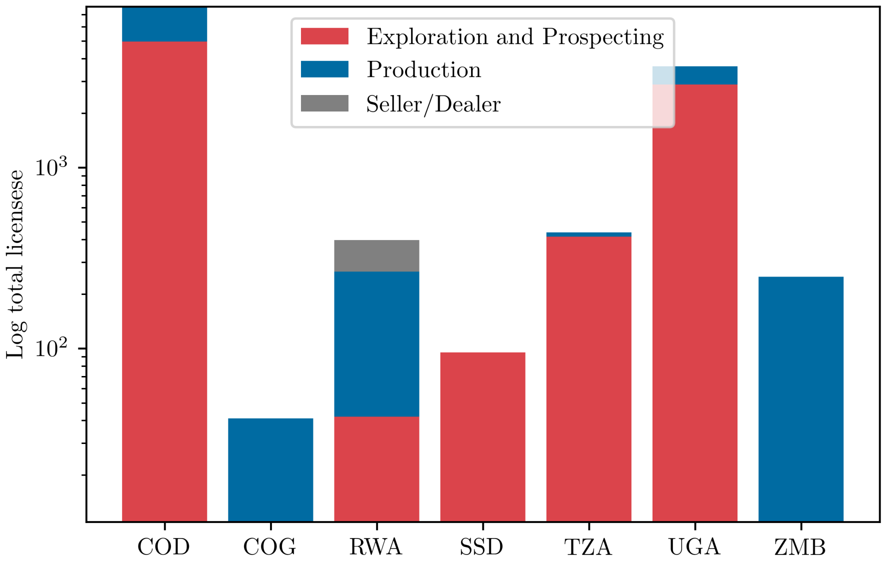


Figure 1: Total number of mining licenses per country (if online cadastre available, AGO and CAF have to no online register yet, BDI publishes only a static version of it's licensed mines). Source: Authors estimates from on national cadastres

This approach provides all formally-mined licenses since independence for each country. Seven out of ten countries affected by the DFA publish their entire mining cadastres online. Figure 1 plots the total number of each license type per country. Whether and how a country documents ownership structures over its mines is certainly not random, but subject to it's intuitions and economic dependence. The analysis discusses selection into treatment in detail. Comparing the actual mining sites[6] to mining licenses, the licenses are on average more than 980 times larger. Map 3(a) plots the location of mining activities for a single grid cell, map 4(b) plots the locations of all mining licenses in the sampple.

[6]Based on mines that are documented in the Open Street Map repository

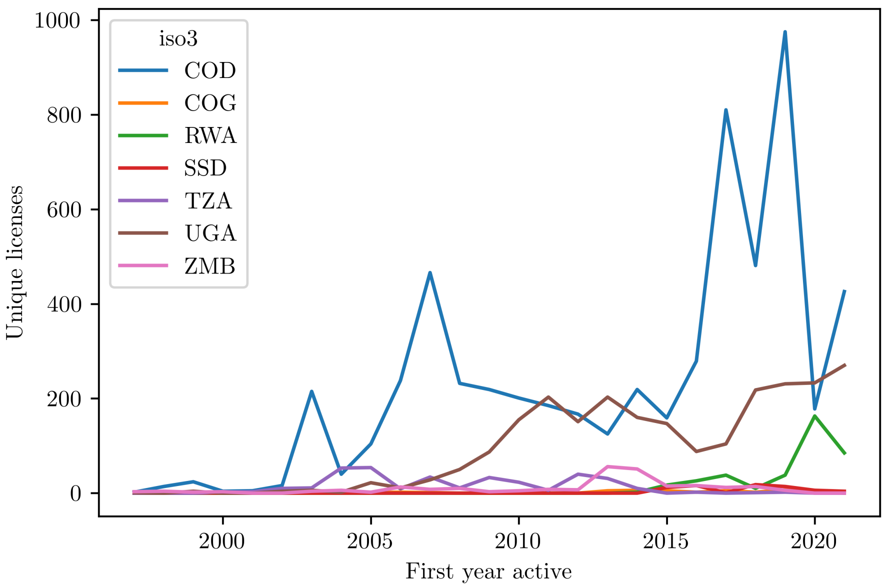
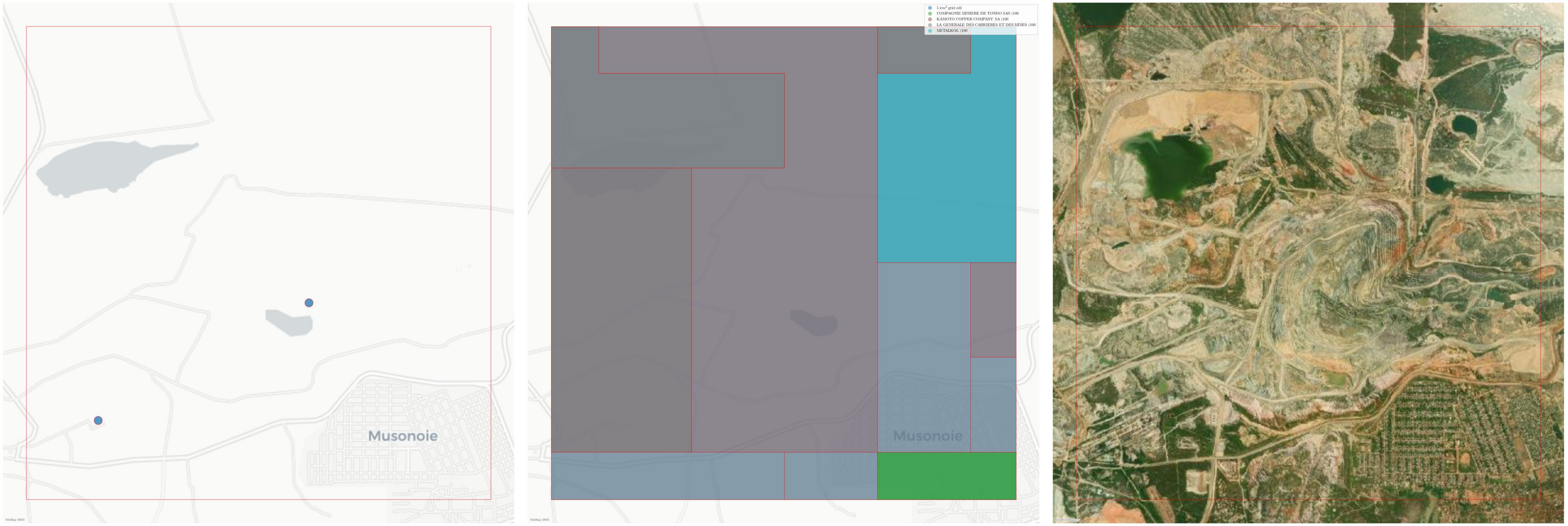


Figure 2: Newly established mining licenses per country 1997- 2021. Source: Authors estimates from on national cadastres

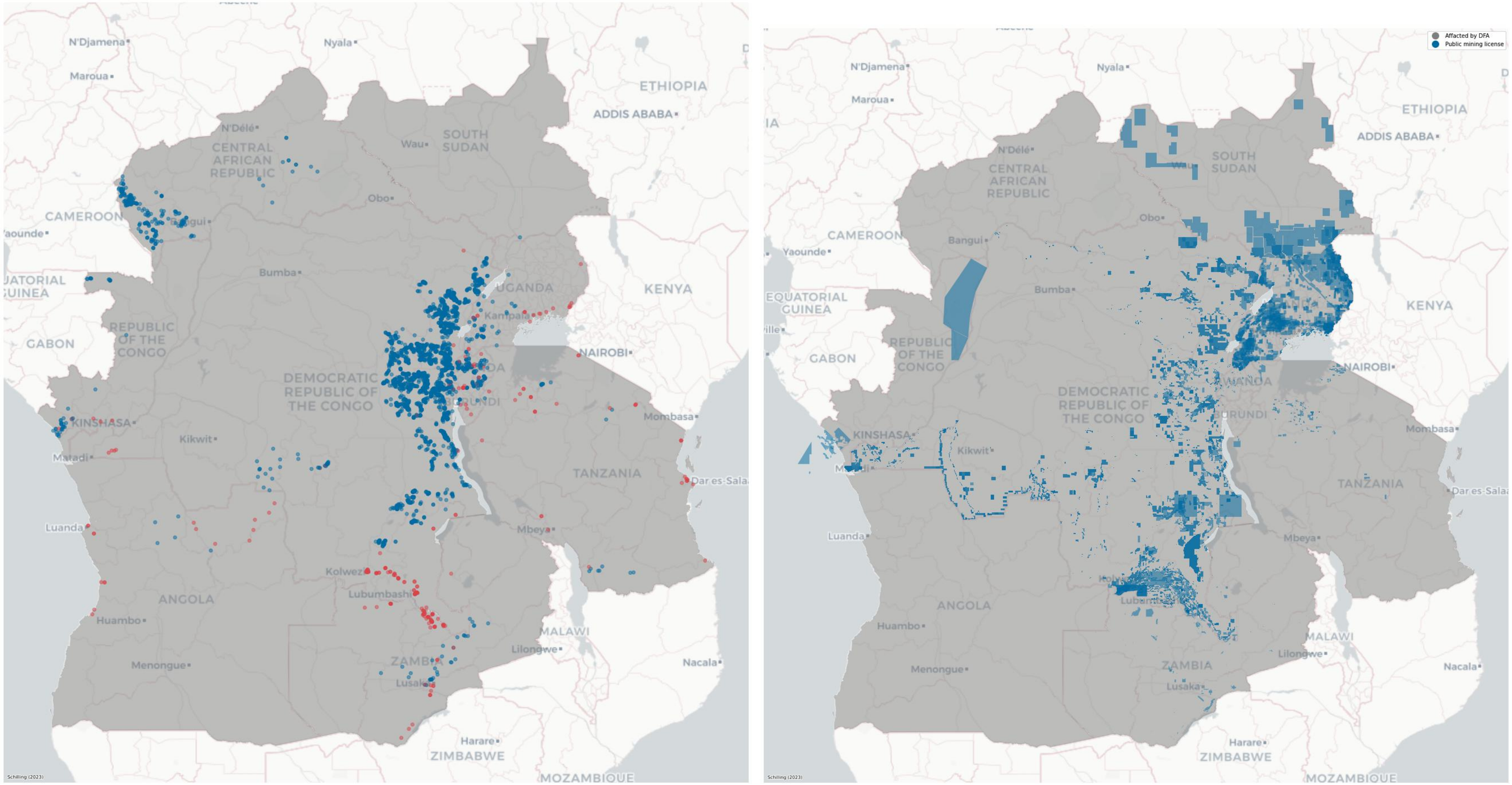


(a) Location of unique production sides on grid cell. Source: See main text

(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 3: Example of the production sides, mining license 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 coppper and cobalt in the DRC. Katanga KOV produced 13.48 thousand tonnes in 2022 and is one of the world's largest Cobalt mines in the world . Both mines are run by the Kamoto Copper Company which is in indirect ownership of the Swiss multinational Glencore (75%) and the sate-owned Gécamines (25%) source. The awared mining licenses in the cell are owned by four different entities and granted for the period 2002 to 2027. The first application for license in this cell is date to 1999.



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

(b) Mining license locations

Figure 4: Location of artisanal or small-scale mining (ASM) and large-scale mining (LSM) sides as well as mining licenses. The dark grey areas marks the territory of countries that are affected by the Dodd-Frank Act (DFA) section 1502 after 2010. Angola and the Central African Republic do not have and online available mining register. Burundi publish only a static repository of mining licenses in 2014.

Illustration: Property right gaps

This section illustrates two examples of how property rights gaps relate to non-market strategies and conflict.

The first example is an instance of LSM mining that is not regulated by the DFA. The Katanga KOV Mine, displayed in Figure 3(a), extracts cobalt and copper. As the map shows, the mining licenses include not only the mine itself but also the village of Musonole, which consists of formal and informal settlements (displayed in the lower right corner of Figure 3(c)). In 2019, 41 artisanal miners died on the edge of the commercial part of the LSM. Glencore, the Swiss mining company that operates the Katanga KOV Mine, claims that an average of 2,000 illegal miners enter their mines (Stans Bujakera and Aaron Ross 2019). In 2018, the government of the DRC collaborated with Glencore to formalize the cobalt sector by establishing the Entreprise Generale du Cobalt (EGC), which should act as a monopoly on all cobalt artisanal materials (Deberdt 2021). In 2022, Glencore reached an agreement over bribery allegations spanning from 2007 to 2018 and paid $180 million USD to the current government (Financial Times 2022). These events suggest that Glencore and the former national government of the DRC jointly designed the legal context of LSM and ASM mining in a way that aligns their mutual interests.

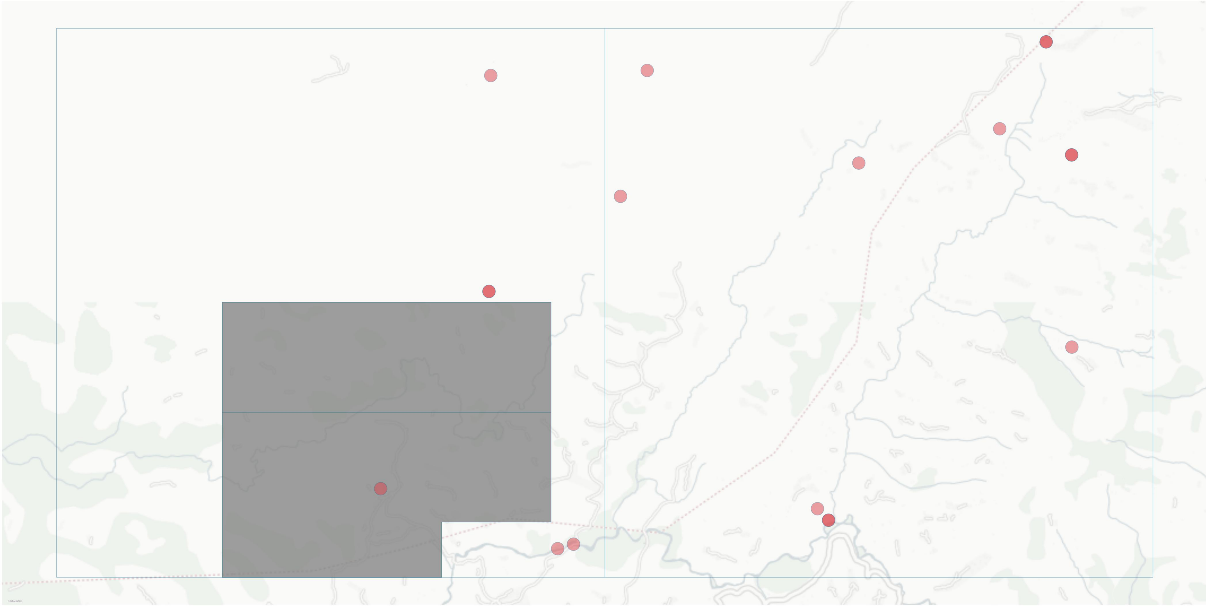
The second example of selective property illustrates the dynamics of non-market strategies in the context of ASM regulated by the DFA. Figure 5(a) plots awarded ASM production licenses and the actual locations of tantalum mines. The location data of ASM was collected by IPIS (n.d.). The mines are located at the border between North and East Kivu in the northern DRC, around 90 km from the provincial capital Goma, which is located at the border between Rwanda and the DRC. Only one of the fifteen mines in these two grid cells operated at some point under an ASM license between 1998 and 2023. Qualitative evidence documents mineral smuggling activities from the DRC into Rwanda (Ojewale 2022). This provides non-market strategies for the central government of Rwanda, the DRC, and local groups like the March 23 Movement (M23), a rebel military group mainly formed of ethnic Tutsi. For instance, the DRC government can reward local militias that are allies to the central government with mining licenses, which lowers their costs of exporting T3 minerals in mines they controll. 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 ASM operations that do not have access to a formal license are increasingly dependent on informal channels to export T3.

Recent events demonstrate that the central government of the DRC has limited control over the Kivu Province. For instance, in November 2022, M23 rebels got close to Goma and displaced around 180,000 people from their homes. The Congolese Army had withdrawn from the region near the village of Kibumba (Aljazeera 2022).

Identification

The purpose of my empirical strategy is to examine whether mining licenses moderate the relation between price shocks and local conflict levels. My source of identification relies on the comparison of $5km^2$ grid cells with different types of mining- activities and licenses. This variation occurs across space, time, license awarding institution, extracted commodity and production scale. This enables me to examine not only the overall local effects of property rights over a mine, but also to separate the legal status of a mine from its economic characteristics. Therefor, I apply a Difference-in-Difference estimation, to distinguish between political and economic characteristics among mines. This helps to delve into the marginal effects of formalization. Here, I leverage exogenous variation in world market prices for each commodity and compare mining license that are increasingly useful for exports after 2010 due to the DFA. Finally, I distinguish between ASM and LSM mining.

This research note contributes more granular measurement of mining production sides and commodity prices. Therefore, I replicated the well established finding that the economic value of mining activities causes higher conflict levels (Berman et al. 2017; Blair et al. 2021). Additionally, I address potential observational selection issues. This could be caused by cofunding factors that determine both a regimes decision to award mining licenses in a grid cell as well as the local conflict levels.



(a) ASM gold and tantalum production, ASM licenses, and boundaries of two 5 km^2 grid cells at the border between North and South Kivu, DRC. The left cell is coded that ASM, regulated by the DFA with 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 5: 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.

Observational selection

If only certain regimes award mining licenses, the present analysis builds up on a pre-selection into treatment. For instance, if only democratic regimes formalize their mining sector, changing conflict levels could be co-founded 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 powered quantitative analysis of determinations when a country formalises its mining sector. Instead, I compare descriptive statistics on a country level to explore the role of political institutions. This includes political variables such as corruption or state capacity as well as export statistics of T3 and other minerals.

Disaggregate legal status, economic value, and commodity type

To disaggregate the legal status and economic value of a each mine, 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 of the economic value of a mine and is often used in the mineral conflict literature. To validate the assumption that prices are indeed exogenous to the countries of interest, Appendix A.2 examines the market power each commodity holds. To estimate commodity prices as accurately as possible, I consider the modal price ration 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 9 compares this measure to prices spot market data from Bloomberg. While existing research estimates the economic values for 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 compassion of cell and a distinction between the political value of property rights over each type of resource. Furthermore this measure is more suitable to account for geological clustering, as many commodities are extracted at the same mine[7]. I compare T3 licenses to other types of mining licenses. i.e. I compare commodities that are regulated by the DFA to

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

Regulation over extracted commodity	Scale of production
DFA	ASM
non-DFA	LSM

Table 1: Type of productions sides for 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

commodities that are not regulated.

Additionally, I distinguish between ASM and LSM as described in the measurement section 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 other minerals that are not regulated (extracted under ASM or LSM) . Each of theses measures is estimate with equation:

$$ECON_{itm} = \sum_{c=1}^{C} M_c \times ln(Pct) \quad (1)$$

Where M_c represent a dummy for an ASM or LSM site that extracts the commodity c. $ln(Pct)$ captures the log of world market price for commodity c in year t. DFA regulated material includes T3 minerals, where $c \in \{tin, tungsten, tantalum\}$. Table 1 summarizes in a 2×2 matrix the four production side types on which I examine whether mining licenses moderate the effects of economic value of a mine and local conflict levels.

Estimation

Based on theses considerations, I now examine how public documented property rights moderate the effects of mining activities on local conflict levels. I interact the economic mining value in each cell with a dummy whether the territory of the mine lays within 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 $Prod_{it}$ presents a dummy for any active mining license at cell i in year t. To account for spatial auto correlation, I cluster the standard errors for both regression using Conley (1999) and control for cell FE Γ_i and year FE ω_t. As start and end date of each mining license are documented, each license treatment remains active until the license expires.

Results

As outlined in the identification section, I present two sets of results. First, I present descriptive statistics about the mining data and country characteristics. Next, I examine the effects of mining licenses on the relationship between commodity price shocks and local conflict.

Descriptive statistics

Examining political and economic characteristics on a country level, 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]. It also indicates whether the country publishes a mining cadastre and whether this cadastre changes over time and intersects with at least one mining production site spatially. Additionally, Appendix 10 plots the annual T3 export for each country. Combined, the data shows a consistent trend. Countries that are affected by the DFA and export T3 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 only a static list of mining licenses but exports T3. One explanation for this exception might be its small size compared to its neighbors. This implies a straightforward selection mechanism for the types of mining licenses ob-

[8] the sources of these data are fDi markets, the IATI database, and Michael Coppedge et al. (2023)

Table 2: Country characteristics of DFA affected countries

iso3	Mining related FDI	First mining aid commitment	Last mining aid commitment	Political corruption	Executive corruption	Deliberative democracy	Public mining cadastre	Δ Production license $\cap$ 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.

served 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.

Moving on to the relationship between commodity prices and conflict, Figure 6 shows the regression of the log prices of extracted commodities on the probability of local conflict events. The first row lists commodities that are regulated by the DFA, while the second row lists those that are not. The first column captures ASM, and the second column captures LSM extraction.

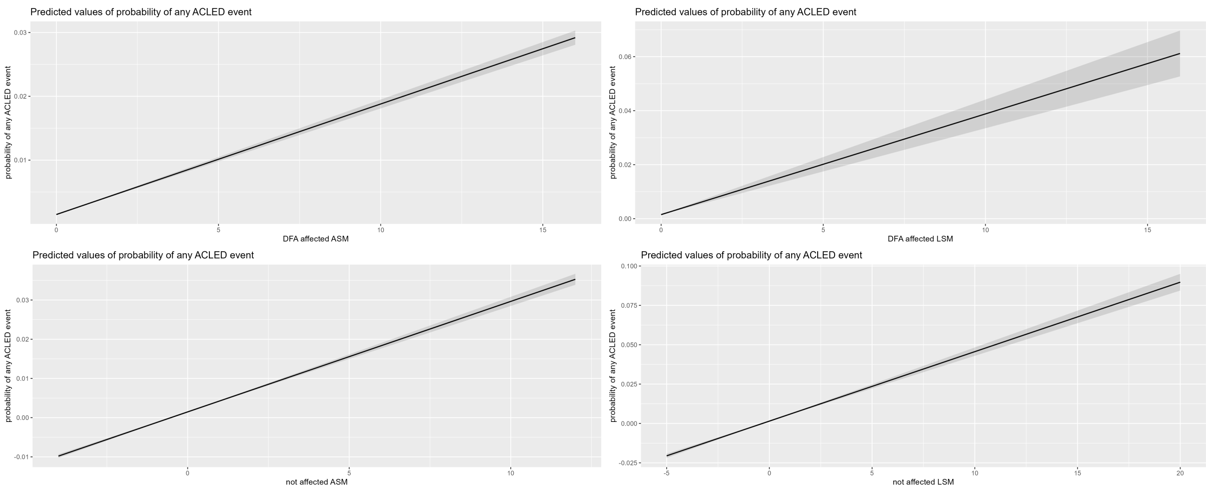


Figure 6: Linear Regression of the log prices of extracted commodity on the probability of local conflict events. The first row lists commodities that are regulated by the DFA, and the second row lists those that are not. The first column captures ASM, and the second column captures LSM extraction.

Regression estimates

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 leverages the DFA to observe commodities that need documentation of origin to be exported, i.e., T3, and similar minerals that do not need documentation for exports. This causes heterogeneity in the economic value mining licenses have for mines. 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 relates to an 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) show the results for commodities that are regulated by the DFA. Model 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 type on a LSM scale. For instance, model 2) predicts that for T3 minerals extracted by LSM, an increase in log prices 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 that 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, models 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 shocks in commodities that are regulated by the DFA.

In contrast, mining licenses for commodities that are not regulated by the DFA do not moderate the relationship between prices and conflict on a significant level. Columns 3) and 4) document the regression estimates for this type of mining. In this specification, an increase by a non-DFA-regulated commodity of one SD is associated with an mining license is even 66 % larger than the same increase without one, while the effect size do not differ on any established significance level.

In sum, these regression results demonstrate two main findings. First, the analysis confirms a well-established finding: the economic value of mines and their local conflict levels 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 and informal mines that prior studies do not consider on an individual level.

Moving on to the role property rights play as a moderator between price shocks and conflict, this analysis shows heterogeneous effects. If mining licenses provide clear utility, as they do for T3 minerals that are regulated by the DFA, they reduce the likelihood of local conflict. This finding holds for both LSM and ASM mines. In contrast, where mining licenses 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. If a miner does not need to document their ownership, they are less vulnerable to political interference. If due diligence reporting becomes mandatory, miners with formal licenses are better protected from the threat of expropriation and political influence. 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 for T3 mines without access to property rights.

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*

Conclusion

In conclusion, this research note 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 conflict potential through investments in administrative capacities. Technical solution to property right documentation alone cannot prevent non-market strategies. Instead they can only increase the costs non-markets strategies, if carefully implemented. In the long run, this can shift the incentive structure of powerful actor to follow institutional rules when they pursue their own interest.

To test this argument, this research note introduces two novel datasets of mining activities and their legal status in ten sub-Saharan countries. Using a Difference-in-Difference design, it shows that formal mining licenses only effectively reduce local conflict levels if they increase the independence of mining activities from political actors. This suggests that mining licenses alone have a limited impact on conflict levels without reducing political influence and might create new dependencies on political actors. Additionally, the introduced datasets show that the number and types of unique mining activities are larger and more diverse than previous data sets of mining activities in Africa.

The paper emphasizes the need for future research to explore the intersection of property rights and weak rule of law in various cases, particularly in countries with valuable resources but low state capacity. These findings apply not only to online mining cadastres, but any technological solution to property rights documentation, including blockchains. Without establishing enforcement mechanisms and institutional constraints to powerful actors in a society, purely technical solutions to property rights have very limited social impact.

This research note suggest that foreign policies and aid can support efforts to strengthen administrative capacities for documenting property rights in low-income countries, but they cannot bypass the domestic characteristics of the political landscape. This calls for further research to understand the characteristics of mines that get formalized and the distribution of property rights, as well as the exclusion of certain actors.

Overall, this research contributes to the understanding of property rights gaps in resource extraction and highlights the need for comprehensive approaches that consider both technical solutions and enforcement mechanisms to address these gaps.

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Appendix

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. First, I distinguish between the political institutions that award the licenses, i.e., I split the sample by country. Second, I disaggregate the baseline regression into a pre- and post-DFA period.

To examine enforcement heterogeneity in mining licenses across countries, I compare how newly established mining production licenses affect local conflict levels across countries between 1997 and 2020 using the event study approach. The main dependent variable represents the probability of a conflict event, documented by ACLED in a given year. Since two-way fixed effects are a biased estimator of difference-in-differences when treatment is staggered and the effect changes over time (Goodman-Bacon 2021), I apply the estimator proposed by Sun and Abraham (2021) to ensure that already-treated units are never included in the comparison group. In this specification, the event study treatment bundles the legal status of a mine and its economic value due to extraction. Here, I leverage only the variation in the legal status of a grid cell, following a two-way fixed effects model:

$$P(CONFLICT)_{it} = \Gamma_i + \delta Prod_{it} + \omega_t + \epsilon_{it}. \tag{3}$$

Figure 7 visualizes the effect of activating a mining license on local conflict events at a cell level per country. I find heterogeneous effects across the countries in my sample. While the formalization of a mine is associated with higher conflict levels in the DRC and Uganda, licenses have no significant effect in Rwanda, Zambia, and the Republic of the Congo. In Tanzania, the formalization of mining activities is associated with lower conflict levels, but the estimation is low powered. This heterogeneity suggests that the

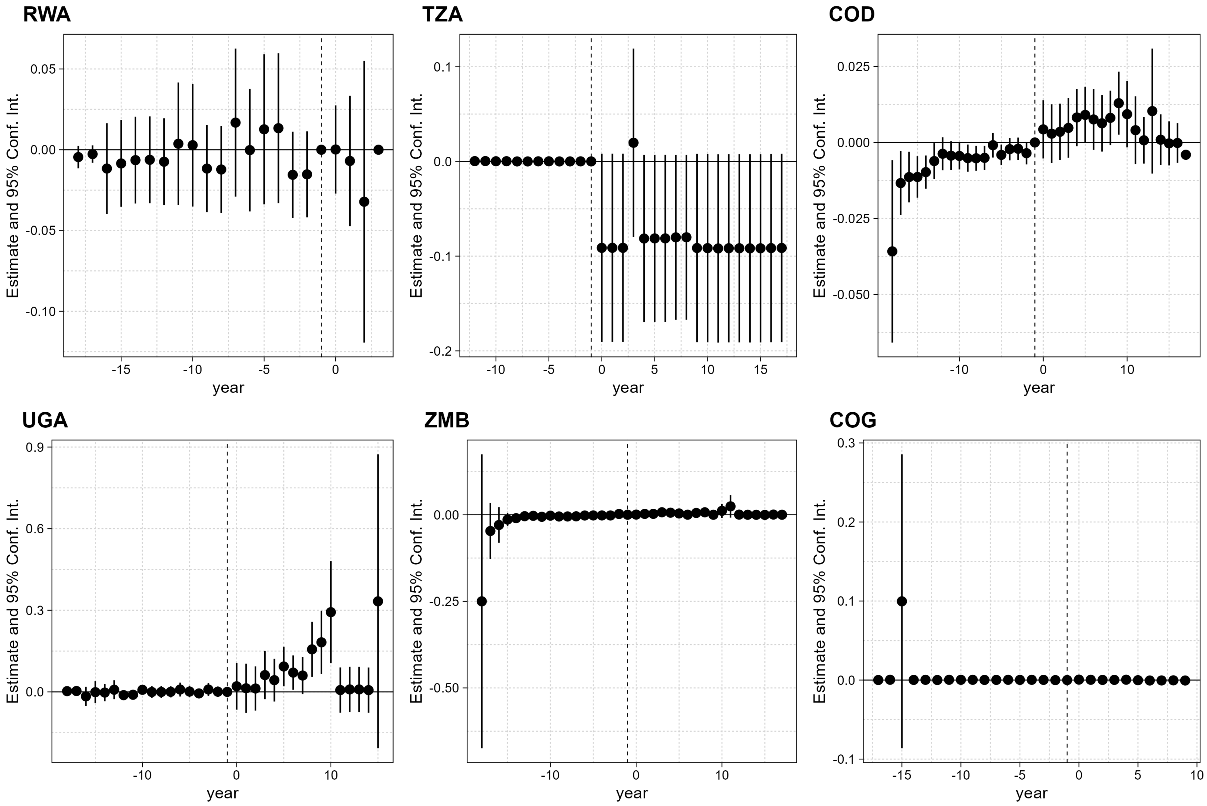

Figure 7: Effects of mining production licenses on the probability of conflict events ($5km^2$ grid cell level) per country that is affected by the DFA and publishes mining licenses 2000-2020.

countries design, award, and enforce mining licenses in different ways, which moderates the effectiveness of the property rights in reducing local conflicts.

As a next step, 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

A.2 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

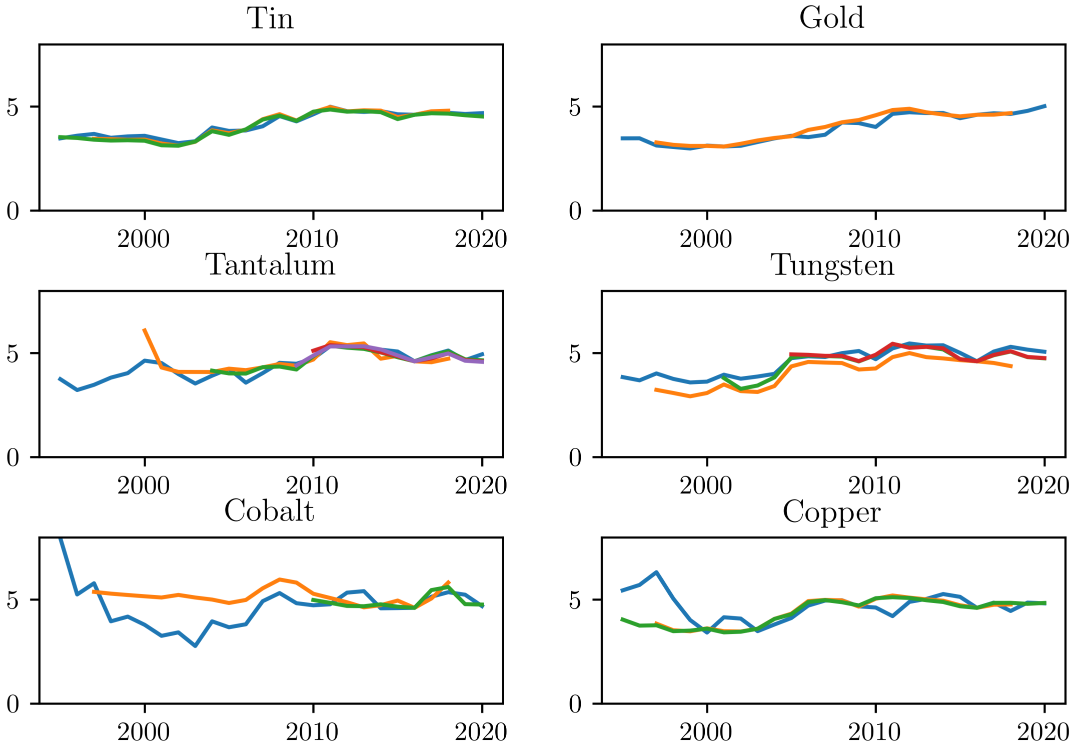

Figure 8: Commodity prices (ln, baseyear 2016) over time, comparing prices from Bloomberg (green, red and purple), BACI (blue), and metalary.com (orange). The Bloomberg data consists of the following prices indices: China Tantalum Concentrate Ta 205 30 % CIF, China Tantalum Metal 99.95 % FOB, China Tantalum 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.

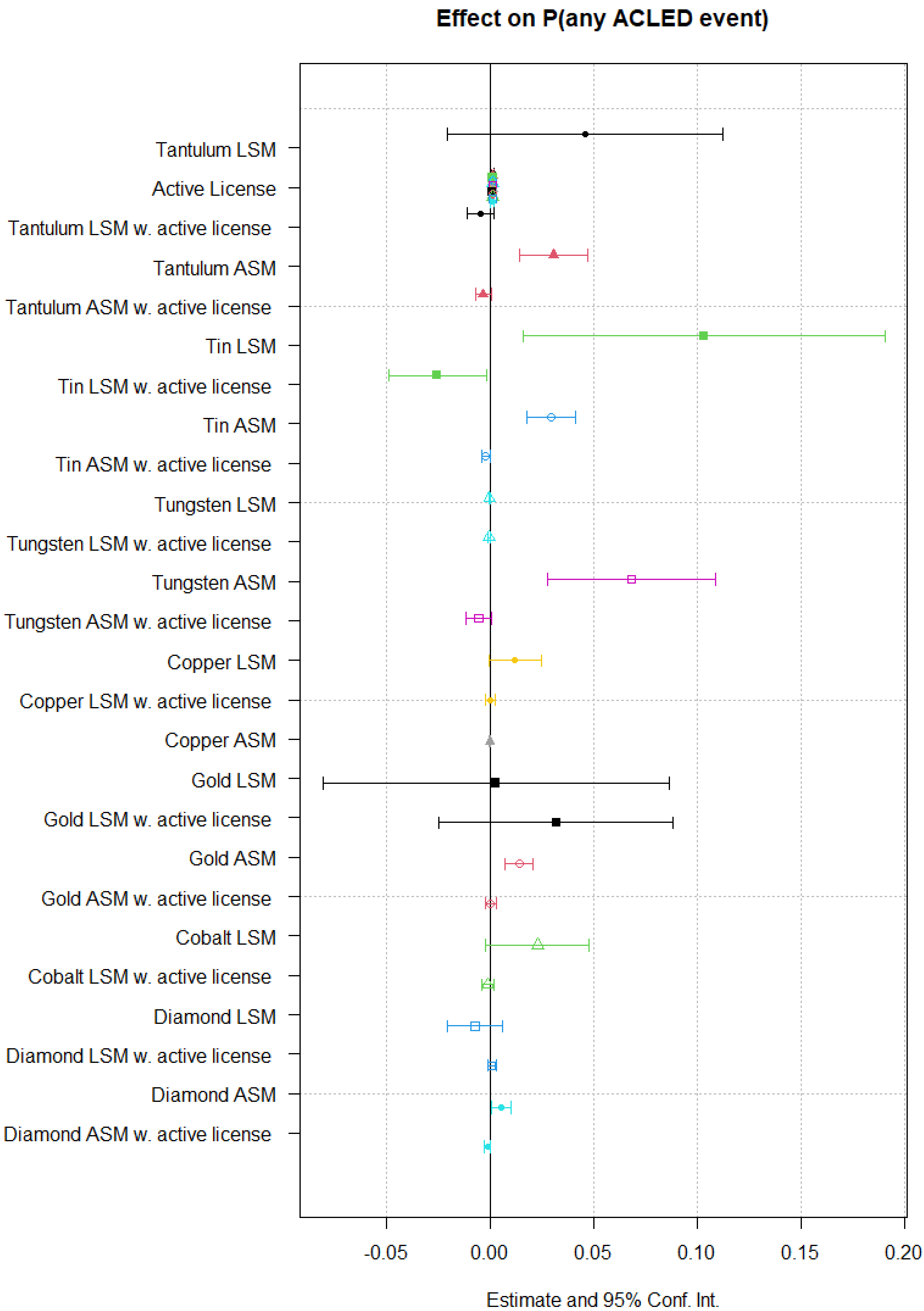

Figure 9: Effects of mining licenses per commodity type

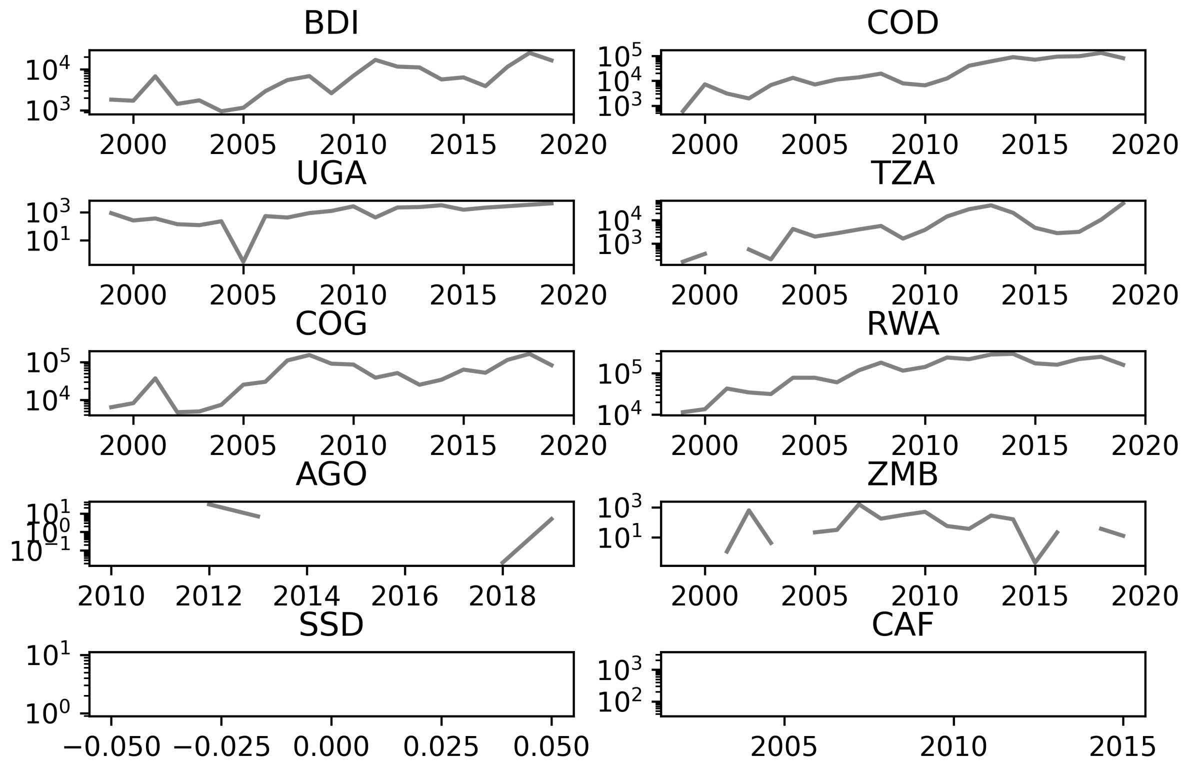

Figure 10: T3 exports per country 2000-2020 (data source: BACI)

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.

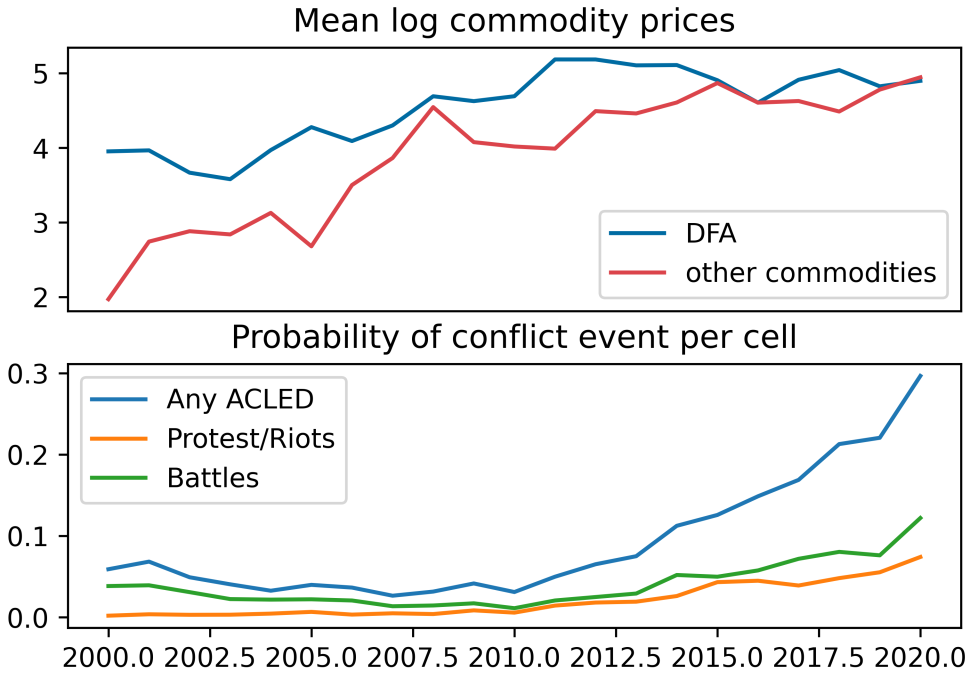

Figure 11: Commodity prices and probability of conflict events per cell over time