Between a Rock and a Hard Place: Livelihood Diversification through Artisanal Mining in the Eastern DR Congo

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Abstract Living conditions of the rural population in the eastern Democratic Republic of Congo (DRC) have suffered from prolonged violent conflicts, poor governance, declining soil fertility, and lack of infrastructure to support economic development. In parallel, artisanal mining has become a widespread livelihood activity in the area. This study investigates how rural households integrate artisanal mining into their traditional farming livelihoods. It uses empirical data collected in household surveys conducted around Kahuzi-Biega National Park and Itombwe Nature Reserve in the South Kivu province in a hurdle regression model to show that mining is used as both complementary and substitutory to farming. Results indicate that households that use mining to complement their farming activities tend to experience higher food security compared to non-mining households. As the reliance on mining increases, households tend to cultivate less land. These findings can help to inform actions against the prevalent issue of food insecurity in the region, but also point to dilemmas and trade-offs among environmental and development goals.

1 Introduction

The Democratic Republic of Congo (DRC) is one of the richest countries in mineral resources, having large deposits of coltan, tin, gold and copper, among others (Edwards et al., 2014). Despite this abundance, poverty is widespread (Kilosho Buraye et al., 2017; Radley, 2020). Especially in the eastern part of the country where extensive gold and 3T (tin, tungsten and tantalum) deposits are located, extraction tends to occur artisanally at a small scale with handheld tools, involving more than 200,000 miners in at least 1,500 mining sites in the North- and South-Kivu provinces alone (IPIS, 2025).

The rise of the artisanal mining sector is linked to the destabilisation of the country over the course of the two Congo Wars (1996-1997, 1998-2003). Especially

in the eastern provinces, armed conflict has never fully settled. As the extractive industry abandoned the country with rising insecurity and rural livelihoods suffered during wartime, artisanal mining emerged as an opportunity to reduce dependencies on smallscale farming with all its vulnerabilities to dimishing soil fertility, looting of armed groups and weather uncertainties, among others (Huggins, 2023; Kelly, 2014).

The link between artisanal mining and the de-agrarianisation of livelihoods in Sub-Saharan Africa has been debated for many years. Previously seen as an entrepreneurial activity pursued by young men with the desire to make a quick fortune, the discourse on artisanal mining has shifted over time (Banchirigah & Hilson, 2010). Its emergence is now largely recognised as conditioned by the deterioration of farming conditions through so-called push factors that make traditional livelihood activities less attractive, in particular the deterioration of smallholder farming viability (Hilson 2016, Hilson & Hu 2022). They include the decline of soil fertility, increasingly unfavourable market conditions for smallholders, and harvest loss from crop diseases and changing weather patterns. In search of alternative income opportunities, mining has been widely accessible given the high density of mines and the low entry barriers (Bycerson & Geenen 2016).

Whereas one strand of the literature has focused on the distinction between factors that push workers out of the agricultural sector and those that pull people towards mining, another strand has focussed more on the complementarity of both activities. Maconachie & Binns (2007), for instance, made the distinction between mining farmers and farming miners. In their study of artisanal mining and farming in Sierra Leone, they found strong seasonal links between the two. Mining was often practised during the agricultural off-season, and generated revenues were feeding back into farm operations to foster rural development. A similar complementary relationship was indentified by Pijpers (2014) in Sierra Leone, Ghana and South Africa, and Hilson et al. (2025) in Mozambique.

The persistent insecurity in the eastern DRC sets it apart from other contexts. The ongoing armed conflict in the eastern DRC has led to 5.8 million internally displaced people (McAuliffe & Oucho 2024), not even counting refugees from the M23 offense that led to the seizure of the provincial capitals of Goma and Bukavu in the beginning of 2025. What has been described as a deterioration of agricultural conditions in other African countries (Banchirigah & Hilson, 2010) comes close to a collapse of agricultural markets in many parts of the eastern DRC, with people losing their farmland, livestock and assets due to displacement and looting of armed groups (Kelly et al. 2014, Cox 2011). Although mining existed as a livelihood activity also prior to the outbreak of the conflict, the role it plays in supporting rural livelihoods has gained in importance since (Kelly 2014). Besides the income opportunity that mining sites provide, the perceived security that armed forces offer is a main motivation for households to relocate to these places and start mining (Maclin et al., 2017).

Also the role of mining in poverty alleviation is different in the DRC context compared to other countries. Whereas mining has been labelled a “platform of wealth creation” (Hilson & Hu 2022) where miners can build up assets to escape structural poverty and strengthen the position of farmers, such a link is less evident in the eastern DRC (Perks, 2011). Although ”career” miners who obtained positions higher up in the hierarchy of mining operations, such as pit managers, often manage

to make substantial amounts of money, similar dynamics of wealth creation among the many miners at the bottom of the hierarchy are less common (Geenen, Stoop & Verpoorten, 2021).

This study explores the role of artisanal mining in the livelihood strategies of rural households in the South Kivu province in the eastern DRC. Through the lens of a livelihood diversification framework (Ellis 2000), it investigates analytically and empirically how mining integrates with traditional farming practises and what its implications are for livelihood outcomes in form of food security and asset ownership. While some work has emphasised the complementary relationship between mining and farming in the eastern DRC, with mining facilitating investment in livestock and agriculture (Iragi Mukotanyi, 2022), other studies have highlighted that a growing number of farmers abandon their fields altogether and replace it with work in the mines (Cox, 2012; Iragi Mukotanyi, 2022; Kelly, 2014). However, both cases may co-exist, and their boundaries can be fluid. The study provides evidence on differences in livelihood outcomes by empirically investigating both the extensive margin (comparing mining and non-mining households) and the intensive margin (distinguishing different degrees of mining reliance). It therefore provides missing quantitative evidence to a debate that has largely been conducted qualitatively (Hilson et al. 2025; Huntington & Marple-Cantrell, 2022). Given the worrying humanitarian situation in the eastern DRC and the need to envision post-conflict opportunities of poverty allevation in the future, a better understanding whether and how artisanal mining can contribute to households' wellbeing is important.

2 Background

2.1 Artisanal mining in the eastern DR Congo

Towards the end of the Second Congo War in 2002, former president Joseph Kabila attempted to regain government control over the artisanally dominated and scattered mining sector. Tax reductions and other incentives were installed in an attempt to re-establish extractive industry in the country, but remained unsuccessful (Geenen, 2014; Kilosho Buraye et al., 2017). In parallel, new laws were passed with the intention to bring the artisanal mining sector under governmental regulation, enforce taxation, organise diggers, and demilitarise mining sites, amongst others (Wakenge et al., 2021). The mining code of 2002 and subsequent decrees in 2003, 2010 and 2012 resulted in a number of stipulations by the Ministry of Mining (de Haan & Geenen, 2016). Accordingly, artisanal miners are obliged to operate inside designated Artisanal Extraction Zones (AEZs). In practice, the number of AEZs is limited, and their status can be revoked at any time, for instance if large-scale industries claim an interest in an area (Kilosho Buraye et al., 2017). Geenen (2012) also notes that AEZs are created by authorities without knowledge of local circumstances and in absence of consultation with miners, leaving many unsatisfied with the areas assigned as AEZs. In practice, artisanal mining continues to occur inside and outside of AEZs alike (Kilosho Buraye et al., 2017).

The second stipulation of the mining code aimed at formalizing artisanal mining by organizing miners into cooperatives (de Haan & Geenen, 2016). These cooperatives were imposed on pre-existent structures by requiring artisanal miners to acquire a 'carte de creuseur', a mining card, paid in cash or an equivalent value in

minerals (PACT, 2010). Cooperatives also serve as a middle-actor through which miners sell minerals to the market. Instead of improved self-organisation and democratic structures, the cooperatives have become hierarchical, monopolistic vehicles of elite capture with strong dependecy structures instead of representing the interests of miners (de Haan & Geenen, 2016, Vogel et al., 2018).

Since the *de facto* implementation of the mining code was weak in the years after the law was passed, a six-month-lasting artisanal mining ban for the regions North-Kivu, South-Kivu and Maniema was announced in 2010 connected to the ambition to reorganise the sector (Geenen, 2012). However, even after the ban was lifted, only minor improvements in law enforcement were observable, while the consequences on livelihoods from the suspension of mining were severe (Cuvelier et al. 2014; Kilosho Buraye et al., 2017).

Finally, in 2012, the *International Tin Supply Chain Initiative* (ITSCI) introduced a color code to label artisanal mines according to risk factors as *green* ("safe"), *yellow* or *red* ("unsafe") based on a mine's human rights standard and the absence of armed groups (de Haan & Geenen, 2016; Wakenge et al., 2021). Minerals from *green* sites are granted certification and are allowed to be traded on the international market, while minerals from unsafe sites are theoretically prevented from entering supply chains. In reality, the coverage of the ITSCI remains partial and has made it more difficult for artisanal miners to engage in the trade of minerals (Vogel, 2018). At the same time, it has not delivered in preventing conflicts (Vogel et al., 2018). Among the 3T-mines listed on the web-map of the International Peace Information Service (IPIS) covering eastern DRC, 41% are currently assessed under the ITSCI, and only 21% earned green classification status (IPIS, 2023).

As these regulations show, previous attempts to target the artisanal mining sector with policy reforms were aiming mainly to steer operations into spaces that could be controlled by the government and streamlined with international markets, but with little considerations of the livelihoods of miners (Vogel et al., 2018)

2.2 Survey area

The data collection for the paper took place in the South Kivu province in villages surrounding Kahuzi-Biega National Park ("Parc National de Kahuzi-Biega", PNKB) and Itombwe Nature Reserve (INR) in the Albertine Rift, known for its outstanding biodiversity, including large numbers of endemic and endangered species (Plumptre et al., 2007) (Figure 1).

The montane forest around Mt Kahuzi in South-Kivu, eastern DRC, was first declared a forest reserve in 1937 under Belgian colonial rule and enlarged in 1951 to also encompass Mt Biega (Flummerfelt, 2022). It gained National Park status in 1970, when communities living inside the park were violently displaced without compensation for the purpose of conservation (Domínguez & Luoma, 2020). Many of the evicted people belonged to the indigenous Batwa people who relied on the forest for their hunter-gatherer livelihoods, and who consequently were stripped off their spiritual, cultural and intellectual identity (Cuni-Sanchez et al., 2019; Simpson & Geenen, 2021). PNKB was further extended in 1975, leading to more evictions, and eventually became listed a World Heritage Site in 1981, even if the title is at risk as of 2022 due to threats from illegal human activities, such as mining and hunting (Kirkby et al., 2015).

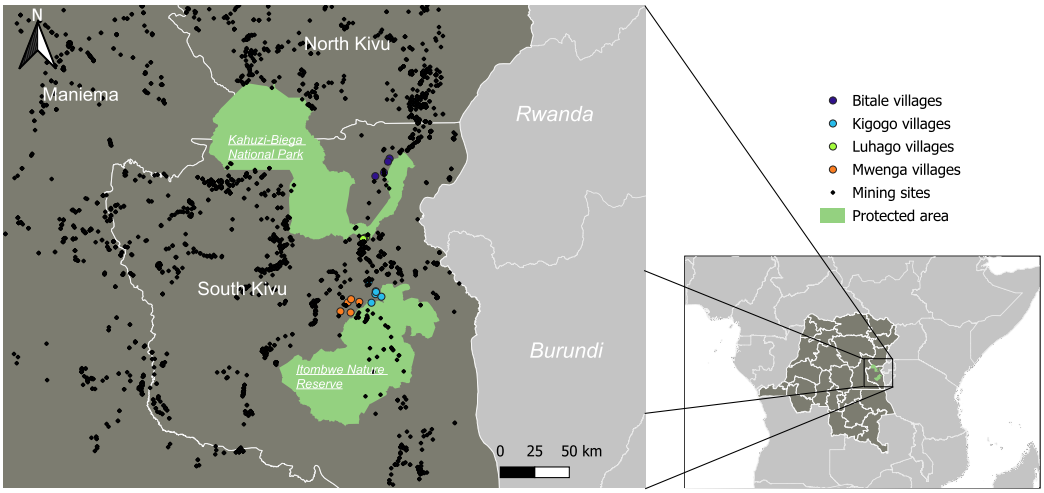


Figure 1: *Map of study area with surveyed villages and mining sites from IPIS (2023) and GPS coordinates collected during field work.*

In 2018, Batwa communities who became landless after the evictions attempted to resettle in their ancestral lands inside the protected area (Barume, 2000; Flummerfelt, 2022; Simpson & Geenen, 2021). At the same time, deforestation inside the park surged (Simpson et al. 2025). Some related the forest loss to changing Batwa livelihoods from their traditional forest reliance to more extractive activities after decades of living outside of the forests, such as the extraction of charcoal, timber and minerals (Simpson & Geenen, 2021). Others interpreted the change to be the result of outside actors instrumentalising the Batwa and using their resettlement to cover up for illegal activities inside the park (Flummerfelt, 2022). Ultimately, in 2019, a new wave of atrocities occurred when armed park rangers joined forces with the Congolese army and violently expelled communities once more, leaving behind destroyed villages (Flummerfelt, 2022). Thus, the history of PNKB displays itself as a case of fortress conservation, where green militarization has been used to isolate the forest from human interference, posing important constraints on the livelihoods of communities who have traditionally lived inside them (Domínguez & Luoma, 2020).

In contrast to PNKB, the discussion to protect the forest of the Itombwe massif only took off in the late 1990s, after observations were made that gorilla and elephant species declined dramatically during the First Congo War (1996-1997) (Simpson & Pellegrini, 2022). The Rwandan genocide in 1994 had initiated a stream of refugees across the border, followed by several armed groups who chose the sparsely inhabited forests as hide-aways and to the day destabilize the region. The area was eventually declared a nature reserve per decree by the minister of the environment in 2006. The absence of dialogue during the gazettement process led to resistance from local communities and conservation NGOs alike, and ultimately to a redrawing of the park boundaries following a participatory mapping process in 2016 (Gauthier & Pravettoni, 2016; Kujirakwinja et al., 2019). The new nature reserve foresees different zones that allow for sustainable hunting and agriculture outside of the core zones (Kujirakwinja et al., 2019). However, the conservation area remains contested

in some communities even after its re-establishment (Simpson & Zirhumana, 2021). The ethnic groups surveyed for this study were mostly of the Warega and Nyindu, of which the latter are farmers who are sometimes considered related to the Twa (Cuni-Sanchez et al., 2019).

Both protected areas impose restrictions on land use and forest resources, thereby reducing the options of coping with deteriorating living conditions during the decades of prolonged armed conflict. In addition, violence-driven displacement limits access to agricultural land and makes long-term planning difficult, as several interviewees reported. The looting of fields by armed groups and raiding of large livestock, once considered the highest valued asset but now largely vanished, have further exacerbated rural poverty and also impacted manure-reliant farming practices in some parts of South-Kivu (Cox, 2012; Kelly, 2014; Verweijen & Brabant, 2017). In combination with declining soil productivity, the dissolution of local agricultural markets and limited capacity to adapt to a changing climate, it has become increasingly challenging to rely solely on farming (Amani et al., 2022; Cox, 2012).

Whereas farming became less viable, mining remained a widespread income opportunity both outside and inside of PNKB and INR (Simpson & Zirhumana, 2021; Spira et al., 2019). It provides a livelihood alternative with higher income than farming and neither requires training nor assets to engage (Bryceson & Geenen, 2016). While providing income to people, "conflict minerals" also act a source of revenue to rebel groups who operate mines, thereby fueling the conflict and adding another layer to the complex livelihood context (Matthysen et al., 2019; Radley & Vogel, 2015; Stoop et al., 2019).

3 Conceptual framework

3.1 Livelihoods framework

We adopt a livelihoods framework as developed in Ellis (2000) and Scoones (1998), among others. This framework has been used previously to inform livelihood diversification from artisanal mining (e.g., Adranyi et al., 2023; Horsely et al., 2015). Assets play a central role in the framework and are distinguished into natural, physical, social, human and financial assets. Conditional on these assets, a household chooses a livelihood strategy consisting of one or more accessible activities, which ultimately determines its welfare and vulnerability status. The stock of household assets may increase over time as the household gets more prosperous, but may also decrease as a household is forced to liquidate assets in response to hardship. The larger institutional, environmental and socio-economic context a household is situated in further influences a household's assets, livelihood strategies and outcomes.

Livelihood diversification is a common phenomenon among the rural poor and describes a process by which households develop a diverse portfolio of activities to rely on in their livelihood strategies. The motivations to diversify can be manifold, including a reduction of income failure risk, seasonal gap filling during agricultural off-season, and responding to negative shocks (Ellis, 2000). The pluriverse of motives commonly gets reduced to factors of necessity and choice (sometimes also referred to as push and pull) in the literature on livelihood diversification (Barrett et al., 2001). This dichotomy has also established itself in the literature for explaining livelihood

diversification through artisanal mining (Banchirigah & Hilson, 2010; Hilson, 2016) (see Introduction). For the purpose of this analysis, we follow Angelsen et al. (2014) and consider diversification to occur mainly for one of three reasons: (i) cover immediate household consumption; (ii) provide safety-nets against negative shocks and as a countercyclical strategy to the seasonality of agriculture; (iii) assist the accumulation of assets and provide a way out of poverty.

In the study region of South Kivu, the livelihood space of communities has been shaped by regular disturbances in the form of immediate rupture, but also as gradual shifts that have initiated a reorientation of livelihood strategies. Ongoing conflicts for the past decades have exposed households to sudden shocks of various forms. Violence-driven displacement stripped farmers of their land or made them lose livestock, harvest and other productive assets, as they became target of raiding armed groups (Kelly, 2014; Verweijen & Brabant, 2017). Branching out into other activities, especially those with low entry barriers, often provided an immediate response against shocks in the absence of savings or assets to liquidise (Angelsen & Dokken, 2018). The constant state of insecurity has also lead to a more gradual reshuffle of livelihood strategies. Pastoral activities have disappeared in most parts of eastern DRC due to raiding of livestock, also affecting manure-dependent agricultural practices (Cox, 2012; Verweijen & Brabant, 2017).

Conservation interventions, present throughout the study area in the form of protected areas, can further disturb traditional livelihoods, given that they limit access to land and forest resources (Baird & Leslie, 2013; Kujirakwinja et al., 2019). Several forms of forest income such as timber extraction, charcoal production and hunting are restricted. These are income sources which usually offer readily available responses to shocks for forest communities due to their availability and quick returns (Angelsen et al., 2014; Wunder et al., 2014). Conservation can also create new opportunities, e.g., through eco-tourism, Payments for Ecosystem Services (PES) or Integrated Conservation and Development Projects (ICDPs) (Baird & Leslie, 2013), but such opportunities have not emerged in eastern DRC where basic structures are lacking to make these work and insecurity remains high.

Further distress on traditional rural livelihoods is exerted by the overall deterioration of agricultural conditions (Cox, 2012). Most farming activities are rain-fed with low inputs, and the adaptation capacity to shifting weather patterns from climate change remains low (Amani et al., 2022; Balasha et al., 2023). Also, crop diseases have decreased yield in recent years and made farming less productive (Amani et al., 2022).

Long-term strategic investment and the build-up of assets are challenging in such an unstable context. Cash crops like coffee or oil palm, for instance, take several years to mature, whereas mining and other forms of resource extraction represent an accessible way to quick returns, making them an efficient response to shocks (Wunder et al., 2014). When alternative coping strategies such as the selling of assets or the spending of savings (Angelsen & Dokken, 2018) are no options, choices necessarily fall on alternative activities with low entry barriers and quick returns. Given the high spatial density of artisanal mines in eastern DRC, mining is an accessible option for diversification, as it does not require initial investment into assets, promises instant cash income and can flexibly complement other livelihood activities. However, it does require the strategic reshuffling of the available labor resources. As labor is limited by household size and composition, committing more

into one livelihood activity implies a trade-off in terms less time spent on another activity, which we highlight in a simple analytical model.

3.2 A simple analytical framework of livelihood diversification

We illustrate a household's choice of a livelihood strategy in an analytical model. The model is a simplification of the complex decision processes that smallholder farmers face, but can help to inform the relationship between different decision parameters given that a set of simplifying assumptions holds. Thereby, it can underpin empirical findings and inform hypothesis formulation.

In the tradition of Singh et al. (1986) and Sadoulet & De Janvry (1995), we assume a household to maximise its expected utility by allocating its available labor L between different livelihood alternatives, which for the sake of the analysis are limited to farming, mining and other income-generating activities (indicated with subscripts f, m and o, respectively). Assets also influence the choice of livelihood activities, but are here assumed fixed and, unlike labor, not subject to an allocation across activities.

We assume households to be risk averse with strictly increasing and strictly concave utility functions, such that:

$$u(E[y]) \geq E[u(y)] \quad \text{with} \quad u'(y) > 0, u''(y) < 0. \tag{1}$$

The optimal allocation of labor can be specified as a constrained optimisation problem of a household's certainty equivalent (CE):

$$\begin{aligned} \max_{L_f, L_m, L_o} \quad & CE = E[w + y] - \pi - \delta(L_m, L_o) \\ \text{s.t.} \quad & y = \sum_{i \in \{m,f,o\}} y_i(L_i, X), \\ & \bar{L} = \sum_{i \in \{m,f,o\}} L_i \end{aligned} \tag{2}$$

Here, the utility depends on the initial wealth w, the risk premium π, the reluctance from reducing labor in traditional farming livelihoods δ , and the realised cash and subsistence income y, i.e., the sum of income from the different livelihood activities. The income y_i from activity i depends positively on the assigned amount of labor L_i and the endowment of other assets X of a household. Especially farming relies on assets such as access to arable land, livestock units (lsu) and other agricultural inputs, whereas mining income does not directly depend on such asset endowments. Instead, mining income has been found to depend on other individual factors, such as experience and the willingness to take risks (Geenen, Stoop & Verpoorten, 2021). To keep the model solvable, we have included these. The amount of labor to be allocated is constraint by a household' s overall available labor force, $\bar{L}$.

If all activities were equally exposed to risk, the risk-reducing effect of diversification could be derived from the risk premium, as defined by Arrow (1971) and Pratt (1978) (see e.g., Bezabih & Sarr (2012) or Baumgärtner & Quaas (2010) for relevant applications). Since differences in risks between activities drive diversification

decisions, we consider the case of multivariate risk exposure. Without further information on the covariance structure of the different risks, we make the simplifying assumption that risks are mutually independent and additive (Duncan, 1977).

Assumption 1
(i) $\frac{\partial y_i}{\partial L_i} > 0$*: The income from activity* i *increases with the amount of allocated labor* L_i*.*
(ii) The risks associated with different livelihood activities $i, j \in \{m, f, o\}$ *are mutually independent, such that* $\sigma_{ij} = 0$ *for all* $i \neq j$*.*

Although assumption *(ii)* is a strict one and unlikely to hold, we prefer it over assuming an arbitrary covariance structure. It is not *a priori* clear whether covariances between risks would be negative or positive, as some shocks have negative impacts on all activities (e.g., sickness of household members) while others can be positive (e.g., the complementary seasonality of mining and farming). Then, similar to Bezabih & Sarr (2012), the risk premium π is specified as the income-weighted sum of risk premiums on the different activities in the livelihood portfolio of a household given the chosen labor allocation:

$$\pi = \frac{\rho}{2} \sum_{i \in \{m,f,o\}} y_i^2 \sigma_i^2 \tag{3}$$

ρ represents the Arrow-Pratt coefficient of risk aversion (Sadoulet & De Janvry, 1995), and σ_i^2 is the variance of income y_i.

As a simplifying assumption to derive the relationship between labor allocation towards farming and mining, we focus only on these two activities in solving equation 2. We make the following relational assumption about the risk associated with farming and mining:

Assumption 2
$\frac{\partial \pi}{\partial L_f} > \frac{\partial \pi}{\partial L_m}$ *for* $L_f = L_m$*: A marginal increase in farming labor leads to a higher increase in risk premium than a marginal increase in mining labor for a given amount of allocated labor.*

Assumption 2 states that farming is associated with higher income risk than mining. It finds well-documented support in the literature (Cox, 2012; Maclin et al., 2017; Spira et al., 2019).

From the first order conditions from equation 2, it can be shown that the optimal allocation of labor is given by (see appendix):

$$[\frac{\partial y}{\partial L_m}(L_m^*) - \frac{\partial \pi}{\partial L_m}(y_m, \sigma_m^2)] - [\frac{\partial y}{\partial L_f}(L_f^*, X)) - \frac{\partial \pi}{\partial L_f}(y_f, \sigma_f^2)] = \frac{\partial \delta}{\partial L_m}(L_m^*) \tag{4}$$

Given that assumption 2 holds, we know that the left-hand side of equation 4 is positive. Under optimal labor allocation, a household thus diversifies its livelihoods towards mining until the additional risk-adjusted marginal income from mining, compared to risk-adjusted income from farming, equals the marginal disutility from having to move from farming to mining.

Assumption 3
(i) $\frac{\partial y_f}{\partial X} > 0, \quad \frac{\partial y_f^2}{\partial L_f \partial X} \geq 0$*: Asset endowment X increases farming income and the marginal labor productivity of farming.*
(ii) $\frac{\partial y_m}{\partial X} = 0, \quad \frac{\partial y_m^2}{\partial L_m \partial X} = 0$*: Asset endowment X has no effect on mining income or the marginal labor productivity in mining.*

Assumption 3 reflects the characteristic of mining being an accessible livelihood activity with low entry barriers that does not require mentionable investments into assets (Bryceson & Geenen, 2016).

Given assumption 3, the following relationships can be derived from the model (see appendix):

$$\frac{\partial L_m}{\partial \sigma_f^2} > 0 \tag{5}$$

$$\frac{\partial L_m}{\partial \rho} > 0 \quad \text{if} \quad \sigma_f^2 y_f \frac{\partial y_f}{\partial L_f} > \sigma_m^2 y_m \frac{\partial y_m}{\partial L_m} \tag{6}$$

$$\frac{\partial L_m}{\partial X} < 0 \quad \text{if} \quad \frac{\partial \pi}{\partial y_f} < 1 \tag{7}$$

Equation 5 states that households will allocate more labor to mining as farming gets more risky. This results explains the emergence of artisanal mining as a consequence of deteriorating conditions of farming, as it has been described in the literature (Cox, 2012; Kelly, 2014). Equation 6 states that more risk-averse households will allocate more labor to mining if the resulting variance-weighted increase in income for mining is lower than the one for farming. Thus, a trade-off between risk and income gain ultimately determines the degree of diversification into mining of risk averse households. Finally, given the higher asset intensity of farming compared to mining, equation 7 establishes that a higher asset endowment is associated with less labor allocation to mining in the respective household. As farming productivity increases with asset ownership, it is intuitive that more assets reduce the attractiveness of mining.

4 Empirical case study: Livelihood diversification in South Kivu

Given the unstable political context in the region, quantitative empirical research on the topic in the eastern DRC has been scarce. In the absence of longitudinal data, a quantitative assessment of causes and implications of artisanal mining cannot be tested in robust ways. Nevertheless, to empirically assess the relationships derived in the analytical model and identify meaningful associations, we employed regression analysis on cross-sectional data collected during fieldwork in June and July 2022 in four different areas, two adjacent to PNKB and two in proximity of INR. Constrained by the area covered in the data and its cross-sectional structure, we consider the empirical analysis as a case study for a particular region and a particular point in time that can provide important insights, but might only have limited external validity.

4.1 Data

Surveys were conducted in the form of 100 structured interviews with miners in the village groups (*groupements*) around Kigogo and Mwenga (INR), and 278 randomly selected household interviews in the villages surrounding Mwenga (INR), Bitale (PNKB) and Luhago (PNKB) (Figure 1). All interviews were held in either Swahili or one of Rega, Mashi or Tembo, depending on the predominant local language.

The 100 individual interviews with miners were conducted to understand better the structural aspects behind mining integration into livelihood portfolios, and to inform hypothesis behind the empirical findings from the regression analysis. For this purpose, we used a snowball sampling strategy (Shively, 2011). Since we were also interested in understanding the share of the population that engages in mining and want to compare mining to non-mining households, we further collected a more representative sample of 278 households. No registry of all households in the village exists, preventing us from drawing a truly random sample, and unannounced household visits were unfeasible given that household members were often not at home during the day and that visits were not appreciated in absence of the household head. All interviews were held in a central place in the village on a voluntary basis after introducing our research aim to the village chief. Although not fully randomised, we believe that this sampling strategy was sufficient to draw tentative conclusions about the overall populations given the generally small village sizes. Yet, we cannot rule out that the sampled sub-population varies from the overall village population in non-random ways. Structural relationships between variables are, however, less sensitive to any biases in the sample.

Given the difficulty to quantify income (or income-equivalent subsistence produce), involvement in different livelihood activities was coded as dummy variables (0-1) and subsequently ranked according to their importance for the household's overall livelihood. Only mining was measured in annual working weeks. Livestock was aggregated into livestock units (FAO, 2011) and recorded assets of a household summarised in a principal component analysis, of which the first component was used as a wealth score.

4.2 Methods

Given that mining is frequently only one among several livelihood activities, the degree to which households rely on it varies. To capture this variation in the outcome variable, we used the number of working weeks spent in a mine as a proxy for the importance of mining in a household's livelihood strategy. The outcome variable is right-skewed but has a high density of zero observations (many households do not mine at all). In the presence of zero-inflated count data, researchers commonly use either zero-inflated models or hurdle models with different underlying distributional assumptions (Hu et al., 2011). The essential difference between the two is that the latter assumes zero-observations to come exclusively from a structural process, while the former also allows for zeros "by chance" from the sampling process (Hu et al., 2011). Since mining as a livelihood strategy is a choice and annual weeks spent in mines are not stochastically zero by chance, we adopted a hurdle model that estimated the model in two steps, defined in Cameron & Trivedi (2013) as:

$$Pr[y = j] = \begin{cases} f_1(0) & if\ j = 0 \\ \frac{1-f_1(0)}{1-f_2(0)} & if\ j > 0 \end{cases}. \quad (8)$$

The first part follows a binomial model which only differentiates between households that have at least one member actively involved in mining activities and those that do not, with a binary mining indicator as the outcome variable, thereby accounting for the zero mass point. The second part of the model seeks to explain the degree of involvement among households involved using a truncated-at-zero count data model (Cameron & Trivedi, 2013).

The two-part model is especially useful for our purpose, as it can give potential insights into characteristic differences between mining as an occasional risk-dispersing activity (first part) and mining as a major income-generating occupation (second part).

It is important to make the right assumptions about the underlying distribution, since misspecification leads to inconsistent estimates (Cameron & Trivedi, 2013). Given that the distribution is over-dispersed, i.e., the mean is larger than the variance of the count distribution, a negative-binomial distribution was assumed for the model estimation (Cameron & Trivedi, 2013; Hu et al., 2011), and the choice was confirmed when comparing it to a model with a Poisson distribution in a Vuong test (p value <0.001) (Vuong et al., 1989). Displaying the goodness of fit in a rootogram (Kleiber & Zeileis, 2016) likewise showed a better fit for the negative-bionmial distribution, but also revealed critical overprediction especially in the middle and right part of the distribution.

We used information on alternative livelihood activities to understand how they relate to artisanal mining (see Table 1). The distinction into forest income (categorised into charcoal, timber and non-timber forest products (NTFP) income) and other income is made as these are structurally different. Like mining, forest income represents an easy-access and flexibly substitutable income source to farming, and may therefore be competing with the choice of working in the mines. The area cultivated by a household was included among the covariates to investigate the relationship between farming and mining engagement.

As argued above, it is reasonable to assume that households who live closer to the subsistence minimum are less willing to take risks, and therefore more likely to diversify. To test this, we included the number of months without sufficient food a household experienced over the last year as a covariate in the estimation.

Finally, in an additional analysis, we used survey information on the names of mining sites and matched that to their location from our own data collection and from the IPIS database (IPIS, 2023) to understand the role of geographic location for livelihood diversification through mining. By drawing connections between village locations and the mines that people target, we got insights on the geographic mobility that miners display (see Figure 1 in the appendix).

4.3 Results

4.3.1 Descriptive statistics

Looking at the livelihood activities pursued by households, we found that 73% relied on more than one livelihood activity and 35% were engaged in more than two.

Table 1: *Share of households reliant on different livelihood activities, by village group.*

Village group	Obs.	Farming	Livestock	Mining	Commerce	Wage labor	Forest income	Other
Bitale	100	0.88	0.47	0.37	0.21	0.16	0.39	0.01
Luhago	75	0.96	0.00	0.35	0.09	0.13	0.07	0.00
Mwenga	103	0.99	0.18	0.27	0.13	0.13	0.05	0.37
all	278	0.94	0.22	0.33	0.14	0.14	0.17	0.13

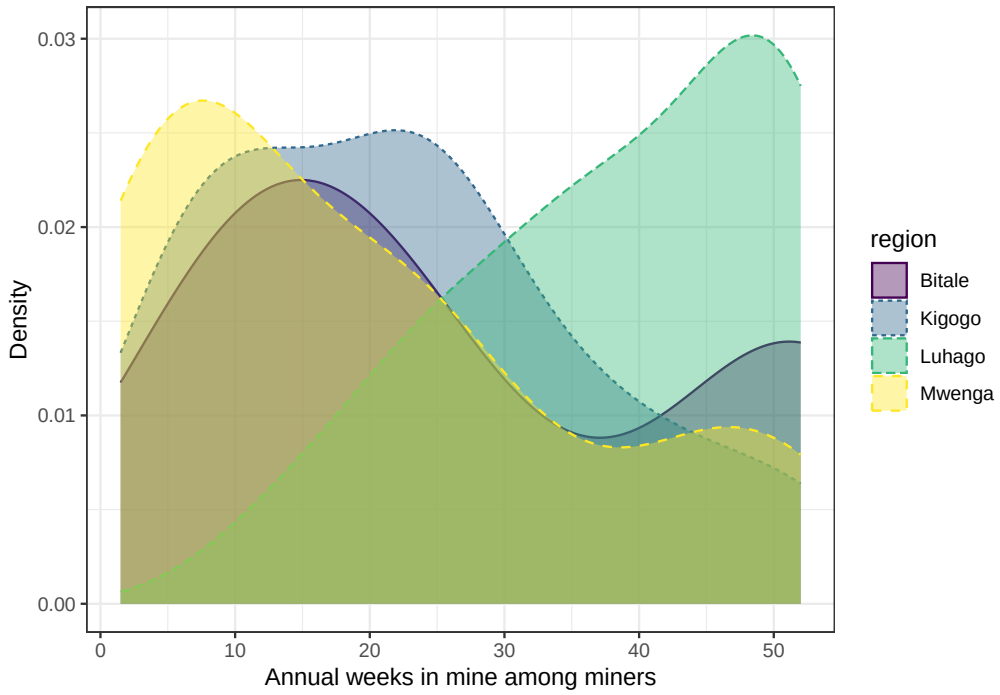


Figure 2: *Distribution of time spent in mines by miners*

With 32% of all interviewed households involved, artisanal mining was the second most practiced occupation after farming (Table 1), although the village-to-village variation was large, with 8% in the lowest and 47% in the village with the highest share of miners. Comparing figures between the two protected areas, we found a higher share of mining households in PNKB (36%) than in INR (24%), where fish farming also played a major role.

Overall, only 19% of mining households stated mining as their most important livelihood activity, as opposed to 72% who ranked farming first, again with notable regional differences between the two study sites (22% in PNKB and 12% in INR). To further understand the extent to which households engage in mining, we collected information on the time each miner spent in the mines over the last year. Plotting the distribution of mining weeks per miner for the sample regions, Figure 2 shows some regional differences. The proportion of miners who worked in the mines on a daily basis was lowest in the INR sites Mwenga (5%) and Kigogo (6%) and highest in PNKB sites Luhago (26%) and Bitale (29%). Especially in Luhago, the density distribution was strongly left-skewed, implying that mining was more a regular livelihood choice than an occasional activity.

These differences could not be explained by geographic location alone, since they even occurred between neighboring villages and geographic distance to mines did

not appear to pose an obstacle. This becomes clear from spatially reconstructing the connections between the villages and the mines where people worked (Figure 1 in the appendix). Especially in the villages around Luhago south of PNKB, distances between villages and mines were small and miners were most likely to work in mines on a daily basis. Other miners covered remarkable distances from their home villages to mining sites, often through difficult terrain without roads.

In the villages around INR, miners predominantly targeted mining sites located deep inside the forests of INR. Given that these are often controlled by rebel groups (IPIS, 2023) and therefore less subjected to governmental regulation and taxation, they may be better suited to provide a quick extra income in times of need compared to mines that are organized in cooperative structures. This fits with the observation that miners in villages around INR spent fewer weeks per year in the mines as compared to those in PNKB.

A comparison in means between mining and non-mining households showed that mining households on average had more household members, experienced less food insecurity and were less likely to engage in commerce and wage labor as other income-generating activities (Table 1 in the appendix).

4.3.2 Regression results

Table 2 shows regression results from the two-part hurdle model. The outcome for all specifications is the annual mining weeks of a household (see Methods). The zero model in the first part in the first four columns was estimated in a binomial logit, while the second part in the last four columns was specified as a truncated count model with a negative binomial distribution.

Model (1) in columns 1 and 4 shows results for the villages around INR. Coefficients were mostly insignificant, which largely owes to the small number of observations and hence noisy estimates.

Model (2) shows results for a sub-sample of villages around PNKB. The sample size was larger and hence the coefficients more precise. The zero model part in column 2 showed a significant and negative relationship between the number of mining weeks per year and alternative income strategies. More specifically, forest income generation decreased the odds that household members spent at least some time in the mines to 0.25 ($p < 0.05$), while other forms of income even indicate odds of 0.16 ($p < 0.001$). In the count model part, we found a baseline count of 3.79 mining weeks among mining households. This decreased by a factor of 0.84 with every additional hectare of cultivated farmland ($p < 0.05$).

Finally, models (3) and (4) used the entire sample and therefore are the most precise estimates. The latter, which included fixed effects for each site, indicated in the zero model (column 4) that every month without sufficient food experienced by a household significantly decreased its odds of being a mining household by 0.47 times ($p < 0.05$). Further, and in line with the labor allocation model derived in the previous section, generating forest income reduced these odds by a factor of 0.27 ($p < 0.05$), and other income by 0.29 ($p < 0.01$). Among the count model coefficients, we only found the cultivated hectares of farmland to be significant, decreasing the number of mining weeks per household by a factor of 0.86 for every hectare of farming.

Overall, mining households were less likely to go short on food and to engage in other alternative livelihood strategies compared to non-mining households. Among

Table 2: *Hurdle model regression results for the total number of working weeks per year and household*

	Zero model (first part)				Count model (second part)			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
(Intercept)	−2.80*	−0.46	−0.90*	−1.00*	4.74***	3.79***	3.64***	3.46***
	(1.09)	(0.54)	(0.44)	(0.50)	(0.85)	(0.28)	(0.27)	(0.35)
Men in HH (#)	0.15	0.07	0.03	0.04	0.12	−0.19	−0.18	−0.15
	(0.39)	(0.23)	(0.19)	(0.19)	(0.29)	(0.15)	(0.13)	(0.14)
Women in HH (#)	−0.01	0.28	0.09	0.09	−0.42	0.14	0.14	0.13
	(0.42)	(0.23)	(0.19)	(0.19)	(0.47)	(0.12)	(0.12)	(0.12)
Children in HH (#)	0.23*	0.07	0.10**	0.10*	−0.13	0.02	0.02	0.02
	(0.09)	(0.05)	(0.04)	(0.04)	(0.07)	(0.02)	(0.02)	(0.02)
Months w. insufficient food (#)	−0.07	−0.13	−0.11*	−0.11*	0.06	−0.06	−0.02	−0.01
	(0.06)	(0.08)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)	(0.03)
Cultivated area (ha)	−0.04	−0.23	−0.03	−0.02	0.09	−0.18*	−0.17*	−0.15*
	(0.19)	(0.15)	(0.10)	(0.10)	(0.15)	(0.09)	(0.06)	(0.07)
Wealth score	0.56	0.25	0.48	0.47	−0.31	−0.06	−0.10	−0.12
	(0.51)	(0.41)	(0.31)	(0.31)	(0.45)	(0.24)	(0.21)	(0.21)
Livestock units	2.02	0.38	0.24	0.22	0.59	0.02	0.00	−0.01
	(2.16)	(0.31)	(0.23)	(0.23)	(1.71)	(0.07)	(0.07)	(0.07)
Forest income (0-1)	−0.33	−1.09*	−0.91*	−0.93*	−2.03	−0.41	−0.46	−0.49
	(1.25)	(0.45)	(0.41)	(0.41)	(1.24)	(0.26)	(0.27)	(0.27)
Other income (0-1)	0.07	−1.63***	−0.91**	−0.88**	−0.70	0.28	−0.05	0.01
	(0.56)	(0.45)	(0.31)	(0.32)	(0.44)	(0.26)	(0.20)	(0.21)
Study site	INR	PNKB	All	All	INR	PNKB	All	All
PA fixed effects	no	no	no	yes	no	no	no	yes
AIC	332.35	810.60	1134.25	1137.47	332.35	810.60	1134.25	1137.47
Log Likelihood	−145.18	−384.30	−546.12	−545.73	−145.18	−384.30	−546.12	−545.73
Num. obs.	102	175	277	277	102	175	277	277

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

households that mine, we further observed that the number of mining weeks decreased with the cultivated area. Coefficients on the wealth score coherently showed a positive relationship in the zero model and a negative relationship in the count model, although all coefficients were statistically insignificant.

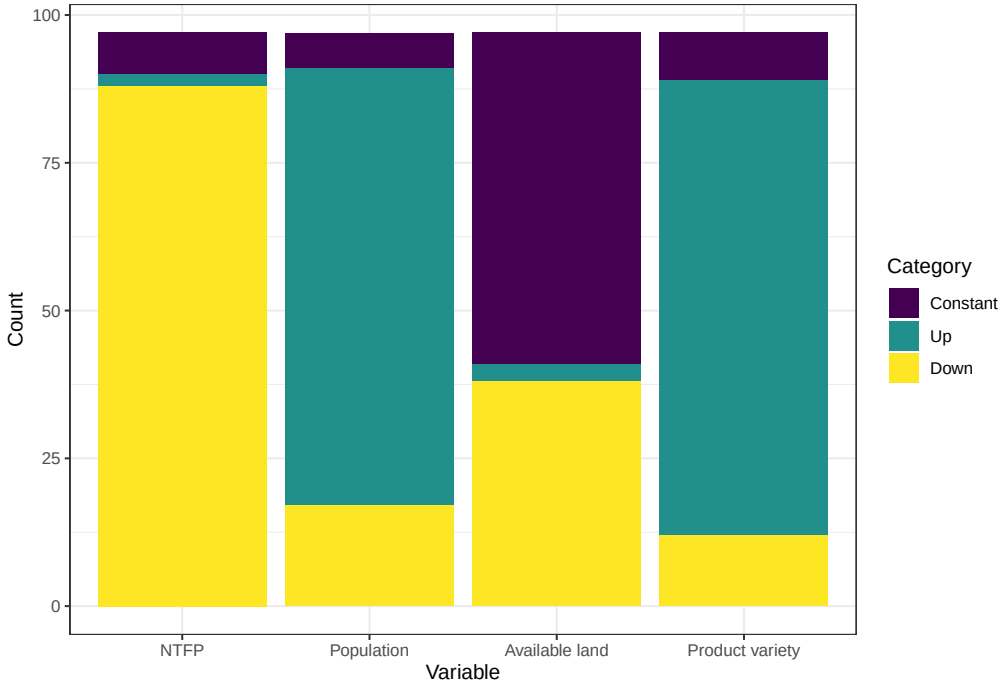
The regression results are - as far as testable - in line with the predictions from the analytical model. Although it is difficult to assess the riskiness of farming directly as derived in equation 5, the higher food insecurity among non-miners might indicate that mining indeed works as a risk-reducing strategy. Although not statistically significant, regression coefficients further indicated a larger degree of reliance on mining for asset-poor households, which is in line with the results derived in equation 7.

4.3.3 Perceived demographic and geographic changes among miners

To inform potential hypotheses on the role of larger demographic and geographic trends on the village level that could be connected with the prevalence of artisanal mining, we asked artisanal miners about perceived changes in land availability, the availability of forest products (e.g., bushmeat), the revenues generated by the households, the variety of products available in the village, and the population size over the previous four years.

Especially in the forest-near areas around Kahuzi-Biega National Park and Itombwe Nature Reserve, the use of forest products can be an important element in supporting livelihoods (Cuni-Sanchez et al., 2019). Of the interviewed miners, 88.9% found that the availability of Non-Timber Forest Products (NTFP) (e.g., bushmeat)

Figure 3: *Perceived changes in the village, reported by miners.*



had decreased during the four years. The most commonly stated reason was progressing deforestation and wood extraction, but also restrictions imposed through conservation was mentioned to cause the declines in forest products. Given that forest products, like mining, are frequently used as gap fillers in times of hardship (Wunder et al., 2014), defaunation and conservation may be a factor in explaining increased mining activities, especially in forest-near locations.

Another factor that can play a role for the emergence of mining is the decreasing availability of arable land. 56.6% of the surveyed miners did not perceive any noticable changes in the availability of farmland over the previous four years, while 38.4% found the availability of land to be decreasing. Many respondents additionally mentioned that they experienced declining yields on the available farmland due to higher prevalence of crop diseases. Thus, land availability and productivity may be a factor for explaining a potential shift from farming towards mining.

Dynamics of internal displacement can lead to local changes in population sizes that also affect livelihood strategies of both migrant and non-migrant households. Of the surveyed miners, 74.8% perceived the village population to be increasing, whereas 17.2% found it to be decreasing. For both tendencies, displacement and insecurity were mentioned as the main explanations. In the case of decreasing population, lacking roads and the "rural exodus" were other reasons stated.

Finally, a proxy of socio-economic status is the variety of products available in the village. This was perceived to be increasing according to 77.8% of the interviewed miners. Only in 12.1% of the interviews, respondents found it to be decreasing, mostly because of the security situation.

5 Discussion

Artisanal mining has become an essential element in the livelihood strategies of rural households in the eastern DRC. With the high availability of mines over the region and the willingness of miners to travel tens of kilometers to reach mines, it is accessible to a large part of the rural population and has already shaped livelihoods significantly (Cox, 2012; Kelly, 2014; Smith, 2011). Using data from South Kivu in eastern DRC, we analytically and empirically investigated the relationship between traditional farming livelihoods and the widespread adoption of artisanal mining.

In eastern DRC, the insufficiencies of smallholder farming outcomes have been aggravating during decades of violent conflicts and poor governance. The depletion of productive assets due to looting and displacement challenges long-term planning, which is essential to build a strong and resilient agricultural sector (Cox, 2012; Kelly, 2014; Verweijen & Brabant, 2017). Furthermore, the collapse of transport infrastructure and dissolution of markets have impeded the sale of agricultural produce with detrimental impacts on farmers (Kelly, 2014; Schouten et al., 2022). Shifting rainfall patterns have also begun to adversely affect planning in the predominantly rain-fed agricultural production (Amani et al., 2022; Balasha et al., 2023; Batumike et al., 2022). As forest income becomes harder to generate due to conservation and forest degradation, mining is often the only available alternative.

The analysis revealed interesting characteristic differences between the intensive and the extensive margin of mining engagement. It thereby empirically tied together two distinct types of findings from previous studies: one in which artisanal mining was identified as a "gap filler" to cover short comings from the agricultural sector in a complementary manner (Banchirigah & Hilson, 2010; Hilson & Garforth, 2012; Iragi Mukotanyi, 2018), and one in which households increasingly turn away from farming and engage into mining as their main income-generating activity (Cox, 2012; Kelly, 2014). Results from the surveyed villages show that both strategies coexist. In accordance with the idea of mining as a way to cope with economic distress, we found that households involved in mining experienced less food deprivation than others, but that this relationship faded as mining households experienced a higher degree of mining involvement and cultivated less agricultural land. Especially the later finding is in line with results from Mabe et al. (2023) who found that land-poor farmers where more likely to engage in mining in Ghana.

The link between artisanal mining and households' food security is important, given the overall precarious situation of food instability that prevales in the entire country and particularly the east (FAO, 2023). However, in its current form, mining is unlikely to be a lasting solution to food shortages, and rather contributes to the problem. While offering short-term relief for households, it creates dependencies on flawed agricultural markets with higher reliance on mining. For their study in Ghana, Nunoo et al. (2023) accordingly found that mining may increase the quality of food in the short-run, but leads to a long-run decrease in food stability at the household level. On the regional level, the moving of labor away from farms into mines has decisively contributed to the precarious shortage of agricultural supply in the area and has driven up food prices in mining settlements (Smith, 2011). Thus, programs aimed to improve the food insecurity in the region necessarily have to start with strengthening the farming sector that has - and still is- suffering greatly under the insecurity. Land access particularly for displaced people, re-establishment

of agricultural markets and the installation of the necessary public infrastructure are only some of the challenges to mention. Only then can potential synergies between agriculture and mining develop, as observed in other geographic contexts (e.g., Hilson et al., 2024; Maconachie & Binns, 2007; Pijpers, 2014).

While the empirical evidence suggests that artisanal mining can be used to support consumption and provide a safety net in the study area, no robust evidence was found in this study that it also provides means for asset accumulation in its current form (Angelsen et al., 2014). In other countries of Sub-Saharan Africa, it has been hinted at the potential of mining to serve as a "platform of wealth creation" that can support the struggling agricultural sector with much needed investments (Hilson & Hu, 2022). However, in a context of ongoing armed conflict, where farmland frequently has to be left behind in the process of displacement and harvest as well as other assets can become targets of raids, a prerequisite for improving livelihoods must be peace and stability.

Building poverty alleviation strategies on the extraction of minerals also brings other risks, given that minerals are non-renewable, deplete over time, and have their value determined on global markets (Pedersen et al., 2021; Vogel et al., 2018). Water and soil contamination, deforestation and biodiversity loss from habitat destruction, pollution and overhunting in the ecologically valuable montane forest of the Albertine Rift are also at stake, as they are often a byproduct of mining activities (Ladewig et al. 2024; Nkuba et al. 2019; Plumtre et al., 2007; Sonter et al. 2018). Thus, a stronger dependence on the extractive sector ultimately involves a gamble with the short and long-term future.

A further challenge is the organisation of the artisanal mining sector in the DRC. Formalisation of artisanal mining in the DRC so far has mostly been detrimental for artisanal miners (Geenen & Radley, 2014; Vogel et al., 2018), although vast gaps between regulation on paper and implementation on the ground remain. The regulations that exist have been imposed top-down and are detached from pre-existing structures, the needs of people and complex realities on the ground (Geenen & Radley, 2014). The imposed cooperative structures have become instruments for serving the interests of an elite rather than those of miners (de Haan & Geenen, 2016; Geenen & Radley, 2014), and the designated artisanal extraction zones in which operations are supposed to take place seldomly meet the needs of artisanal miners. Also the ITSCI tracability scheme, aimed to create conflict-free global mineral supply chains, was ultimately detrimental to miners' livelihoods while full of loop holes (Vogel, 2018). It further does not prevent armed groups from generating revenues, as inofficial taxation on minerals and other traded goods often occurs at road blocks along transport routes and makes up for an estimated 25-50% of transport costs (Schouten et al., 2022).

The seizure of large parts of the Kivu provinces by the M23 rebel group in early 2025 has demonstrated the weak state capacity in the area that impedes needed reforms. As Geenen & Radley (2014) note, the state first has to undergo fundamental transformation itself before it can be "expected to play a non-predatory, positive role in mining sector reform." In the light of recent events, a more realistic and immediate approach is to start by strengthening local structures and build on existing organisational forms instead of imposing more regulations from above. Especially benefit sharing mechanisms that include miners and the larger surrounding communities have to be at the center of improvements (Wakenge et al., 2021).

Also alternative income opportunities beyond mining are of great importance, and miners interviewed for this and other studies expressed their willingness to leave the sector if only presented with viable options (Spira et al. 2019). Unfortunately, there is "a dearth of evidence from independent evaluations of local development interventions in ASM communities" (Huntington & Marple-Cantrell, 2022), which leaves researchers, policy makers and NGOs to speculate how the dependence on mining can be reduced. Priotising the strengthening of smallholder agriculture in order to reduce the reliance on mineral extraction to make ends meet could be a starting point. A recent experiment with unconditional cash transfers in mining communities in the Maniema province has shown that many participants reduced their mining activities while increasing agricultural activities and investment, but also higher investment in protective equipment and mining gear among those who did not (IPIS, 2024).

A few caveats should be kept in mind in the interpretation of the results. First, the analytical model is a simplified abstraction of reality that cannot take the entire complexity and heterogeneity of household decisions to diversify livelihoods into consideration. Instead, it is meant to give a stylised insight into how differential risks, incomes and assets play a role in these decisions. Second, the geographic area covered by the empirical part is relatively small and the limits of external validity should be kept in mind, also in regard to the highly volatile temporal context in the region. Third, as indicated earlier, the number of observations and the structure of the data do not allow us to use robust methods for deriving causal relations. For instance, it is not possible to disentangle whether more mining-reliant households give up agricultural land or if land-poor households are more likely to develop a higher dependence on mining. The analytical model helps to provide intuition and it generally matches with the regression results, but does not ultimately resolve these issues. Thus, better data with a higher number of cross-sectional units and a larger time horizon is needed to confirm the hypotheses stated in this study.

6 Conclusion

Artisanal mining has established itself as a widespread livelihood strategy in eastern DRC, but has seen increasing attention in international policy debates for its adverse social and environmental effects. Our analysis adds to a better understanding of livelihood diversification through mining, acknowledging that diversification comes in many forms and degrees. We point to important differences between miners who only mine occasionally and those who seek it as a more regular income opportunity. Findings showed that livelihood diversification through mining can work as an efficient gap-filler as an immediate response to food insecurity, but may lead to crowding-out of agriculture as reliance on mining increases and thus reinforces insufficiencies on the regional level.

The artisanal mining sector in the DRC has been targeted with sectoral reforms and supply chain policies, mostly to address the involvement of non-state actors and the often precarious working conditions. Also, the environmental consequences of artisanal mining start gaining attention among policymakers (Sonter et al., 2018; World Bank, 2021). These reforms predominantly came at the expense of local livelihoods. Improving livelihoods in rural eastern DRC is closely tied to the strong artisanal mining sector, as many people rely on it for their survival. The availability

of income alternatives can reduce the reliance on mining in the medium- to long-run, but crucially requires the political stabilization of the region that would give rural households the needed securities to invest in long-term livelihood activities.

Our results also point out at the differences across sites (Kahuzi-Itombwe) and even villages within one site. Therefore, instead of one-size fit-all policy recommendation, engaging local populations with diverse societal actors to collaboratively and iteratively produce knowledge, action and societal change, would be preferred (Chambers et al., 2021; Wyborn et al., 2019).

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