The Gold Digger and the Machine
Evidence on the Distributive Effect of the Artisanal and Industrial Gold Rushes in Burkina Faso *

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Abstract

This paper uses a quasi-natural experiment, the recent gold boom in Burkina Faso, to document the local impact of two alternative mining techniques: artisanal and industrial mining. Artisanal mines have a bad reputation. When these mines (labor intensive and managed in common) compete for land with industrial mines (capital intensive and privatized), governments tend to favor the latter. However, more than 100 million people depend on artisanal mines for a livelihood. Our identification strategy exploits two sources of variation. The spatial variation comes from the exposure of households to different geological endowments, and the temporal variation comes from changes in the global gold price. We are the first to document the economic impact of artisanal mines. We show that a 1% increase in the gold price increases consumption by 0.12% for households near artisanal mines. Opening an industrial mine, in contrast, has no impact on local consumption.

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1 Introduction

Karma, January 2015: 3 to 6 million euros' worth of equipment on the construction site of True Gold vanish in flames after a local community protest (Capitant, 2017). Karma is located in Burkina Faso, a country where 43% of the population in 2014 was living on less than 1.90 dollars per day but which, thanks to heavy investments by industrial mining companies such as the Canadian True Gold, became Africa's 4th major gold exporter within a few years. Yet the population of Karma – in particular the population linked to artisanal mining activities – expressed extreme discontent with True Gold's investments. The case of Karma is not exceptional: abundant qualitative evidence can be found on local resistance to industrialization, notably from people engaged in traditional activities, whether in the mining sector or in other sectors (Hilson and Andrew, 2003; World Bank, 2009; Stoop et al., 2018; Christensen, 2019).

We investigate one essential aspect of the tension between local populations and industries: the local economic consequences of traditional *versus* industrial activities. Artisanal mining is a traditional and labor-intensive activity that extracts natural resources under a regime of common property management.[1] The settlement of an industrial mine substantially increases the capital intensity and the productivity while privatizing the natural resources, since the production area is enclosed. Such a setting echoes the instances when a traditional activity (low in productivity, but accessible to all and labor intensive) is replaced by a modern activity, for example switching from traditional to modern agriculture, or replacing a communal forest with an oil field or any other type of heavy industry (with clear property rights often held by a foreign firm). Each of these replacements entails major local changes and affects the expected and actual revenue sharing.

The evolution of gold extraction in Burkina Faso since the late 1990s offers an ideal quasi-natural experiment. Artisanal and industrial mines target overlapping areas in the contry, and the multiplication by four of the world gold price between 1998 and 2014 directly affected their benefits. As a result, in 2014, we estimate that 640,800 Burkinabes, representing nearly 4% of the total population of the country, were directly involved in artisanal and small-scale gold mining (henceforth, ASM). Multiplying each artisanal miner by five dependents, the multiplier used by the UN report (2016), makes artisanal mining central to the livelihood of 3,200,000 people, which corresponds to 18% of the country's population at the time. While Burkina Faso has a long tradition of ASM, the intensification of activity reflects the boom in gold prices (diggers earn more during the boom since the price at which they sell their gold,

[1] Such that *"property rights are exercised (at least partly) collectively by members of a group. There must also be rivalry in consumption of the resource within the group"* (Seabright, 1993, p. 113)

typically above 83% of the international gold price, mirrors the evolution of the international gold price, Alvarez et al., 2016; Balme and Lanzano, 2013). Moreover, following both the price boom and the adoption of an investor-friendly mining code in 2003, eight major and three minor industrial mines opened in the country between 2007 and 2014. All the gold deposits big enough to build these industrial mines had been known for decades, but it became cost-effective to exploit them. The timing of the industrial gold boom is thus independent of local factors. At the national level, the settlement of industrial gold mines increases production and exports: gold represented 2% of exports in 2007, and 55% in 2014. At the local level, this settlement casts aside artisanal miners, who lose access to the resource in the areas privatized by the industrial mines (Côte and Korf, 2018). The question we ask is: what are the consequences of both artisanal and industrial mining on the living standards of local populations?

To identify the impact of artisanal mines, we implement an analysis in which the treatment comes from variations in the global gold price and the average distance to artisanal mines. The gold price induces a time variation in gains from mining, and Burkina Faso is a price taker on the global gold market. To define the location of artisanal mines, we exploit original data on all the registered artisanal mines and novel geological information. To identify the impact of industrial mines, we exploit the difference in their years of opening (which follow the global gold price), as well as the distance of households to these mines. We are able to isolate the effects of the gold boom by combining four waves (1998-2003-2009-2014) of household surveys collected by the national statistical agency of Burkina Faso, the INSD. These data have never before been exploited over such a long period, and we are the first to build the GPS coordinates of households, allowing us to track changes at the local level. We use household consumption as the main indicator of household economic well-being (Deaton and Zaidi, 2002),[2] and also investigate the effects on the two other aspects of human development (health and education).

Our results first document the strong positive impact of artisanal mining on consumption. A 1% change in the gold price leads to a 0.12% increase in nominal consumption for households located close to artisanal mines. This additional consumption is economically significant: the recent gold price boom translated into a 15% increase in households consumption (around 9 cents in euros each day for each person living nearby an artisanal mine). Despite the polluting nature of artisanal mines and concerns that they may employ children, we do not find any adverse effects on either health or education. If anything, we document a marginally significant amelioration in children health that is consistent with the income

[2]Our main analysis uses nominal consumption data. In the absence of repeated price data at the local level we cannot compute real consumption. However, in subsection 5.3 we suggest that it is unlikely that a change in prices drives our results.

effect of artisanal mines outweighing any pollution effect.

We then proceed to show that industrial mines do not improve local economic conditions. Despite strongly increasing gold extraction, our estimates show that the opening of industrial mines has no impact on the consumption by neighboring households (the point estimate, while reasonably precise, is close to zero). Thus, the efficiency gain arising from the privatization of the gold resource by industries does not translate into a gain for local labor. It is an important result since the development of industrial mines is often presented by governments and industries as a way to increase wealth and foster job creation, either through the direct creation of jobs in the mining sector or a local multiplier effect.[3]

Available evidence is inconsistent with our results being driven by changes in migration or local prices. Most importantly, we show that artisanal mining activities in Burkina Faso are highly seasonal, and we document their positive consumption effect outside the main mining season.[4] While seasonal migration may take place, we document that the gold boom does not affect households' characteristics (such as age, size or education), a result inconsistent with permanent selective migration driving the change in consumption. Moreover, the artisanal boom effect is concentrated on certain households, who may directly diversify their income sources by mining, or else indirectly benefit from the gold boom by providing gold diggers with goods and services. Households in the service sectors are by far the main beneficiaries, followed by households in the trade and agriculture sectors. We also document the absence of effect of mining activities on various price proxies (such as the share of food in consumption Almås, 2012; Almås et al., 2019).

We therefore make three significant contributions to the literature. We provide the first nation-wide study of the local impact of artisanal mining on living standards, thereby reducing the knowledge-gap on ASM. ASM has a bad reputation and is often seen as a source of conflict and poverty. For example, the main international initiative focused on ASM, the Communities and Small-Scale Mining Initiative of the World Bank, stated that its aim was to transform artisanal mining *"from a source of conflict and*

[3]In the case of Burkina Faso for example : "*The government of Burkina Faso intends to make exploitation of mineral resources one of the pillars of the economic revival through the creation of jobs and wealth*", said a journal newspaper in 2016 (*Industrie minière : la belle place au soleil du Burkina Faso*, Le Point, March 23rd 2016). "*As well as gold, Burkina Faso's soil contains riches such as manganese, zinc or phosphates providing many investment opportunities in the sector. That brings stable job opportunities: up to 17,000 jobs are expected to be created in the mining sector"*, reports another newspaper (*Burkina Faso wants to share its gold wealth*, Euronews, December, 5th 2016). This objective can be put in perspective by the numbers reported by industrial mines. In 2014 in Burkina Faso the industry claimed to employ directly 6,464 people, 90% of them being from the country (ITIE, 2016).

[4]Mining takes place mainly in winter, when people have nothing to do in the fields. We exploit data collected between the months of May and July (or until September for one of the waves), that is during the plantation and growing period, when people are in the fields. This period also coincides with the rainy season during which ASM activities are illegal because the rainfall increases the danger of the mines collapsing. Thus, we assume that households are able to smooth consumption through savings (Deaton, 1989; Dupas et al., 2018). Any imperfect consumption smoothing will bias our results on the artisanal minning boom downward.

poverty into a catalyst for economic growth and sustainable development" (World Bank, 2007). Yet, more than a hundred million people globally, representing 1.5 to 4% of the world's population, depend either directly or indirectly on ASM for a livelihood (considering both miners and their families, World Bank, 2009; artisanalmining.org, na) and these mines produce 20% of the minerals that we use (Buxton, 2013). Faced with such figures, we may be surprised by the quasi-silence of the quantitative literature on the impacts of ASM.[5] This quasi-silence comes from the technical challenge of pinning down artisanal mining activities. A few recent works aim to overcome this challenge by means of either extrapolation from the type of deposit, or first-hand data from specific regions. These works have focused so far on the impact of ASM on conflicts (Lujala et al., 2005; Rigterink, 2018), institutions (Sánchez de la Sierra, 2019) and health (Parker et al., 2016).[6] More recently, Guenther (2018) documents a positive correlation between artisanal mines, income, and deforestation in the Southern half of Ghana. Without underestimating the possible negative effects of ASM on conflicts and other dimensions of well-being, we exploit new and nation wide data from Burkina Faso to provide causal evidence that ASM activities may have a significantly positive effect on local consumption.

Second, our results contribute in two important ways to the literature on the impact of extractive industries on local living standards.[7] Our results call for further attention to the distinct impact of opening *versus* discovering a deposit or expanding the production of an existing industrial mine. The impact of industrial mines on local development is subject to debate. Mamo et al. (2019) document contradictory effects of *discoveries* of industrial deposits on precise household level outcomes (positive on a wealth index, negative on water infrastructure, null on infant mortality); despite the positive impact of

[5] A World Bank report, aiming to summarizing the state of knowledge notes that *"An important caveat is that the focus of the study is on large-scale 'industrial' gold mining and not artisanal and small-scale gold mining that often takes place in proximity to large-scale mining. The data cannot be disaggregated to distinguish between these two classes of mining"* (World Bank, 2015, p. 11). Cust and Poelhekke (2015), in their literature review on the local impact of extractive activities, both call for more research on ASM, and summarize the overall negative perception of this activity: *"Finally, more research is warranted on a variety of fronts. The first is to look at an even finer spatial scale, such as artisanal mining, which in many rural areas may cause severe environmental and health risks, conflict and generally few economic benefits."* The only published work we know of that considers the economic spillovers of artisanal mines in a quantitative analysis, Zabsonré et al. (2018), actually merges their impact together with the impact of industrial mines. They find an overall positive impact on living standards. However, the fundamental differences between the two management modes, if only in terms of labor intensity, calls for further work on distinguishing their impacts. Such a distinction is all the more important in that the qualitative research on ASM offers a nuanced picture, and often outlines both the insurance effect of artisanal mining and its social costs (Hilson, 2006). To help overcome this challenge, a consortium of research and policy institutions joined to build up the Delve website. Currently in beta mode, the website aims at collecting data on ASM (see https://beta.delvedatabase.org/about).

[6] Santos (2018) or Romero and Saavedra (2016) also study the effects of mining on education or health, but they focus on illegal versus legal mining: they do not assess the heterogeneity of the impacts by size of the industrial and artisanal mines. Our data allows us to distinguish the impacts of industrial and artisanal mines, while encompassing the impact of both the legal and the illegal artisanal mines.

[7] Given the debate on the existence of a resource curse at the macroeconomic level (see van der Ploeg, 2011; Venables, 2016, literature reviews), researchers have investigated the consequences of extractive activities at the local level (see Cust and Poelhekke, 2015, for an overview).

both discoveries, openings and expansions on district level nightlight emissions. Focusing on the *expansion* of industrial gold mines, Aragón and Rud (2013) document the positive impact of local content requirements on income in Peru, but Aragón and Rud (2016) observe the negative impact of increasing production on agricultural productivity (and consumption) in Ghana. We show here that the *opening* of new industrial mines in Burkina Faso has no local economic effect.[8]

We also show that the coefficient of industrial mines opening remains stable when we introduce a control for artisanal mines. Such an observation is reassuring for the credibility of the existing estimates in the literature. Indeed, although in many cases artisanal mines precede or co-exist with industrial mines (World Bank, 2009), virtually all the existing literature omits the distinctiveness of ASM, thus mixing together the impacts of the two mining techniques.[9]

Finally, our results bring empirical evidence to the mostly theoretical debate on the impact of the private management *versus* the common management of natural resources. Artisanal mines are not the ideal type example, but they do display the core features of common property management (absence of efficient production planning and the resource being accessible to all), while industrial mines restrict access. A rich literature debates the distributive consequences of each mode of management, starting with works by Weitzman (1974); Pattanayak and Sills (2001); Baland and Francois (2005); Baland and Bjorvatn (2013). In particular, Weitzman (1974) shows that, although efficient, privatization can be obtained at a distributional cost, making labor worse off. Indeed, under common property management, all gains go to the variable production factor (in our case, labor); while, under private ownership, the variable product gets only a share of the gains (the remainder goes to the owner of the fixed factor, here, the owner of the mine). Baland and Francois (2005) go further, showing that everyone may lose after privatization when markets are incomplete. Indeed, open access to the resource may be used as an asset of last resort for poor populations. However, it is challenging to find empirical evidence. To the best of our knowledge, our study offers the first large scale empirical evidence on the local impact of common *versus* private management of an extractive natural resource. Privatization is often a bundle treatment which, together with the nature of the property of the resource, changes the capital intensity of the extractive activity. We provide a reduced form estimate of the impact of this bundle treatment.

[8]Beyond the production stage of the mine, the characteristics of the local market for inputs is also likely to be an essential aspect of a policy betting on a local multiplier effect: the Peruvian production sector is more varied than that of Burkina Faso (or Ghana), such that the realization of the local linkages should be easier in Peru. Even within industrial mines, variations in extraction techniques are also likely to matter: open pit gold mines such as the ones in Burkina Faso are particularly capital intensive (Pelz and Poelhekke, 2018).

[9]The most notable exception is the recent work of Stoop et al. (2018) on conflicts with overlapping artisanal and industrial mines. The literature on diamonds and conflicts reviewed in Rigterink (2018) takes a different perspective since artisanal and industrial diamond deposits do not overlap as gold deposits do.

Our takeaway is that the competition for land between traditional and industrial mines translates into a trade-off between local labor consumption and State revenue (plus possible non local consumption that we do not measure). Artisanal mines increase local consumption, but their contribution to the State revenue is smaller than the contribution of industrial mines, in both relative and absolute terms.[10] Interestingly, a back of the envelope calculation suggests that ASM and LSM total contributions in terms of money flowing in the country have comparable order of magnitudes. If we combine (1) the local consumption effect attributable to artisanal mines in 2014 and (2) the ASM sector contribution to the state budget, the two numbers add up to represent 58% of the total contribution of industrial mines to the state budget for households living within 10 kilometers of an artisanal deposit. If we consider the consumption effect for households within 25 kilometers of an artisanal mine (which brings in more people and people who are on average richer), the contribution of artisanal mines to the economy of Burkina Faso represents 158% of the contribution of the industrial mines.[11] Where they heavily differ is in terms of who earns and spends the money.

The paper is organized as follows. In the next section, we describe gold mining in Burkina Faso. Section 3 focuses on the data and identification strategy. Section 4 provides the main results. Section 5 proposes a discussion of these results: we explore labor market effects and seasonality and the potential effects of migration and prices. Section 6 concludes.

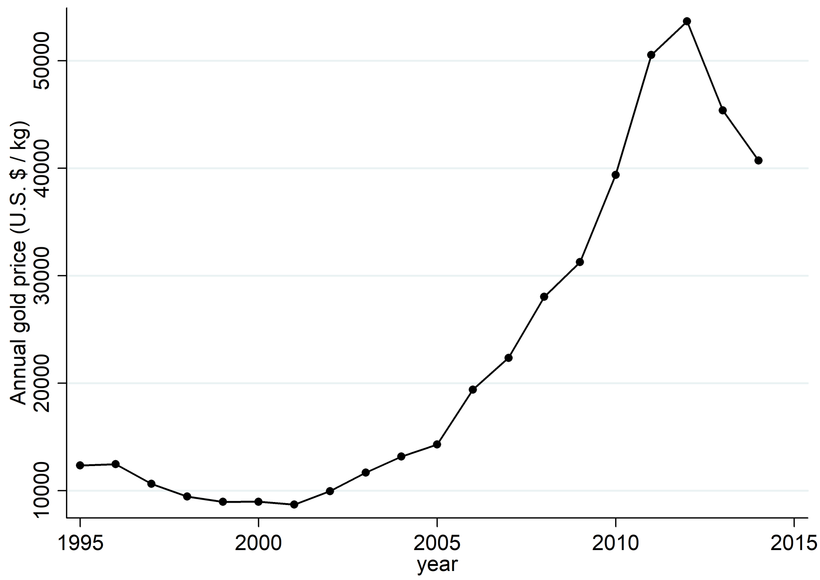
2 Gold Mining in Burkina Faso

Several features of gold extraction in Burkina Faso make it the ideal candidate from which to assess the impact of artisanal *versus* industrial gold extraction. First, we describe why the interaction of the two main drivers of the recent gold rush, namely the gold price and gold reserve locations, is exogenous to the action of local populations. Second, we present the organization of artisanal gold mines. Third, we describe the setting in which the industrial gold boom has taken place.

[10] In 2014, artisanal mines contributed to the revenue of the State of Burkina Faso 5% of the value of their declared production, while industrial mines contributed 19% (ITIE, 2016).

[11] Note that in these sums, although industrial mines may benefit capital and firms' owners, or potentially urban households if they benefit more from the increase in tax revenue, we assume their consumption effect to be zero. This simplifying assumption allows us to obtain an approximate order of magnitude. This order of magnitude should be reasonably close to reality for several reasons: firstly, we do document the absence of a local effect on the consumption of industrial mines; secondly, industrial mines employ few people in total (and we have no details on the number of people hired in the country outside the mining areas, but it seems likely that most employees are around mines) ; thirdly, the capital owners of all industrial mines (beside the 10% of the State of Burkina Faso) are foreign companies; fourthly, our calculation assumes that the whole amount due in taxes stays in the country such that a potential increase of consumption among urban households because they would benefit more from the taxes appears in our calculation, through the tax totals.

Figure 1: Evolution of the gold price, 1994-2014



Note: data sources are the gold price from London Gold Fixing.

2.1 How Gold Affects Burkina Faso

While gold price fluctuations directly determine the benefit of gold extractive activities, Burkina Faso is a price taker on the international gold market. In 2012, its gold production of 28 tons made it the 22nd largest producing country in the world, far behind the 403 tons produced by Russia (indexmundi). Still, gold has become central for the economy of the country since the surge in the gold price in the 2000s (Figure 1) and gold is now the country's main export: it represented 55% of exports in 2014 (the last year in our study) against only 6% in 1998 (the first year in our study). We aim to assess how the artisanal and industrial gold rushes have affected the country's 17 million inhabitants, about half of whom live on less than $1.90 per day (from 80% in 1998, to 43% in 2014, 2011 PPP, World Bank).

The location of gold deposits all over the country is exogenously determined by the geological environment. Burkina Faso lies on top of the Birimian greenstone belts, a type of rock likely to host gold deposits within its core or at its frontiers (Béziat et al., 2008). Because of its geological setting, Burkina Faso hosts hundreds of artisanal and small-scale mines and has granted hundreds of exploration permits for industrial mines. Both types of mines compete for overlapping areas, as is clear from the repartition of artisanal mines and industrial research permits across the country, both overlapping with the Birimian belts (Appendix Figures 7 and 8). Importantly, if an exploration permit is successful and results in the construction of an industrial mine, artisanal miners lose access to that extraction site (Côte and Korf, 2018). Appendix Figure 9 takes the example of the mine of Kalsaka: the industrial mine is enclosed by a fence, and within the fence lie some places where artisanal miners used to dig. Local populations may perceive negatively the displacements of artisanal miners (documented among others by Jaques et al., 2006; Thune, 2011). In the qualitative work of Pokorny et al. (2019) in Northern Burkina Faso, households from both the Gorom district (located near Essakane mine) and the Kalsaka district report that "*industrial mining displaces traditional mining sites*" is one of the main negative effects of industrial mining.

2.2 Artisanal Mines

Artisanal and small-scale gold mining (ASM) has been taking place all over Burkina Faso, in particular since the droughts in the 1980s (Gueye, 2001), with recent variations in the extent and profitability of the activity following the change in the gold prices. Indeed, local buyers pay gold diggers a percentage of the world gold price shown in Figure 1, that amount being typically above 83% (Alvarez et al., 2016). According to the 2003 mining code, traditional artisanal mines encompass any *"action that consists in extracting and concentrating mineral substances to retrieve commodities from them using traditional, manual methods and processes."*[12] Concretely, ASM sites look like a series of narrow shafts that may be several dozen meters deep. Gold diggers go down the shaft to bring the ore to ground level where further work allows the gold to separated from the useless dirt. In 2003, Jaques et al. (2003) already observed over 200 ASM sites in the country. In 2014, the number of ASM sites was estimated to be 700 to 1,000 (400 of which were registered, Zerbo and Ouedraogo, 2014; ITIE, 2016).

Artisanal and small-scale mines offer an original example of common property resource management (Rodríguez et al., 2018). ASM displays both aspects of a common property resource outlined in Seabright (1993). First, the property rights of artisanal and small-scale mines *"are exercised (at least partly) collectively by members of a group"*. In fact, as outlined below, several pivotal people have claims over a share of the resource; they are constantly re-negotiating and newcomers will always be able to take part in the production process. Second, there is rivalry in consumption of the resource within the group for one cannot mine what has been mined by one's neighbor.[13] Last, ASM is prone to the investment externality: while small groups manage to organize to extract ore from their shaft with basic tools, there is a coordination failure when it comes to strategic planning of the speed of extraction or to

[12]The original version reads, in French: *"opération qui consiste à extraire et concentrer des substances minérales et à en récupérer les produits marchands pour en disposer en utilisant des méthodes et procédés traditionnels et manuels."*

[13]By opposition to a public good, gold provides a private utility to individuals who dig it. Newcomers will always be able to take part because there is no long term planning and anticipation of the exhaustion of sites, but they are also unlikely to access to the most productive pits unless they have connections (Balme and Lanzano, 2013).

bigger investments that would make production more efficient.

Since the 1980s, life in the country's artisanal and small-scale mines has kept following some reasonably stable –informal– rules, despite changes to the –formal– legal framework (Gueye, 2001; Jaques et al., 2003, 2005; Côte and Korf, 2018; Werthmann, 2017).[14] These rules organize the production and ore repartition both within each shaft and between shafts. There are two key actors systematically entitled to a part of the ore: the gold diggers (by which we mean both the actual diggers and the other manual workers involved in the ore processing) and the shaft owner (who invested in opening the shaft).[15] These unwritten rules are still subject to bargaining. For example, Côte and Korf (2018) report instances when local communities managed to leverage taxes from artisanal miners that allowed them to finance a water pump, a mosque, or school classrooms. Newcomers are welcome on mining sites. A newcomer will either dig a new well or join an existing team (Balme and Lanzano, 2013; Werthmann, 2017). The main features of these rules appear in other ASM sites worldwide and as far as in Columbia (Rodríguez et al., 2018).

An exceptional feature of the ASM sector in Burkina Faso is that it is possible to know approximately where mining may take place from ongoing artisanal mining authorizations. Unfortunately, the authorization does not specify who is mining since when or how much. However, any authorization corresponds to a place where mining has gone on at some point. ASM authorizations cover one square kilometer and were meant to empower gold diggers, but Balme and Lanzano (2013) or Werthmann (2017) outline that the bureaucratic knowledge necessary to get an authorization is such that, in practice, private trading posts have secured the authorizations. These trading posts then enforce a monopsony over the commercialization of the ore in their surroundings.[16] Artisanal mines remain managed in common in so

[14]From a legal point of view, from 1986 onward, the CBMP, a state-owned trading post, was supposed to have monopsony power over the organization and buying of gold throughout the country. In 1997, the creation of private gold trading posts was authorized and the CBMP had such trouble competing with the private posts that it stopped working in 2005. In 2003, a new mining code changed the legislative framework for industrial mines with little effect on artisanal mines, save for a slight lowering of taxes. Another mining code was voted in 2015, that is after the last household survey that we use.

[15]Once prospectors identify a new spot, either one of them or the owner of the land invests in opening a new shaft. Property rights for shafts are informal and follow a first-come, first-served basis. Up to several hundred shafts can be dug on a single site (as long as the site produces). The person who puts money into digging the shaft will be the shaft owner (she needs to have some capital because she provides food to the diggers while they dig the new shaft). The moment the shaft starts producing, the shaft owner and the diggers share the ore (usually with a 50:50 rule, and if the local landowner is not the shaft owner, she may collect a lump sum rent or a share of the ore). Hence, the gold diggers, the shaft owner, and the people processing the ore are paid according to 1) the amount and type of their input, and 2) chance, since 2a) the pay is a percentage of the ore, but actually gains are never known before the end of the transformation process, and 2b) the activity is risky for gold diggers and death is always a possibility (Mégret, 2008). A typical shaft is mined by 4 to 8 gold diggers. A last pivotal actor, present in all registered mines, is the trading post, which tries to secure a monopsony on buying the gold produced in the perimeter of the artisanal mining authorization. A typical shaft is mined by 4 to 8 gold diggers (Balme and Lanzano, 2013).

[16]While this claim is illegal for places outside the authorization, and gold diggers may and do sell their gold to different gold trading posts or even smuggle it abroad, trading posts often manage to reach their goal. Post holders may enforce their

far as private gold posts do not act as strategic planners charging efficiency tolls for the use of their property (as is the case in the private ownership equilibrium in Weitzman, 1974). Moreover, while attempts by gold trading posts to enforce monopsony over the gold trade in some areas may limit the number of options for gold diggers to sell their gold, it does not limit access to the artisanal gold mining site (Balme and Lanzano, 2013).

Finally, ASM activities are likely to have local linkages and spillovers. These activities are labor intensive and gold diggers' needs are likely to induce a high local labor multiplier (Moretti, 2010). Artisanal mining is a labor-intensive activity performed by local labor, from neighboring rural communities or floating populations from various regions (Werthmann, 2017). From the household survey we have, approximately 640,800 people from Burkina Faso were active in mining at some point in 2014. This local labor interacts with the local population for services, ranging from water supply to prostitution (Werthmann, 2017).

Taking the multiplier of 1 artisanal miner for 5 dependents used in the UN report (2016), artisanal mining in 2014 was central to the livelihood of 3,200,000 people, which corresponds to 18% of the country's population at the time. While the tendency of gold diggers to practice conspicuous consumption on items such as beer, electronic gadgets or motorcycles may create tensions with local traditions (Cros and Mégret, 2010), it also participates in the local redistribution of the money earned from digging. Gold diggers also stimulate local trading for their inputs, be they batteries, kerosene, dynamite, hammers, pickaxes, shovels, wood ladders, ropes, buckets, calabashes, plastic bags, mortars, sluicing plates and wood or metal sieves. All these inputs are traded by local shops and some of them may be produced locally, mechanically increasing the number of jobs created around each gold digger (Bohbot, 2017).

2.3 Industrial Mines

The country's mining potential has been known for decades and hence the recent industrial gold boom can be judged independent of local factors. Two key elements changed during the 2000s and attracted international investors in Burkina Faso: the promulgation of a new mining code in 2003 and the sharp increase in gold prices (Figure 1).[17]

The 2003 mining code is the result of a move toward a liberalization of the mining sector encouraged

monopsony in different ways, from lending money to gold diggers who need it to open new shafts (Balme and Lanzano, 2013; Hilson and Ackah-Baidoo, 2011), to the extreme case of physical violence (Werthmann, 2017).

[17] The only industrial gold mine in the country, the Poura gold mine, encountered great difficulties and had such limited production that it closed in 1999 when the gold price was low (Jaques et al., 2003).

by international organizations. It opened the sector to international investors and made the tax regime more company friendly. As a result, in 2014, Burkina Faso had 11 running industrial gold mines with three under construction. Appendix Table 7 presents each of these mines.[18]

Gold extraction within industrial mines results from profit-maximizing decisions, in line with the logic of private ownership equilibrium in Weitzman (1974). The property rights over the fixed factor (here the ore) take the form of industrial extraction permits owned by international companies.

The recently flourishing mining industry and the artisanal mines are likely to have different local spillovers. Industrial gold mines are capital-intensive, high-tech branches of international companies. The few employees of industrial gold mines have mostly formal contracts with fixed pay and are highly skilled. To put things in perspective, next to the estimated 640,800 gold diggers active in the country in 2014, the industrial mining sector declared that it employed 6,464 people (ITIE, 2016). In addition to limited direct contacts between the employees of industrial mines and the local population (employees' dorms are enclosed within the fence of the industrial mines; see Appendix Figure 9 for the mine of Kalsaka), the inputs of industrial mines such as large-scale mills and generators or trucks need to be imported from abroad. Still, given the scale of the recent boom in industrial gold extraction throughout the continent (with some positive spillovers, Benshaul-Tolonen, 2019), the competition for land between artisanal and industrial mines, and the observation that local content policies as encouraged by the World Bank may in some contexts be successful (see Aragón and Rud, 2013), it is important to assess the local impact of these mines.

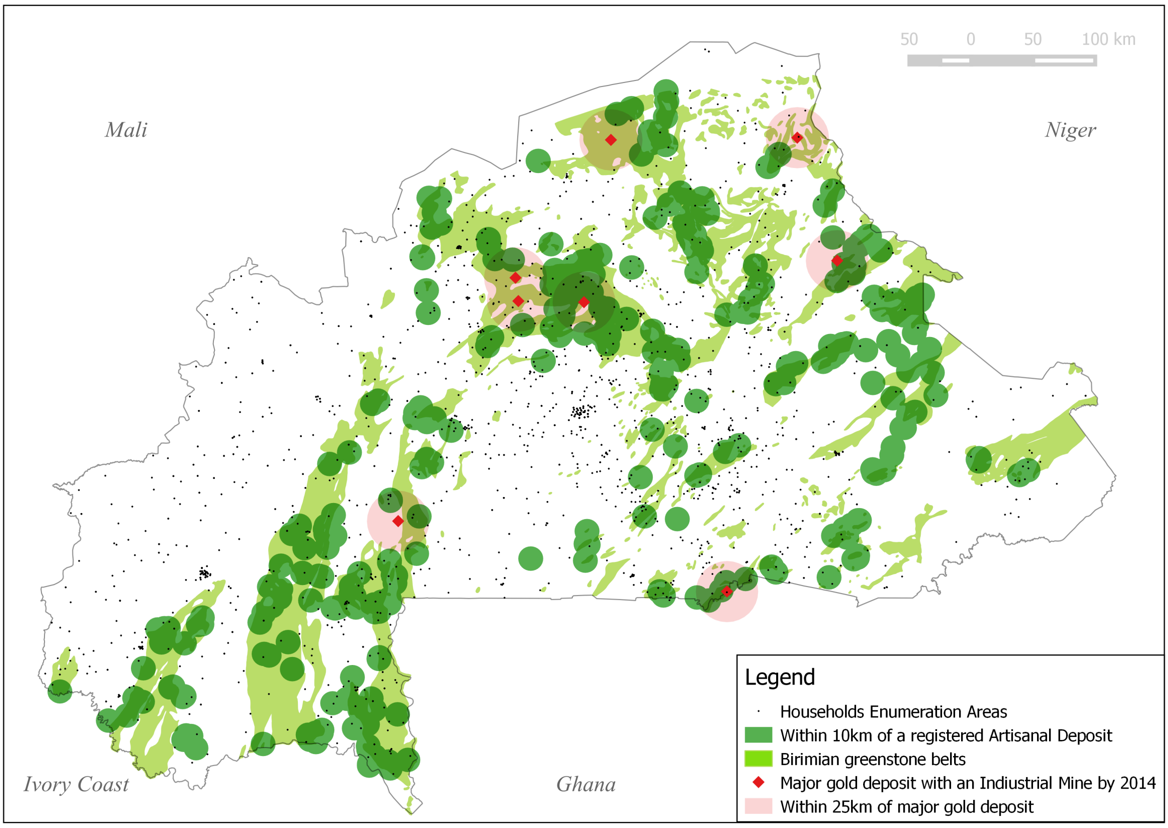
3 Data and Identification

3.1 Data

We build a nationally representative dataset that is a repeated cross section comprising over 30,000 households surveyed by the INSD (the National Institute of Statistics and Demography, based in Ouagadougou) in 1998, 2003, 2009 and 2014. The 1998, 2003 and 2014 surveys are registered in the World Bank Microdata Catalog, and the 2014 survey is additionally part of the Living Standards Measurement Study collection. We are the first to exploit the time dimension of these surveys over such a long pe-

[18]Two other major mining projects are under way in the country, one for zinc (production started in 2013) and the other for manganese (operation permit from 2012, but production still subject to a judicial decision).

Figure 2: Location of enumeration areas for household surveys and mines (both industrial and artisanal)



riod.[19] We are also the first to build and exploit their geocoding (with the geodesic center of each village, or city neighborhood).

Each survey wave encompasses 8,300 to 10,030 households, which are spread out over 426 to 900 enumeration areas in 223 to 301 of the country's 351 municipalities. Our final sample omits Ouagadougou due to the specificity of events in the city in year 2014.[20] The drawing of enumeration areas for each survey is such that we have observations for at least two different points in time for 96% of the municipalities in our sample. Figure 2 gives an overview of the repartition of enumeration areas over the country.

The core focus of INSD household surveys remained unchanged through time: assessing the stan-

[19]Grimm and Gunther (2007) and Zabsonré et al. (2018) use the 1998, 2003 or 2009 surveys. The 2014 survey has not yet, to the best of our knowledge, featured in an academic publication.

[20]The city was at the core of the year-long protest of the "balai citoyen", requesting the departure of president Blaise Compaoré after his 27 years in power. According to ACLED, Ouagadougou hosted over 78% of the 51 protests that had taken place in the country by June 2014, the end collection date of our reference survey round for 2014. ACLED records a total of 139 events in the year 2014. To put this number in perspective, there are on average 22 ACLED events over the period 1997-2013 (with a minimum of one per year and a maximum of 63). Results are however robust to either including Ouagadougou, or to excluding entirely the data from 2014.

dard of living and material well-being of households in Burkina Faso. Beside consumption, all surveys include standard questions such as household size and composition; the activity, education and age of the members; the type and comfort of their house; etc.

Our measure of consumption includes information on expenditures for daily consumption (food, alcohol, tobacco, clothing, etc.), health and education. We omit rents as estimated by households because 85% of households own their house. We follow Deaton and Zaidi (2002) and omit exceptional expenditures on ceremonies, durable items (such as electronic items, jewelry, or modes of transportation) for which we cannot compute the rental equivalent.[21] This procedure gives us the nominal total consumption of each household. We do not have data on the evolution of local prices, however, subsection 5.3 provides several pieces of evidence that are inconsistent with a change in prices driving our results.
We further check the robustness of our estimates when we exclude one year at a time.

The main challenge for us to answer our research question is obtaining the actual location of artisanal mines. We are able to provide a first answer to this challenge thanks to exceptional data from Burkina Faso. The Ministry of Mines gave us access to original data on the location of every registered artisanal gold mine. Obviously, due to the mobility of artisanal miners, this list does not include every artisanal mine. However, we do know that artisanal mining has taken place at some point in each of these registered locations. As a result, this list allows us to compute a first estimate of the impact of artisanal mining.

One may be concerned that specific places, that are, for example, closer to the capital, or more populated, are more likely to have registered artisanal mines. One may also be concerned that there is positive selection in the declaration of mines such that bigger and most productive artisanal mines are the only one registered. Unless the impact of a gold boom goes in opposite directions around big

[21] Items listed in the questionnaires changed somewhat from one survey to another. This is unfortunately often the case with household data. More precisely, the 1998 survey asks about 34 food-related items in the last two weeks and 31 other items in the last month, including health spending, while education spending questions are asked annually. The 2003 survey asks about 125 food-related items in the last two weeks and 40 other items in the last month, including health spending, while education spending are asked annually. The 2009 survey asks about 353 food-related items and 944 other items that households consumed in the last 12 days, including education and health, and then asks about the frequency of these consumptions (from daily to yearly). The 2014 survey asks about the consumption of 64 food-related items in the last 7 days and the consumption of 129 other items in either the last 7 days or the last three months, including education and health. All the 1998 to 2014 surveys ask respondents to recall, for each item, the CFA equivalent of their consumption that they bought, obtained as a gift, or auto-consumed (for food related items). We apply a similar procedure to the raw data of each survey round. In particular, for each year and item and source of consumption, we replace extreme outliers – values that are beyond five standard deviations from the mean – by their median. For each survey round, less than 1% of the households have such outliers. We then compile the data yearly for everyone. As long as any differences in the survey questionnaires are not correlated with our treatment (artisanal and industrial mine location), including year-specific effects is enough to account for each survey specificity. We further check the robustness of our estimates when we exclude one year at a time.

and small artisanal mines, such positive selection will leave results either unaffected or downward bias. However, more generally, we acknowledge that the frontier of legal and illegal activities is often blurred. Balme and Lanzano (2013) outline at least two reasons why this frontier is not clear cut. First, artisanal mining is a short-lived phenomenon and gold diggers are very mobile. Even when the artisanal mines are registered, the operations may take place outside the delimited area. Moreover, an entrepreneur interested in registering artisanal extraction will follow (illegal) gold-diggers to ask and obtain a formal authorization in order to get a monopoly over the commercialization of the gold they extract (Balme and Lanzano, 2013). Registered and illegal mining activities are thus likely to be close to each other in either space or time.

As an original check of the quality of the data on registered mines, we can overlay them with the location of the Birimian greenstone belts. Virtually all the gold of Burkina Faso lies in the Birimian belts (Béziat et al., 2008), mirroring what Fernihough and O'Rourke (2014) exploit for coal in the UK. Figure 2 shows the location of artisanal mines with a 10-kilometer buffer in dark green and the Birimian greenstone belt collected by geologists of the BRGM Orléans in light green. Registered artisanal mines clearly seem to follow the Birimian greenstone belt. We may however note that the two artisanal treatment definitions cover distinct household samples: they overlap for a maximum of 40% of the treated households.[22]

The Ministry also gave us access to each industrial mine's location, yearly production and estimated reserves. Enumeration areas within a red zone in Figure 2 encompass households which live within 25 kilometers of a major industrial mine that was running by 2014. The data do not tell the exact boundary (fences) of the industrial mines, making it impossible to quantify the precise effect from loosing access to artisanal mining fields. What the data allow is a comparison of the artisanal gold boom and the opening of industrial mines. This opening acts as a bundle treatment, involving the creation of some formal jobs in the industrial mine and the loss of access to some artisanal mining fields.

Each household survey wave provides information on more than 1,300 households living next to an artisanal deposit and more than 170 living next to a producing industrial mine (Appendix Table 8). The final sample for the years of the gold boom (2009 and 2014) includes 3,199 households living only in the artisanal mines' footprint, 387 households living only in the producing industrial mines' footprint and

[22]Treated meaning either living within 10 kilometer of a registered artisanal mine, that is in a dark green area, or living inside or within 5 kilometer of the Birimian greenstone belt, that is in a ligh green area or its close surroundings, accounting for the observation that many deposits lie on the edge of the belt. We can also use no buffer or a 10 kilometers buffer around the Birimian greenstone belt, it yield similar results, but lower correlation coefficients with the presence of registered artisanal mines.

Table 1: Summary statistics

	Mean	se
head age	45	0.1
head is male (%)	89	0.002
rural household (%)	86	0.002
head can read (%)	23	0.003
household size	7	0.03
number of workers in the household	4	0.02
head works in the agricultural sector (%)	84	0.002
head works in the extractive sector (%)	0.01	0.0006
consumption per capita	119,481	823.03
Total number of households in the sample= 30,502		

Note: The mean and its clustered standard error are calculated using sample weights. Consumption is measured in CFA francs. Since January 1999, the CFA franc has had a fixed exchange rate with the euro (656 CFA Francs = 1 euro)

256 households living in the footprint of both mines.

Table 1 presents an overview of the characteristics of the households in our sample. We estimate the means and standard errors using sample weights and clustering by primary sampling unit to account for the sampling design. For a more detailed overview, appendix Table 9 provides descriptive statistics by location of the households (close to and artisanal deposit, an industrial deposit, or no deposit) and period (before or after the gold boom).

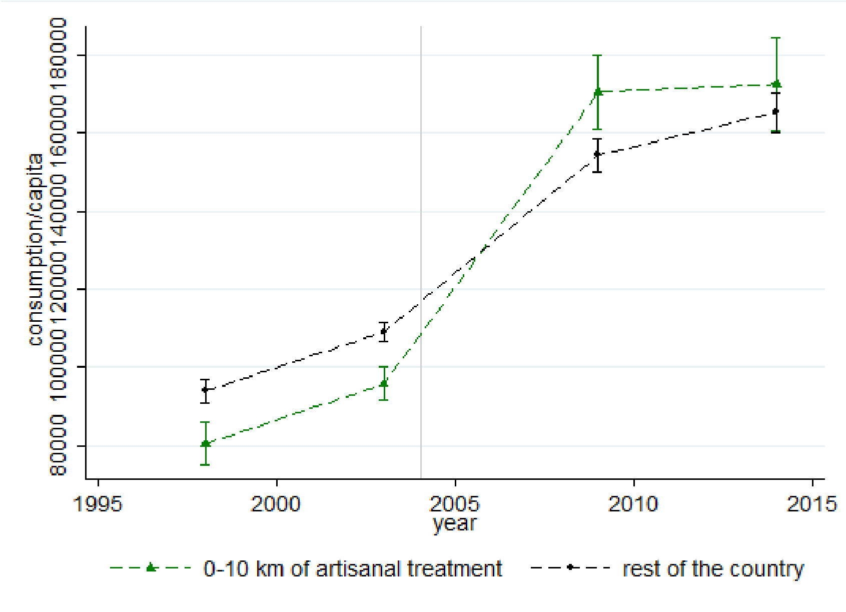
3.2 Identification Strategy

Our aim is to estimate the effect of both gold mining techniques on household living standards. We exploit two sources of variation: temporal (the global gold price boom) and spatial (household distance to gold deposits providing a source of heterogeneous exposure to potential mines). In this subsection, we successively explain how this allows us to identify the effect of artisanal and industrial mines.

We identify the locations of artisanal deposits by using the census of artisanal mines registered at the Ministry of Mines. In our baseline specification, we use a 10-kilometer buffer to distinguish treated and non-treated households. We consider alternative distance definitions in robustness checks. We also use the Birimian belt, a purely geological definition of the spatial treatment.

The boom in the gold price provides a time-varying treatment. The idea is that the gold price is the main driver of the benefit of (artisanal) mining activities since it directly determines the expected gains of the miners (Alvarez et al., 2016). When the gold price increases, it may become profitable for households to switch activities or to increase their labor supply in order to benefit from new earning opportunities. Moreover, even for a fixed supply of work, the money that the gold diggers get for their

Figure 3: The evolution of household consumption before and after the gold price boom



Note: Each point represents the mean level of consumption per capita for households in the specified treatment over each year. The treated group encompasses households living within 10 kilometers of an artisanal deposit. The control group (the rest of the country) excludes the treated areas. The bars around each point represent the 95% confidence intervals.

gold will be a function of the gold price, meaning that they will be able to spend more and generate more local economic activity.

The validity of the empirical strategy relies on the assumption that the evolution of consumption in areas far from and close to these artisanal mines would have been similar in the absence of the increase in gold mining activities. Since the boom in the gold price started in 2004-2006, to be in the ideal setting for a double difference, similar trends should be observed between 1998 and 2003. The next survey wave (2009) already includes the effect of the gold boom. Figure 3 shows the yearly consumption of households located within 10 kilometers of a gold deposit that may be mined artisanally, and of those further away. Figure 3 supports the parallel trend assumption. The level of consumption is significantly lower in areas close to artisanal mining deposits in 1998 and 2003 but trends are parallel. The trends start to diverge only between 2003 and 2009, which is consistent with our hypothesis. The consumption level of households located around artisanal mines catches up with or even overtakes the consumption level of households in the rest of the country after the boom in the gold price.

To estimate the impact of artisanal mines on household consumption more formally, we propose

Equation 1:

$$C_{ivt} = \alpha(\text{gold boom}_t \times \text{artisanal deposit}_v) + \beta\text{artisanal deposit}_v + \gamma' X_{it} + \delta_m + \eta_t + \epsilon_{ivt} \quad (1)$$

C_{ivt} is the log of the per capita consumption for household i living in village v of municipality m at time t. α is our coefficient of interest; it gives the estimated impact of the gold boom on the consumption level of households which live next to a gold mining site. In fact, gold boom$_t$ measures the gold price boom in three alternative ways: through year dummies, or a dummy equal to 1 in 2009 and 2014 (the years when the gold price was high) or the natural logarithm of the gold price. Artisanal deposit$_v$ is a dummy variable taking the value 1 if the household is exposed to an artisanal mine. In our baseline estimate, this dummy takes the value 1 if the household lives within 10 km of an artisanal gold deposit and 0 otherwise. X_{it} is a set of controls. In its full form it includes the age, sex, literacy, sector of occupation and nature of work of the household head, the number of household members and income earner members, a dummy for households in rural areas, and controls for electricity and water supply (mirroring controls in the seminal paper of Aragón and Rud, 2013). We also present results with a minimal set of controls, excluding sector of occupation, nature of work of the household head, income earning members and electricity and water supply, since these might be affected by the mining opportunities. We also include municipality fixed effects δ_m and year fixed effects η_t.[23] ϵ_{ivt} is the error term. Standard errors are clustered to take into account serial correlation at municipality level (Bertrand et al., 2004).

Our identification strategy may lead to two main biases. We acknowledge them both, but argue that those, if any, are attenuation biases.

First, a bias may come from the under-declaration of artisanal mining when using the census of registered artisanal mines. Importantly, if any contamination of the treatment by the control –or of the control by the treatment– occurs because of an inappropriate definition of the deposit areas, this mechanically implies an attenuation bias of our results.[24] In most specifications, we use 10 kilometer buffers around the registered mines, such buffers allow us to take into account the spillovers of illegal mines in the close surrounding of the registered ones. We also consider alternative buffers and check the overlay of registered artisanal mines and the Birimian greenstone belts.

[23]The municipality is the smallest geographic entity for which we can include fixed effects. These fixed effects are fine grained: the country comprises 351 municipalities. Since one municipality encompasses several enumeration areas, we account for the specificity intrinsic to the enumeration areas surrounding artisanal mines through the dummy $deposit_v$.

[24]One may be concerned that there is positive selection in the declaration of mines such that bigger and most productive artisanal mines are the only one registered. Unless the impact of a gold boom goes in opposite directions around big and small artisanal mines such positive selection will leave results either unaffected or downward bias.

Second, our definition of the time treatment is imprecise, and we may consider some places as treated by the gold price, or else in 2009 and 2014 (when our gold boom dummy is equal to one), whereas no mining occured in these places at the time. This possible contamination of the treatment by the control due to our imprecise definition of the time treatment would again mechanically lead to an attenuation bias.

Concerning industrial mines, we also exploit time and spatial variations. As with artisanal mines, the spatial source of variation is the household distance to a major gold deposit, as a source of heterogeneous exposure to a mine (that would open in such deposit). Here, we use a 25-kilometer buffer to define treated households.[25]

The time variation comes from the years when the industrial mines opened. As can be seen in Appendix Table 7, the opening of the industrial mines was staggered, the first one opening in 2007 and the last in 2013. More precisely, four mines opened between the 2003 and 2009 surveys and seven other mines opened between the 2009 and 2014 surveys.[26]

Our identification again relies on the assumption that the effect of a mine declines with distance and that the evolution of consumption in areas far from and close to an industrial mine would have been similar in the absence of the mine. Figure 4 shows consumption trends. There never is a statistically significant difference in samples averages within each year: the levels of consumption of households located within 25 kilometers of an industrial mine or elsewhere in the country are statistically impossible to distinguish during each of the four survey waves. Importantly, we need to keep in mind that for the years 2009 and 2014, consumption in the treated areas of Figure 4 reflects the consequences of two changes. First, the artisanal gold rush taking place also targeted major gold deposits (artisanal and industrial mines target overlapping areas; see Figure 2). And, second, the opening of industrial mines was staggered after 2007, most openings actually taking place between 2009 and 2014 (these openings also reduced the land available for artisanal mines; for precise dates see Appendix Table 7). Figure 4 gives a rough overview which mixes both of the treatments; the regression analysis allows us to disentangle them.

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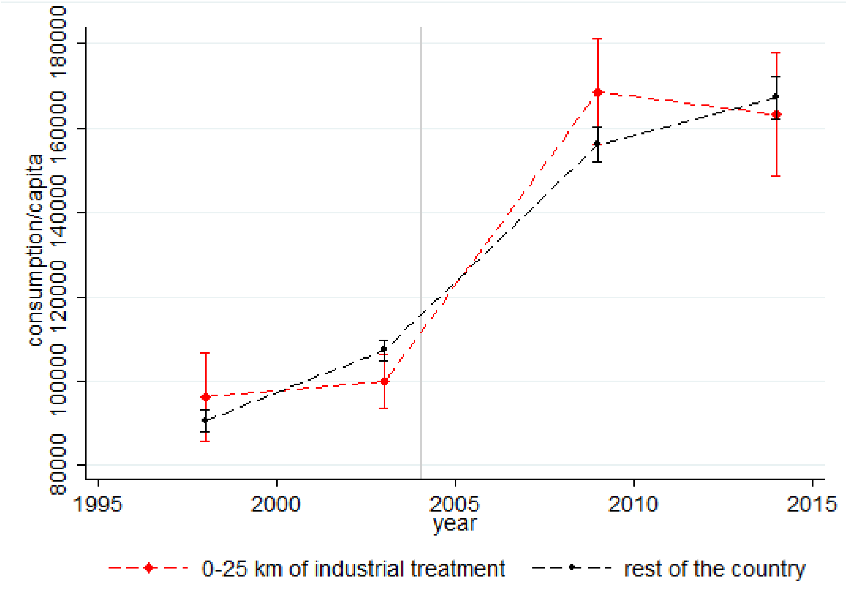
[25] There is no consensus in the literature on the relevant buffer size. von der Goltz and Barnwal (2019) use a 5-km buffer, Aragón and Rud (2013) and Parker et al. (2016) a 20-km buffer in Ghana and DRC respectively, while Aragón and Rud (2016) use a 100-km buffer in Peru. Our baseline definition of buffers implicitly assumes that the demand shock around LSM is likely to be greater than the demand shock around ASM (because LSM are de facto bigger than ASM). We however also show that results are robust to using the same threshold for both types of mines.

[26] In the empirical analysis, we also consider the possible spillovers coming from the construction of these mines. The exploration and construction phases, before actual production starts, are intensive in unskilled labor. We create a dummy equal to one for each industrial deposit in the two years before the corresponding industrial mine starts producing and include this dummy in Equation 2. The choice of two years is based on qualitative interviews with mining company engineers and experts from the BRGM. It typically takes about two years to open a mine. It is also consistent with Benshaul-Tolonen (2019).

Figure 4: The evolution of household consumption before and after the opening of industrial mines



Note: Each point represents the mean level of consumption per capita for households in the specified treatment over each year. The treated group encompasses households living within 25 kilometers of an industrial deposit (four mines opened between the 2003 and 2009 surveys, seven other mines opened between the 2009 and 2014 surveys, and two more were in construction in 2014). The control group (the rest of the country) excludes the treated areas. Bars around each point represent the 95% confidence intervals.

To formally estimate the effect of the opening of an industrial mine, we propose the following Equation:

$$C_{ivt} = \chi(\text{industrial mine}_t \times \text{major deposit}_v) + \lambda \text{major deposit}_v + \gamma' X_{it} + \delta_m + \eta_t + \epsilon_{ivt} \quad (2)$$

Where industrial mine_t is a dummy variable taking the value 1 when a mine is producing, 0 otherwise. χ gives the effect of opening a new mine and we can compare it to λ, which controls for areas with major known gold deposits (major deposit_v) such that $\chi + \lambda$ gives the estimated *net* impact of a new mine on household consumption. In our baseline estimates, major deposit_v is a dummy variable taking the value 1 if the household lives within 25 km of the deposit, 0 otherwise. Other variables are similar to those included in Equation 1 and again we cluster standard errors at the municipality level. The year fixed effects partial out any spillovers that industrial mines would have that are averaged at the national level, for example, through taxes that allow the state to improve the population's general level of well-being.[27]

[27] While industrial mines do contribute to the state revenue, we focus here on the direct impact that industrial mines may have on the populations surrounding them. Resource-induced taxes do not always affect the living standard of the population, even when local authorities report spending of this kind (Caselli and Michaels, 2013), and the state-level consequences of natural resources are the subject of a specific debate (van der Ploeg, 2011; Venables, 2016).

4 Results

4.1 The Effects of Artisanal Mining

Table 2 documents the positive impact of artisanal mining on household consumption. We first consider households living close to registered artisanal mines (columns 1 to 3). Looking at household consumption for each survey wave, we show that households living close to artisanal mines are poorer than the rest of the country in 1998 and 2003 and richer in 2009 and 2014 (column 1). The treated places in 2003 do not differ significantly from the baseline, while the treated places do differ from the baseline in both 2009 and 2014 (the years of the gold price boom). We reject the hypothesis that the sum of the artisanal mine and gold boom coefficients is equal to zero, which means that the net effect of living close to an artisanal gold deposit is positive during the gold boom. The net effect of the gold price boom is an increase in consumption of about 9 percentage points (column 2). Alternatively, using the gold price as a continuous definition of the time treatment, a 1% increase in the gold price increases these households' consumption by 0.12% (column 3).

The concern is that registered artisanal mines do not provide an accurate picture of artisanal gold mining since not every mine is registered and there may be endogeneity in the selection of mines that are registered. The fluid nature of artisanal activity makes it hard to alleviate this concern. We pursue three different approaches in response to this. First, we take advantage of the geological features of Burkina Faso. The Birimian belts are the main gold provider in the country and households living close to the Birimian belts are exposed to both declared and undeclared gold mines. We code all the households living on the Birimian greenstone belt as if they were living close to a gold mine. Since not all of the Birimian belt hosts mining, such coding provides a lower-bound estimate of the impact of artisanal mines. Results based on the Birimian greestone belt definition in columns (4) to (6) are qualitatively similar to those for registered artisanal mines (columns 1 to 3 of Table 2). However, results based on the Birimian greenstone belt are of a lower magnitude than results based on registered mines: the main effect of any illegal mines seems to occur mainly within the 10-kilometer footprint of the registered mines.[28] Thus, in the rest of the paper, we keep declared mines as our baseline definition of artisanal mines.

The two next strategies we pursue in acknowledgment of the imprecise registration of artisanal mines is to vary the size of the buffer that we use to measure the mine footprint, or to define the mine treatment at the municipality level. Results appear in the next section, together with the estimates of industrial

[28]We can also estimate jointly the effect of the registered mines and the Birimian belt treatments. In this case registered mines eat up most of the effect of artisanal mines. Such results (not included) need to be interpreted with caution since the registered artisanal mines and Birimian greenstone belts have a 40% correlation.

Table 2: The effects of artisanal mines on household consumption: baseline estimates

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.: ln pc Cons						
Artisanal mines proxy:	registered atisanal mines			Birimian greenstone belt		
Artisanal deposit	0.0369			0.0359		
× year 2003	(0.0556)			(0.0433)		
Artisanal deposit	0.224**			0.140*		
× year 2009	(0.0929)			(0.0842)		
Artisanal deposit	0.153**			0.124**		
× year 2014	(0.0638)			(0.0609)		
Artisanal deposit		0.163***			0.110*	
× gold boom		(0.0577)			(0.0582)	
Artisanal deposit			0.122***			0.0871**
× ln(gold price)			(0.0427)			(0.0438)
Artisanal deposit	-0.112*	-0.0879*	-0.786***	-0.0710	-0.0491	-0.552*
	(0.0614)	(0.0479)	(0.283)	(0.0531)	(0.0420)	(0.286)
Observations	30,502	30,502	30,502	30,502	30,502	30,502
R-squared	0.380	0.380	0.379	0.379	0.379	0.379

Note: All columns include municipality fixed effects, year fixed effects and minimal household level controls (age, sex, ability to read and the number of household members) and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

mining (see columns 5 to 7 of Table 3 and Figure 5). The results are consistent with the omission of illegal mine leading to an attenuation bias.

4.2 The Effects of Industrial Mining (together with Artisanal Mining)

We now turn to the effect of opening an industrial gold mine. All industrial mines active in 2014 opened in the late 2000s. Before this, many of the areas where industrial mines settled were exploited by artisanal miners, in artisanal and small-scale mines, with unrestricted entry for gold diggers (Côte and Korf, 2018). Industrial mines thus offer an original case of the privatization of a common-pool resource. Any industrial mine opening corresponds to a bundle treatment, with both the opening of the industrial mine and the closing of any artisanal mine that was operating within its boundaries.

Table 3 shows the (absence of) effect of opening industrial mines on consumption. Throughout the table, we control for any specificity of the areas around major gold deposits (prone to the installation of industrial mines) through a dummy variable equal to 1 for households living nearby an industrial gold deposit. The absence of effect of industrial mines holds independently of the set of controls: a minimal set of controls in column (1), or the full set of controls used in Aragón and Rud (2013) in column (2). The absence of effect of industrial mines on household consumption also holds independently of the way in which we account for industrial mines activities: the absence of effect is independent of the size of the industrial mine and we observe no effect when accounting for mine construction (including a dummy

Table 3: The effects of industrial and artisanal mines on household consumption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dep. Var.: ln pc Cons.							
Definition of buffers:	baseline				10km	25km	municipality
Artisanal deposit			0.162***	0.178***	0.180***	0.177***	0.153***
× gold boom			(0.0572)	(0.0563)	(0.0570)	-0.0567	-0.0502
Artisanal deposit			-0.0904*	-0.0978**	-0.0968**	-0.115**	
			(0.0477)	(0.0446)	(0.0450)	-0.051	
Industrial deposit	-0.0899	-0.0621	-0.0871	-0.0588	-0.134	-0.0762	-0.0504
× active mine	(0.0722)	(0.0700)	(0.0738)	(0.0717)	-0.0816	(0.0650)	-0.0566
Industrial deposit	0.157***	0.132**	0.152**	0.128*	0.214***	0.132**	
	(0.0570)	(0.0629)	(0.0595)	(0.0675)	-0.0721	(0.0616)	
Observations	30,502	30,502	30,502	30,502	30,502	30,502	30,502
R-squared	0.379	0.416	0.380	0.418	0.418	0.419	0.418
Controls	minimal	full	minimal	full	full	full	full

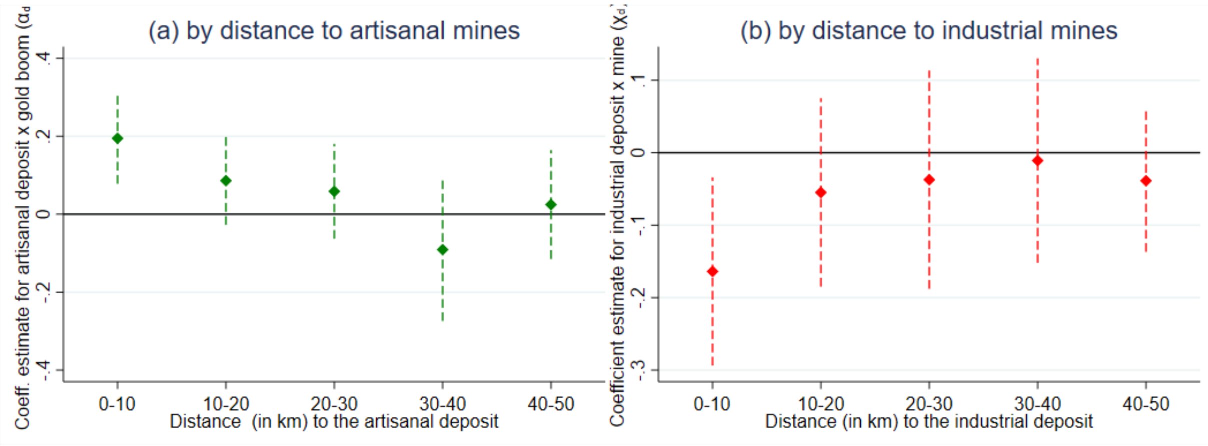
Note: The baseline buffer sizes are 10 kilometers for artisanal deposits and 25 kilometers for industrial deposits. All columns include municipality fixed effects, year fixed effects and household-level controls (minimal: age, sex, ability to read and the number of household members. Full adds: the sector of occupation and nature of work of the head of the household, the number of adult members, the electricity connection and main source of drinking water of the household) and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

equal to one for households living within 25 kilometers of an industrial mine that started production within two years), or when using an interaction term between the industrial mining and the gold price (Appendix Table 10).

Significantly for the existing literature on the local impact of industrial mines, we also show that the coefficient of industrial mines remains stable when we introduce a control for artisanal mines (comparison of the coefficient between columns 1 and 3, or betwen columns 2 and 4, of Table 3). The data does not report the exact boundary (fences) of the industrial mines, making it impossible to test the precise effect of losing access to artisanal mining fields (as shown in Appendix Figure 9 for the mine of Kalsaka). What the data allow is a comparison of the effect of (1) the artisanal gold boom and (2) the opening of industrial mines. Our preferred specification, to account for both type of mining and allow a comparison of the two, considers (1) registered artisanal deposits multiplied by a dummy for the gold price boom and (2) a dummy for active industrial mines (results are qualitatively similar if we use the gold price to measure artisanal mining activities, not included).

We then show that the results do not critically depend on the size of the buffers around industrial and artisanal mines. The use of different buffer sizes for artisanal and industrial mine may be subject to debate. Table 3 shows that the results remain consistent if we consider similar buffers for all activities, be they 10 or 25 kilometers buffers (columns 5 and 6). The last strategy that we pursue is to define the treatment at the municipality level, considering that an entire municipality is treated by artisanal mines

Figure 5: Impact of each type of mines on consumption, by distance



Note: Each point represents the coefficient estimate for the treatment (artisanal or industrial) for households living at a given distance from the mine. Bars around each point represent the 90% confidence intervals. For panel (a) we estimate all the coefficients from a the modified version of Equation 1 though: $C_{ivt} = \sum_d [\alpha^d(\text{gold boom}_t \times \text{artisanal deposit}_v^d) + \beta^d \text{artisanal deposit}_v^d] + \chi(\text{industrial mine}_t \times \text{major deposit}_v) + \lambda \text{major deposit}_v + \gamma' X_{it} + \delta_m + \eta_t + \epsilon_{ivt}$, where d indicates the distance between the household and the closest mine, considering 10 kilometers intervals for households living between 0 and 50 kilometers from the closest mine. Gold boom is a dummy equal to one for the years 2009 and 2014. We similarly transpose Equation 2 to estimate the coefficients in panel (b) for each of the five ranges of distances, while controlling for the presence of artisanal mines.

as soon as it hosts at least one artisanal mine (and similarly for industrial mines). In this case the main effects of the artisanal and industrial deposits are absorbed in the municipality fixed effects. The results remain unchanged (Table 3 column 7).

To test the relevance of the spatial dimension of our identification strategy, we then show the estimated coefficients of mine activities for different ranges of distance. Figure 5 panel (a) shows that the positive effect of artisanal mines on household consumption decreases with distance to the mine, consistent with our identification strategy. The effect remains positive although the two corresponding coefficients lose significance for households living within more than 10 but less 20 and more than 20 but less than 30 kilometers of an artisanal mine. It may be the case that either unregistered mines are concentrated around registered mines, or that the footprint of each registered mine extends beyond 10 kilometers. As for industrial mines, the coefficient is never significantly different from zero except for households within 10 kilometers of an industrial deposit. We note that for these households the effect, if any, is negative (p-value at 0.12, consistent with a loss for households nearby industrial mines but the sample size of 49 households makes us cautious about interpreting this effect).

Last, the results are robust and remain remarkably stable under different checks. We have focused at first on variations in the definition of the treatment (Tables 2 and 3 and Figure 5). We may however be concerned that the impact of mining in a rural area is fundamentally different from mining in an urban area. Appendix Table 11 shows that the effects of artisanal mining are qualitatively similar in both areas, although slightly greater in urban areas (columns 1 and 2). Urban areas are, if anything, losing if an industrial mine opens but few households live in an urban area that is within 25 kilometers of an industrial mine (we observed only 90 such treated households in 2014). We are also uncertain that we used the appropriate control group. We checked that the results held independently of sample variations aimed at making the treatment and control groups more comparable: reducing the sample either to households living within 50 kilometers of an artisanal mine, or households not living within 25 kilometers of an industrial mine, or including the capital city of Ouagadougou (Appendix Table 11 columns 3 to 5). Since the survey questionnaire slightly changed over time, we also checked that no particular survey had driven the results (Appendix Table 11, columns 6 to 9). Finally, since Burkina Faso has a different climate in different parts of the country, we checked that results were robust to omitting each of the 13 regions one by one (Appendix Table 11). Alternatively, we checked that the results held when including region-specific trends or region-year fixed effects (Appendix Table 11, columns 10 and 11).

Overall, we conclude that as of 2014, the artisanal gold boom led to an increase in local living standards, while the opening of industrial mines led to no such increase. The comparison of effects for each mining technique in Table 3 allows to underline the importance of the link to the local economy. These shed a first nation-wide light on the local economic impact of artisanal mines. These results also allow us to qualify some existing results on industrial mines. Focusing, in particular, on the extension of existing industrial gold mines, Aragón and Rud (2013, 2016) document positive effects through local linkages on income in Peru and negative effects through pollution on agricultural productivity in Ghana. In a country with little production of intermediary goods (unlike Peru) and before the mine extension leads to major use of chemicals (unlike Ghana), the effect of a mine opening appears to be zero. Last, our results are also aligned with the literature which points to commons as beneficial for local labor, or even for the whole local population, despite their lower productivity. Privatization is presented as efficiency enhancing. Nevertheless, this efficiency may come at a distributional cost such that the net gain is not granted, to local labor in particular (Weitzman, 1974; Baland and Francois, 2005).

Industrial mines may have other benefits, which may appear in the longer run, in other places, or at a more macro level (such an impact is the subject of a wide literature and debates reviewed in van der Ploeg, 2011; Venables, 2016). In particular, industrial mines do contribute much more to the state budget than artisanal mines do. In the case of Burkina Faso, the extractive sector contributes to $286.545 millions to the state budget in 2015 (ITIE, 2015).[29] Moreover, industrial mines may create job opportunities elsewhere in the country (industrial mines in the country employed a total of 6,464 people in 2014 ITIE, 2016). Our results however shed light on a reason why the arrival of a new industrial mine may locally trigger discontent (the social unrest roughly doubles after industrial mining starts in Africa according to Christensen, 2019).

4.3 Extension: Effects on Health and Education

While the main focus of this article is on consumption patterns, it may be interesting to investigate the impact of artisanal and industrial mines on the two other main dimensions of human development, namely health and education. Artisanal mining has a bad reputation in both these dimensions, while scholars have documented ambiguous effects from industrial mines (Ahlerup et al., 2017; Aragón and Rud, 2016; Corno and de Walque, 2012; Hilson, 2006; Benshaul-Tolonen, 2019; Romero and Saavedra, 2016; von der Goltz and Barnwal, 2019). We are not equipped to investigate these aspects in detail – they would each deserve a dedicated study and specialized data – but we can present some basic results.

The expected health effect of extractive activities is ambiguous. If the artisanal gold boom has positive effects on income, it should increase the ability of households to take care of their health.[30] However, artisanal mines also have notoriously bad working conditions and use polluting substances such as mercury, which have a negative effect on health. In parallel, industrial gold mines may provide health infrastructures as part of their corporate social responsibility investments and thus may improve the health of households in their surroundings without increasing households' own health spending. These mines however may also pollute (with consequences on local health, Aragón and Rud, 2016).

In Appendix Table 13 columns (1) to (3), we investigate the evolution of the probability of falling sick for households living next to artisanal and industrial gold mines.[31] Overall, we document no deterioration of health during the mining boom. If anything the health of 6-to-16-years-old children during the artisanal gold boom improves (column 2), consistent with the income effect dominating the pollution effect at least in the short run. However, after multiple testing adjustment, the p-value is outside the threshold for significance at the 10% level (Holm, 1979; Newson, 2003).[32] Industrial gold mines do not

[29] But only 0.4% are transferred to local authorities (ITIE, 2015).

[30] Symmetrically, Parker et al. (2016) show that a *reduction* of mining activities (following economic sanctions) increases mortality rates by reducing the consumption of health care goods in DRC.

[31] One health proxy is consistently recorded throughout our survey data through the question "Have you been sick or injured in the last 15 days?".

[32] The p-value is at 0.036 for a requirement below 0.033 if we adjust multiple testing for the three tests on education. The requirement is below 0.017 if we adjust for all three tests on health and on education together.

appear to significantly affect the health outcome of populations in their surroundings.

Finally, we investigate the possible effects on education. Once again, expected results are ambiguous. The increase in job opportunities would reduce the incentive to attend school around artisanal mines and increase it around industrial mines (Ahlerup et al., 2017; Ebeke et al., 2015; Santos, 2018). The income effect would increase school enrollment around artisanal mines.

In Appendix Table 13 columns (4) to (6), we document the effect of mining activities on the probability of being at school for different age samples. We observe no significant effect of the artisanal boom for any age group. We also do not find any effect from opening an industrial mine. While corporate responsibility investment may increase health or educational amenities, such improvement had not yet impacted, as of 2014, households significantly.

5 Discussion

After showing that artisanal mining has a positive effect on consumption while industrial mines do not, it seemed interesting to uncover where this effect comes from. In the literature on the local multiplier, the additional income coming from extractive activities would lead to a local demand shock which would benefit other groups (for example, groups providing inputs or services to gold diggers, see Werthmann, 2017). In the literature on common-pool resources, the main effect comes from direct access to the resource. Households which allocate time to gold extraction might increase their income, which would have an effect on the local economic conditions.

In this section, we document the likelihood of different channels through which the effect of artisanal mines might be transmitted to the labor force as well as through migration. We also investigate whether extractive activities appear to have persistent effects on local prices.

5.1 Labor Market Effects and Seasonality

Gold extraction offers local workers new earning opportunities, which could trigger either an increase in employment, or a reallocation of the labor force in favor of working in the extractive sector or providing inputs for this sector (Aragón and Rud, 2013; Kotsadam and Tolonen, 2016; Aragón et al., 2018). However, Table 4 contradicts both intuitions. Column (1) shows that the probability of having a job is independent of both kinds of mining. In column (2), we estimate the probability of having a permanent job and still find no effect. Finally, we document no effect of artisanal mining activities on the probability

Table 4: Labor market effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Probability that the head works in					
Dep. Var.:	any work	permanent position	agriculture	extractive	services	trade	public service	health education
Artisanal deposit	0.00608	0.0286	-0.0217	0.00829	0.00638	0.00969	0.00237	-0.00786
× gold boom	(0.00913)	(0.0473)	(0.0237)	(0.00694)	(0.00757)	(0.0103)	(0.00467)	(0.00662)
Artisanal deposit	0.0150*	-0.0439	0.0342	-0.00921	-0.00519	-0.0178	-0.000928	0.00843
	(0.00896)	(0.0357)	(0.0248)	(0.00717)	(0.00738)	(0.0114)	(0.00435)	(0.00665)
Industrial deposit	0.0147	-0.0377	0.0602	-0.0170	-0.0144**	-0.0156	-0.00106	0.0107*
× active mines	(0.0165)	(0.0647)	(0.0546)	(0.0300)	(0.00727)	(0.0113)	(0.00291)	(0.00568)
Industrial deposit	0.0140	0.0307	-0.0706	0.0509	0.0121	0.0205	0.00163	-0.00545
	(0.0140)	(0.0468)	(0.0847)	(0.0514)	(0.0107)	(0.0151)	(0.00325)	(0.00402)
Observations	30,653	21,838	30,727	30,727	30,727	30,727	30,727	30,727
R-squared	0.125	0.427	0.341	0.081	0.119	0.135	0.070	0.085
mean dep. var.	0.914	0.446	0.731	0.00638	0.0514	0.0630	0.0169	0.0267

Note: All columns include municipality fixed effects, year fixed effects and household level controls (age, sex, ability to read, the number of household members and adult members, the electricity connection and main source of drinking water of the household) and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

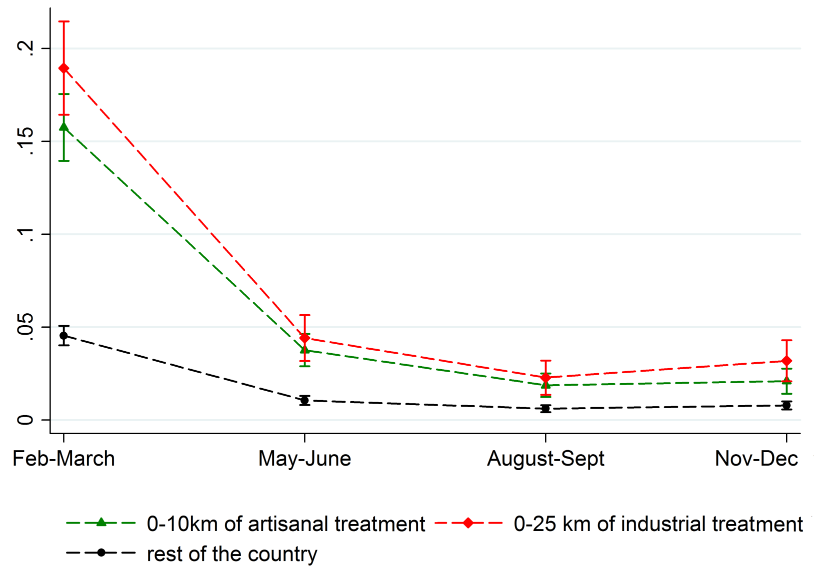
of working in one or another sector.[33] Thus, the effect of mining on consumption is not likely to come from a direct massive increase in job opportunities in artisanal mines. At the same time, the opening of an industrial mine seems to lead to a small reallocation of workers from the service to the health and education sector (columns 5 and 8, however the p-values do not pass a multiple testing adjustment).[34] The absence of a labor re-allocation in favor of the extractive sector may seem puzzling in a country hosting gold and during a period where the gold price was multiplied by four.

The exceptional features of the 2014 survey allow us to show that the apparently puzzling (absence of) results in Table 4 is actually a matter of survey timing. The 2014 survey is exceptional in that it is quarterly: we are thus able to check whether people work in the extractive sector at different times of the year. Figure 6 shows that the share of workers in the extractive sector is in fact highly seasonal. Extractive activities are defined to encompass all forms of extraction, be they industrial or artisanal. Given that artisanal and industrial activities overlap spatially and given the formal nature of employment in industrial mines, we interpret the seasonality of extractive activities within 25 kilometers of industrial

[33]We have a consistent record of a 1 digit level definition of sectors of activities. Most sector titles are self explanatory. The extractive sector encompasses people working in both the artisanal and the industrial mines. The service sector encompasses activities related to finance, cleaning, the fabrication or transportation of water or electricity, or construction. The trade sector encompasses activities related explicitly to trade as well as the housing market.

[34]Column (8) results are consistent with the significant corporate social responsibility programs implemented by the industrial mines. Column (8) results could also be consistent with part of the taxes levied on industrial mines benefiting their home localities. However, the latter interpretation is not consistent with the absence of increase in the number of civil servants in the locality (column 7). Replicating the same exercise on female alone to investigate the gender-specific effects that Kotsadam and Tolonen (2016) point at, we do not observe a significant impact of artisanal mining on female labor force participation. The opening of an industrial mine on the other hand decreases female labor force participation by 6% and their probability of working in the extractive sector by 2% (results not included).

Figure 6: Share of workers in the extractive sector in the successive quarters of 2014



Each point represents the share of active household heads who are involved in the extractive sector for each period and location. The extractive sector encompasses all forms of extraction, whether artisanal or industrial. The treated groups are defined spatially and encompass households living either within 10 kilometers of an artisanal deposit, or within 25 kilometers of a deposit that would host an industrial gold mine by 2014. The control group (the rest of the country) excludes the treated areas. Bars around each point represent the 95% confidence intervals.

deposits as driven by the timing of artisanal mining. Figure 6 also shows that the seasonality of extractive activities affects households everywhere in the country although the effect is higher when they are close to gold deposits. Extractive activities take place mainly in the first quarter of the year. Since households in the 1998 to 2009 surveys were approached during the second or third quarters, when most people had already left the extractive sector to go back to their usual activities, it is easy to understand why no impact of the gold rush on the labor market can be observed Table 4.[35]

The seasonality of extractive activities has at least two causes. First, artisanal mining takes place when there is nothing to do in the fields (Jaques et al., 2005). In most of the country, the rainy season, marking the beginning of the seeding period, starts in May.[36] Second, because the peak of the rainy

[35]The 1998 and 2003 surveys were held around the second quarter, while the 2009 survey took place around the third quarter. For consistency, all the results presented for the years 1998-2014 in this article rely on data for the second quarter of 2014. The results are robust to using the third quarter of 2014 (not included). We do not know where gold diggers practice their activity, other than they appear to strongly cluster around gold deposits. Yearlong gold diggers are much less numerous, and may either bypass the government ban by staying in Burkina Faso or migrate to neighboring countries. To have an idea of the magnitude of the phenomenon, according to the 2014 survey, extractive activities were the main source of activity for 640,800 individuals in February-March; 159,300 individuals in May-June, and 37,200 individuals in August-September. These numbers are important given that the total population of Burkina Faso was 17.6 million in 2014, 3.3 million of whom lived within 10 kilometers of an artisanal deposit.

[36]Out of the 65 locations for which records are available throughout the 13 regions of the country, 22% have 40mm of rain or more in April, 66% in May, and 22% in June (https://fr.climate-data.org/country/14/). In particular, the entire Sahel region is the one where the rainy season starts only in June. However, this inter-region variation during the rainy season does not seem

season puts artisanal mines in danger of collapsing, the government forbids artisanal activities between June and October (there is evidence that the ban is not always followed, but it clearly reduces the extent of the activity, Compaoré, 2011). In either case, one important implication of Figure 6 is that mining does not appear to lead many individuals to permanently abandon other activities, such as agriculture. Rather, mining appears to be a seasonal complement to pre-existing activities. Moreover, mining is mainly practiced by households who live close to artisanal mines: Appendix Figure 11 shows that the probability of working in the extractive sector decreases quickly with the distance to a mine, even when we focus on the answers to the February-March survey of 2014 (at the peak of the extractive activity).

Since we document the economic spillovers of artisanal mining outside the mining season, we implicitly assume that households are able to somehow smooth consumption in the course of the year. Life-cycle smoothing may be difficult in the context of Burkina Faso, but the existence of within year smoothing is consistent with the literature on savings in developing countries. For example, Deaton (1989) suggests that savings take the form of small assets, while in Dupas et al. (2018) an extreme 97% of households surveyed in Uganda reported storing money either at home or in a "secret place". If households cannot perfectly smooth consumption, it means we would find greater effects if we were able to perform the entire study in February-March, when artisanal mining income is being earned (consistent with a downward bias in results).

Finally, we document how the artisanal and industrial gold booms affect the consumption of households in certain sectors of activity, while leaving others unaffected. Table 5 displays the results of estimating Equation 1 over different sub-samples defined by the sector that the household head works in: agriculture, extractive industries, services, trade, public service or health and education. The artisanal gold boom appears to lead to a 54% increase in consumption of the households whose head works in the service sector (column 3) but has no effect on the consumption of households whose head works in the health and education sectors (column 6).

Households affected the most by the artisanal gold boom are those able to either diversify their income by engaging in gold digging part-time, or to answer the demand shock created by the gold boom (meeting gold diggers' demand for goods and services). These households are those where the head works in agriculture, trade, or services (columns 1, 3 and 4 of Table 5).[37] The magnitude of the effect is particularly high for households in trade and services (columns 3 and 4). Coefficients are however

to drive our results: omitting each region in a row leaves our results unchanged as shown in Appendix Table 12.

[37] We obtain overall similar effects if we split the sample according to households having at least one member working in one or another sector (meaning that some households then appear in several columns). The only difference in the later case is that industrial mines stop having any effect on anyone except a reduction of consumption by public servants (table not included).

Table 5: Heterogeneous effect according to the sector of occupation

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Var.: ln pc Cons.						
Sample: hh head works in	agriculture	extractive	services	trade	public service	health education
Artisanal deposit	0.146***	-0.479	0.540***	0.331*	-0.115	0.0217
× gold boom	(0.0521)	(0.650)	(0.150)	(0.189)	(0.0843)	(0.160)
Artisanal deposit	-0.0697	1.064	-0.0302	-0.277	0.731***	0.211
	(0.0446)	(0.703)	(0.197)	(0.184)	(0.0989)	(0.144)
Industrial deposit	-0.0688	0.844**	-0.494***	-0.261	-0.0108	-0.100
× active mines	(0.0811)	(0.320)	(0.151)	(0.169)	(0.196)	(0.102)
Industrial deposit	0.131*	1.162**	-0.121	0.270*	0.636**	0.324
	(0.0712)	(0.471)	(0.181)	(0.146)	(0.309)	(0.299)
Observations	22,406	198	1,611	1,963	522	831
R-squared	0.360	0.786	0.508	0.477	0.667	0.654
mean dep. var.	11.33	12.02	11.97	11.93	12.42	12.36

Note: All columns include municipality fixed effects, year fixed effects and household-level controls (age, sex, ability to read, the sector of occupation and nature of work of the household's head, the number of household members and adult members, the electricity connection and main source of drinking water of the household) and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

imprecise and we cannot rule out the equality of coefficients across some of the columns. Focusing on the main beneficiaries, what we can conclude is that the gold boom coefficient estimated on the sample of household heads active in the service sector is significantly different from the coefficient estimated in all other columns except column 4 (household heads active in trade, the second main beneficiary according to our table and consistent with qualitative evidence, Cros and Mégret, 2010). The effect of the artisanal gold boom on households in both the agricultural and service sectors is significant also after adjusting for multiple testing (requiring a p-value below 0.02, Holm, 1979; Newson, 2003).

Public servants offer the perfect counter-factual (Table 5, column 5). They have full-time formal jobs with better pay than the average, hence neither the time nor the need to go gold digging. Moreover, their pay is fixed by the state. Hence, it makes sense that their consumption level should not change with the gold price, no matter how close they live to an artisanal or industrial mine. People employed in health and education are a mix of public servants and employees in a variety of institutions that may be private (column 6).

Last, households related to the extractive sector do not benefit from the artisanal mining boom, they benefit only from the industrial mining boom (column 2). Given the timing of the surveys, these are households whose head practices an extractive activity outside the main period of artisanal mining. Thus column (2) covers two groups. First, the sample covers the employees of industrial mines, who are in the same situation as public servants: they have full-time formal jobs and their pay is unrelated to the artisanal boom. Second, the sample covers some year-long gold diggers, in which case it means that gold diggers do not receive a significant share of the increase in benefits induced by the artisanal gold boom, (which rather go to intermediaries and local traders, consistent with the results in columns (3) and (4) and qualitative observations in Côte and Korf, 2018). The positive impact of industrial mines opening in column (2) is consistent with the fact that the likelihood of the first explanation increases with the opening of an industrial mines and workers in industrial mines earn on average more than gold diggers.

We may finally note that households whose head is active in the service and trade sectors are both the main beneficiaries of the artisanal mining boom and the main losers when an industrial mine opens (columns 3 and 4). These results would be consistent with a decrease in the artisanal activity following the privatization of the area by the settlement of an industrial mine, translating into reduced benefits for artisanal miners' providers. However, our sample does not allow us to formally test this interpretation.

5.2 Are the Effects Driven by Migration?

A possibility remains that the gold boom induced migration (Fafchamps et al., 2017). If migrants are positively selected, the increase in average consumption around artisanal mines would not be the result of an income increase as such, but the effect of a population change. A population change may be good news, but corresponds to another channel than an actual increase in economic activity. The data do not allow us to directly study migration patterns. However, several observations are inconsistent with a selection of permanent migrants being the main driver of the consumption results, these results rather hint at seasonal migration.

First, it is important to keep in mind that artisanal mining is a seasonal activity (as seen in Figure 6). Although some artisanal gold mines may attract hundreds, even thousands of gold diggers, non permanent gold diggers are not surveyed as households belonging to the area of the artisanal mine. In fact, a person is considered to be a resident of an area only if she spent at least six months there. This means that all gold diggers who are seasonal migrants will be counted as members of their families of origin. Any money sent by these seasonal migrants to their family will increase the family's consumption, creating another source of attenuation bias of our estimates (since some families that we consider as untreated may actually benefit from the gold boom thanks to the remittances of the seasonal migrants from Appendix Figure 11). In other words, we show a positive impact on consumption by resident households and this consumption effect persists after the return of short-term migrant.

Second, migrating to settle in agriculture is unlikely and households working in agriculture benefit from the artisanal mining boom in their locality (Table 5). Such a benefit may come from answering the local demand shock induced by diggers, or income diversification within the year (becoming part time diggers).

Third, the evolution of the number of permanent resident households appears to have been similar around artisanal and industrial mines and in the rest of the country. Indeed, since our dataset is a repeated cross section, the statistical agency drew a new sample of households for each survey round and it provides weights that should ensure that the sample is representative nationally. Burkina Faso conducted a new Census in 2006, just between our pre-treatment and post-treatment periods. Appendix Figure 10 provides suggestive evidence that the artisanal gold rush did not induce any significant inflow of population.

Last, we can go further and show that not only the absolute number of resident households, but also the characteristics of these households, were not affected by the artisanal gold boom. By doing so we aim to check whether selective migration took place, or whether migration within the extended family increases, inducing a change in local population that is independent of the number of households. The gold boom does not affect the size of households, their sex or age composition, or level of education (columns 1 to 7 of Appendix Table 14). Such persistence of household characteristics in the face of the mining boom is inconsistent with a self-selection of specific individuals into migration to mining places.

5.3 Are there changes in the Price Structure.

Another challenge is assessing whether the mining boom affects local prices. Indeed, all consumption estimates rest on nominal consumption figures. Importantly, all data come from outside the mining season. Hence, we document the positive consumption effect of artisanal mines outside the main mining season. One may still be concerned that the local demand shock induced by the gold boom may persistently affect local prices, leading to a persistent increase in nominal consumption that may not reflect the real consumption level. We are unfortunately not able to compute price indexes in all the surveys. However, several observations are consistent with a real impact of the artisanal gold boom on consumption rather than a purely nominal impact.

First, three sets of existing results are consistent with an increase in households consumption in real terms. We indeed control for any region-specific inflation when we include regional trends or fixed effects at the region $\times$ year level and the result remains stable (Appendix Table 11 column 10 and 11).

We also document a potential amelioration in health during the artisanal gold boom (for 6-16 year-old individuals) which is consistent with a positive (real) income effect (Appendix Table 13 column 2).

Moreover, the heterogeneity of the impact of the artisanal gold boom according to households' ac-

Table 6: Effects of mines on proxies of price levels

Dep. Var. :	(1) share food	(2) ln(minimum income)	(3) ln(rent)	(4) food issue
Artisanal deposit	0.0152	-0.0120	0.0596	-0.0143
× gold boom	(0.0136)	(0.0681)	(0.118)	(0.0279)
Artisanal deposit	-0.0189*	0.0620	-0.0503	-0.00939
	(0.00996)	(0.0524)	(0.124)	(0.0255)
Industrial deposit	-0.00701	-0.126	-0.173	-0.0307
× active mines	(0.0164)	(0.116)	(0.254)	(0.0360)
Industrial deposit	0.0292**	0.0473	0.0526	-0.0486
	(0.0122)	(0.0744)	(0.153)	(0.0405)
Observations	30,726	23,725	30,198	38,066
R-squared	0.380	0.306	0.568	0.194

Note: share food is the share of consumption spending dedicated to food. Ln(minimum income) is the log of the answer to the question "What is the minimum income level you would need to fulfill your basic needs?" asked in the 2005, 2007 and 2014 surveys. ln(rent) is the log of the estimation by households of the renting value of their living place as recorded in the 1998, 2003, 2009 and 2014 surveys. Food issue is a dummy taking the value 1 if the household answered yes to the question "Did you face difficulties to fulfill food household needs during the last year" and recorded in the 2003, 2005, 2007, 2009 and 2014 surveys. All columns include municipality fixed effects, year fixed effects and household level controls (age, sex, ability to read, the number of household members and adult members, the electricity connection and main source of drinking water of the household) and a control for urban areas. Column 1 controls the log of total consumption per capita. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

tivities is inconsistent with the idea that local price inflation is driving our results. If the impact of the artisanal gold boom were circulating through local prices rather than through a change in real consumption, we would observe a similar impact on everyone, from the public servants to the service providers, since everyone faces similar prices. Instead, the artisanal gold boom has heterogeneous effects, according to households' sector of occupation. The main winners are households which are able to either directly or indirectly participate in gold digging activities (Table 5), consistent with an increase in the real consumption of these households.

Second, we can show that the share of food spending in total consumption is unrelated to artisanal extractive activities. The share of total consumption spent on food is a good indicator of price levels (used to compute both cross-country and within-country price deflators, Almås, 2012; Almås et al., 2019). The share of food spending is likely to be particularly sensitive to prices when the population is closer to subsistence consumption. In Burkina Faso, according to the World Bank, 44% of the population lived on less than 1.90 dollars per day in 2014 (2011 PPP). With such a poverty rate, if prices were increasing, many households would need to re-allocate their spending to ensure a minimum food intake.

Table 6 column (1) shows that the shares of spending on food by households living around artisanal mines and in the rest of the country are statistically impossible to distinguish, either during the artisanal gold rush or outside the rush. Such an observation is inconsistent with a surge in local prices around artisanal mines.

Last, Table 6 shows additional evidence inconsistent with a surge in local prices during the artisanal boom. In column (2), we report how much income households think they would need to meet their basic needs. If there had been a boom in local prices following the gold boom, households would be expected to report that they needed a higher income, but they made no such report. In the third column, we calculate the impact on rents.[38] We find no impact of artisanal or industrial mines activities. In the last column, we investigate whether households faced difficulties to fulfill their needs in terms of food during the gold boom. The result is not significant. We should note that the share of households stating that they had difficulties dropped sharply between 2003 and 2009 (when more than 60% of households said they had difficulties) and 2014 (when there were 30%). Overall, none of the results of this section are consistent with a surge of prices during the artisanal mining boom.

6 Conclusion

More than a hundred million people globally depend on artisanal mines for a livelihood and the competition for land between artisanal and industrial mines leads to local conflicts (World Bank, 2009; artisanalmining.org, na). This paper provides the first nation-wide analysis of the impact of artisanal *versus* industrial extraction of a natural resource on local living standards.

Overall, we estimate that the boom in the gold price increased consumption by about 15% for people living near artisanal mines. This additional consumption is economically significant. In comparison, despite the amount of money transiting through private industrial gold mines (and claims that they trigger job creation), their opening does not affect local households' consumption. These results are robust to a battery of checks, including changes in the definition of the treatment, the set of controls, and the size of the treatment and control groups.

Our results add novel evidence to the literature on the local impact of extractive activities in three dimensions. This is the first paper to empirically assess the impact of artisanal mining on households' living standards with nationally representative data, thereby reducing the knowledge-gap on artisanal mines and qualifying the general perception that artisanal mines are a plague. Second, we show that the local spillover effects of industrial mines are not granted. Third, we document that omitting artisanal mines from the picture (as virtually all economists do when assessing the local impact of industrial mines) does

[38]We interpret column 3 results keeping in mind that 85% households own their house, but still include it here since homes are the least tradeable good.

not affect our estimates for industrial mines: in our sample, independently of the specification, opening an industrial gold mine does not affect local consumption.

Moreover, our results provide empirical evidence aligned with the theoretical prediction that although efficient, privatization may be obtained at a distributional cost, making local labor worse off (Weitzman, 1974; Baland and Francois, 2005). We however also note that industrial mines contribute more to the state revenues than artisanal mines do (15% and 5% of the value of their respective production in 2014) and may directly affect living standards elsewhere in the country or abroad (for capital and firms' owners, or even urban households if they benefit more from the increase in tax revenues). Thus, the competition for land here translates into a trade-off between consumption of local workers *versus* tax revenues for the State and non-local consumption.

The distinctive features and benefits of artisanal and industrial mines match cases of the worldwide competition for land, for example between traditional and modern agriculture or forests and oil fields. The reflection that there may be a trade-off between local labor consumption and state revenues may help to understand or prevent violent protests by local communities when they see the land around them move into different hands. Such understanding may help to avoid the serious waste of resources, such as the millions of euros that vanished in flames in the construction site of the industrial mine of Karma.

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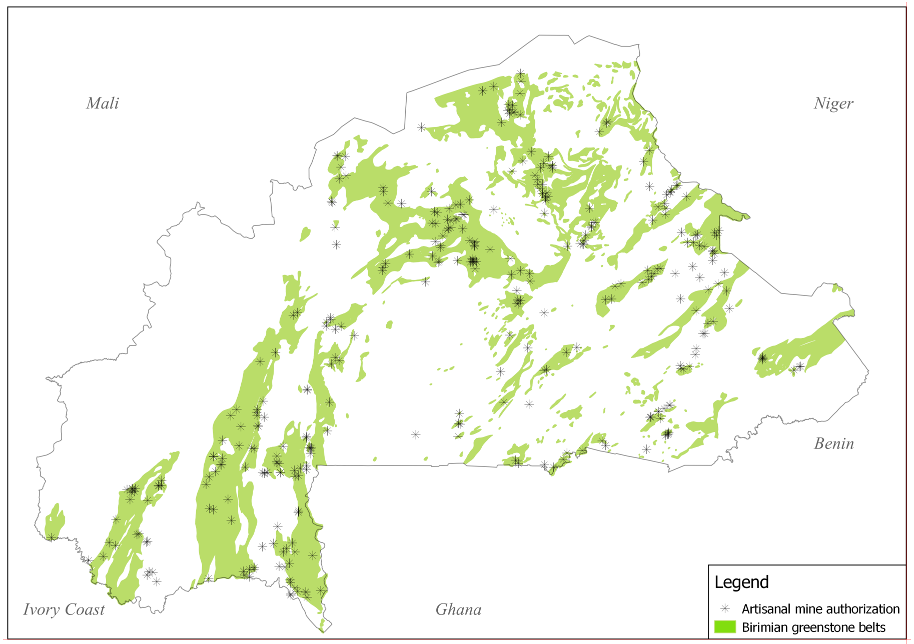
7 ONLINE APPENDIX, NOT FOR PUBLICATION

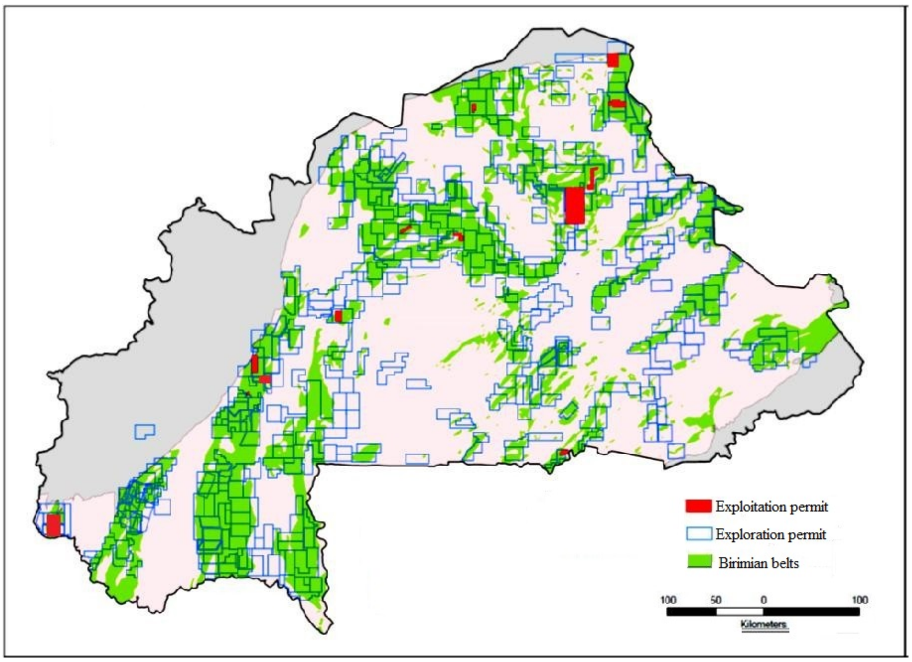
7.1 Appendix Figures

Figure 7: The overlap of Birimian greenstone belts and artisanal extraction permits



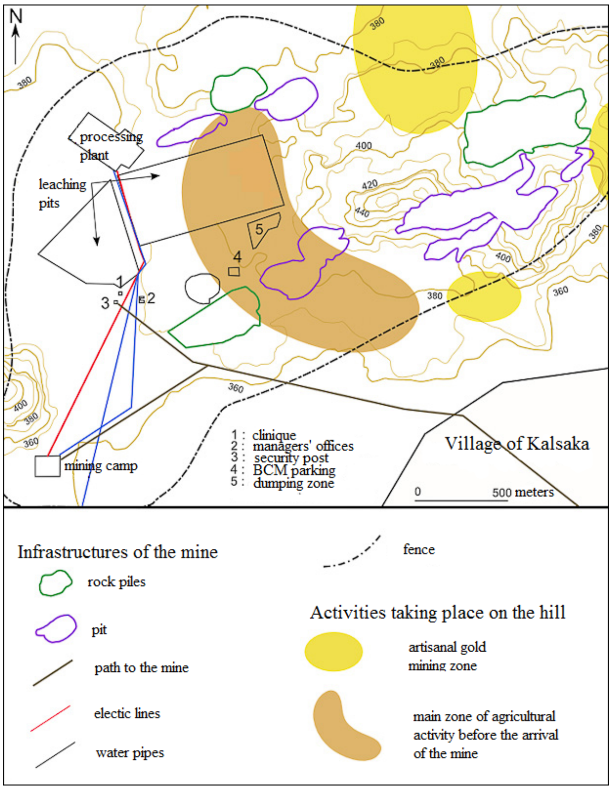
Note: authors' calculations

Figure 8: The overlap of Birimian greenstone belts and industrial exploration permits



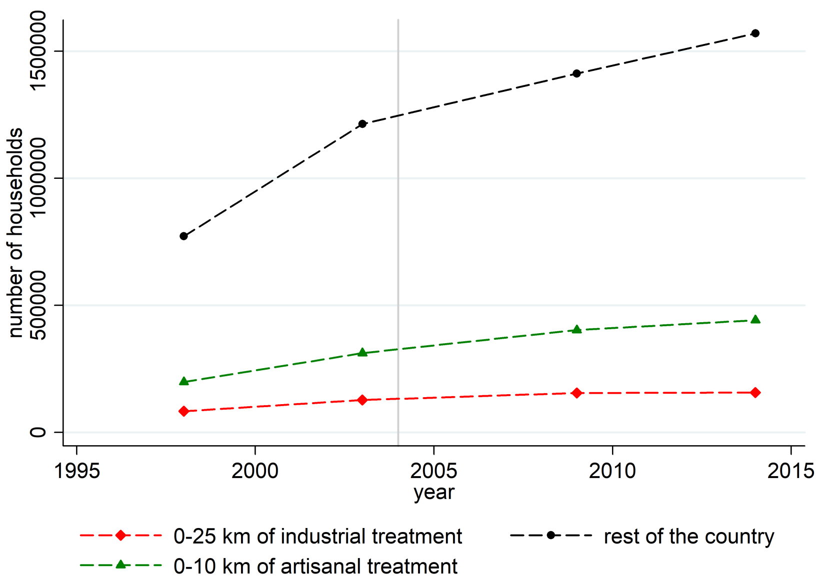
Note: source: http:www.burkina-emine.com, translation is ours

Figure 9: Organization of space within and around an industrial mine, the example of Kalsaka



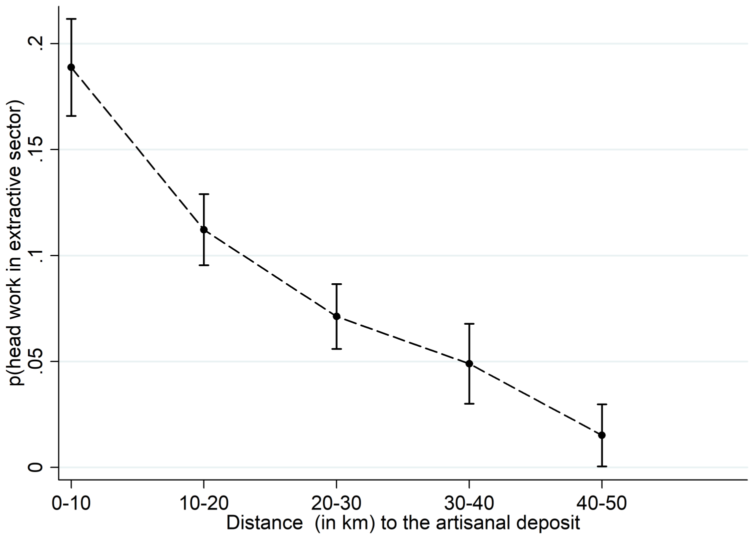
Note: Figure from Thune (2011), translation is ours.

Figure 10: Evolution of the population of Burkina Faso



Note: Each point represents the total population in this area. The treated groups encompass households living either within 10 kilometers of an artisanal deposit or households living within 25 kilometers of a deposit that would host an industrial gold mine by 2014. The control group (the rest of the country) excludes the treated areas.

Figure 11: The probability of working in the extractive sector, by distance to artisanal mines



Note: Each point represents the share of household heads who are involved in the extractive sector in the 1st survey period of 2014 (February-March), according to the distance between the household and the closest artisanal mine. The extractive sector encompasses all forms of extraction, whether artisanal or industrial. Bars around each point represent the 95% confidence intervals.

7.2 Appendix Tables

Table 7: Industrial and mechanized gold mines in Burkina Faso, producing and about to produce in 2014

Name	Cumulated production in 2014 in tons	Estimated gold reserves in tons[a]	Year production started	Country of main controlling company
Taparko	23.1	35	2007	Russia
Kalsaka	10.2	20	2008	UK
Mana	36	35	2008	Canada
Youga	16.1	25	2008	Canada
Essakane	46.9	100	2010	Canada
Inata	20.0	22.5	2010	UK
Pinsapo	0.33	NA	2012	Switzerland
Seguenega	1.7	5	2013	Australia
Bissa	15.7	34	2013	Russia
Guiro	0.24	1.6	2014	Canada
Sotexmi	0.01	NA	2014	Burkina
Karma	0	29	2016[b]	Canada
Niorka	0	20	2016[b]	Australia
Poura	0	7	2017[b, c]	Australia

Note: data from the Ministère des Mines et de l'Energie of Burkina Faso completed by the authors for the smallest mines. All gold mines in Burkina Faso are open-pit. [a] Estimation from time of feasibility studies. [b] Estimated production start as of 2014 information of the Ministry. [c] That mine had a marginal production in 1998 before closing in 1999.

Table 8: Number of households in each round of the survey, by place of residence.

	1998	2003	2009	2014
Households that live within:[a]				
- Artisanal deposit	1,404	1,398	1,530	1,925
- Birimian belt	3,351	3,356	3,272	4,504
- Industrial deposit	776	770	829	1,126
- Industrial mine	0	0	178	465
Total households in the survey	6,796	6,804	7,388	9,514

Note: data from the INSD. [a] Treated samples overlap with each other. The final sample for the years of the gold boom (2009 and 2014) includes 3,199 households living only in the producing artisanal mines' footprint, 387 households living only in the industrial mines' footprint and 256 households living in the footprint of both mines.

Table 9: Summary statistics by household location

	Control				Artisanal deposit				Industrial deposit			
	Before		After		Before		After		Before		After	
	Mean	se	Mean	se	Mean	se	Mean	se	Mean	se	Mean	se
consumption per capita	103552.8	1099.075	160310.8	1832.943	88923.28	1669.057	171650.2	3914.33	98563.59	2843.03	166295.9	4929.693
head age	45.29	0.173	46.16	0.168	44.90	0.307	46.33	0.311	45.08	0.453	48.43	0.453
head is male (%)	91.4	0.003	86.5	0.004	93.2	0.005	87.99	0.006	92.1	0.008	86.11	0.009
rural household (%)	84.2	0.003	81.1	0.004	89.7	0.005	91.4	0.004	86.3	0.009	87.8	0.006
head can read (%)	20.6	0.004	27.6	0.005	16.4	0.007	23.7	0.008	15.4	0.009	20.7	0.011
household size	6.71	0.046	7.31	0.053	6.71	0.081	7.49	0.098	6.62	0.118	8.13	0.148
number of workers in the household	3.59	0.028	3.96	0.031	3.73	0.051	4.14	0.057	3.65	0.071	4.53	0.088
head works in the agricultural sector (%)	80.2	0.004	72.7	0.005	86.4	0.007	80.0	0.008	78.2	0.012	78.5	0.010
head works in the extractive sector (%)	0.16	0.0004	0.54	0.0008	1.03	0.002	1.87	0.002	4.88	0.008	1.37	0.003
Number of Households[a]	9,808		12,256		2,802		3,455		1,546		1,955	
Total number of households in the sample= 30,502												

Note: The mean and its clustered standard error are calculated using sample weights. Consumption is measured in CFA francs. Since January 1999, the CFA franc has had a fixed exchange rate with the euro (656 CFA Francs = 1 euro). The *Before* samples tell averages from the household surveys of 1998 and 2003. The *After* samples tell averages from the household survey that took place during the years of the gold boom, in 2009 and 2014. [a] Deposit samples overlap with each other. The final sample for the years of the gold boom (2009 and 2014) includes 2,691 households living only in the artisanal deposits' footprint, 1,191 households living only in the industrial deposits' footprint and 764 households living in the footprint of both deposits.

Table 10: Robustness to varying the definition of the industrial mine treatment.

	(1)	(2)	(3)
Dep. Var: ln. pc. Cons			
Artisanal deposit	0.179***	0.178***	
× gold boom	(0.0565)	(0.0563)	
Artisanal deposit			0.141***
× ln. gold price			(0.0418)
Artisanal deposit	-0.0987**	-0.0978**	-0.913***
	(0.0448)	(0.0447)	(0.275)
Industrial deposit	-0.0229		
× active mines × ln. gold reserves	(0.0221)		
Industrial deposit	0.0235*		
× ln. gold reserves	(0.0123)		
Industrial deposit		0.00619	
× construction mines		(0.0736)	
Industrial deposit		-0.0580	0.753
× active mines		(0.0715)	(0.541)
Industrial deposit			-0.118
× active mines × ln. gold price			(0.0824)
Industrial deposit		0.127*	0.132*
		(0.0677)	(0.0672)
Observations	30,502	30,502	30,502
R-squared	0.418	0.418	0.418

Note: Gold reserves set at zero for the two mines without information on the size of the reserves. All columns include municipality fixed effects, year fixed effects and a control for urban areas. All columns include household level controls (age, sex, ability to read, the number of household members and adult members, the electricity connection and main source of drinking water of the household). Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

Table 11: Robustness to the sample definition and specification.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep. Var: ln. pc. Cons											
			within 50km of	without areas	including	omiting one survey round at a time				controling for	
Sample:	only rural	only urban	arti. deposit	next indu. mines	Ouaga.	omit 1998	omit 2003	omit 2009	omit 2014	region×trends	region×year
Artisanal deposit	0.145***	0.268***	0.176***	0.206***	0.213***	0.167***	0.206***	0.134***	0.233***	0.174***	0.172***
× gold boom	(0.0538)	(0.0934)	(0.0595)	(0.0629)	(0.0595)	(0.0537)	(0.0668)	(0.0490)	(0.0888)	(0.0453)	(0.0419)
Artisanal deposit	-0.0786*	-0.0898	-0.0923**	-0.0960*	-0.120**	-0.0955**	-0.120**	-0.0559	-0.112**	-0.0947**	-0.100***
	(0.0444)	(0.111)	(0.0463)	(0.0508)	(0.0464)	(0.0476)	(0.0583)	(0.0402)	(0.0548)	(0.0368)	(0.0352)
Industrial deposit	-0.0784	-0.278***	-0.0669	NA	-0.0554	-0.106	-0.0778	-0.0769	0.0281	-0.0863	-0.0743
× active mines	(0.0747)	(0.0467)	(0.0726)		(0.0711)	(0.0945)	(0.0893)	(0.0627)	(0.123)	(0.0784)	(0.0765)
Industrial deposit	0.108	NA	0.134**	NA	0.136**	0.116	0.148	0.0500	0.235***	0.122*	0.118*
	(0.0664)		(0.0673)		(0.0690)	(0.0866)	(0.0920)	(0.0398)	(0.0887)	(0.0674)	(0.0694)
Observations	22,541	7,961	27,351	27,001	34,308	23,706	23,698	23,114	20,988	30,502	30,502
R-squared	0.392	0.487	0.432	0.426	0.469	0.389	0.413	0.516	0.420	0.433	0.437

Note: All columns include municipality fixed effects, year fixed effects and a control for urban areas. All columns include household level controls (age, sex, ability to read, the number of household members and adult members, the electricity connection and main source of drinking water of the household). Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

Table 12: Excluding each of the 13 regions one by one

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dep. Var: ln. pc. Cons.													
Artisanal deposit	0.179***	0.171***	0.213***	0.141***	0.173***	0.187***	0.178***	0.182***	0.151***	0.194***	0.178***	0.171***	0.191***
× gold boom	(0.0604)	(0.0580)	(0.0572)	(0.0513)	(0.0597)	(0.0590)	(0.0568)	(0.0610)	(0.0513)	(0.0612)	(0.0600)	(0.0587)	(0.0616)
Artisanal deposit	-0.0911*	-0.0932**	-0.136***	-0.0942**	-0.0999**	-0.0948**	-0.0979**	-0.0907*	-0.102***	-0.106**	-0.0873*	-0.0732	-0.105**
	(0.0478)	(0.0450)	(0.0442)	(0.0457)	(0.0476)	(0.0468)	(0.0449)	(0.0492)	(0.0384)	(0.0497)	(0.0470)	(0.0474)	(0.0478)
Industrial deposit	-0.0735	-0.0570	-0.0433	-0.0152	-0.0875	-0.0539	-0.0562	-0.0575	-0.0778	-0.125	-0.0592	-0.00551	-0.0558
× active mines	(0.0811)	(0.0721)	(0.0758)	(0.0798)	(0.0814)	(0.0727)	(0.0721)	(0.0723)	(0.0696)	(0.0801)	(0.0718)	(0.0672)	(0.0729)
Industrial deposit	0.137**	0.127*	0.138**	0.153**	0.133*	0.127*	0.125*	0.125*	0.133**	0.145*	0.126*	0.0512	0.124*
	(0.0695)	(0.0698)	(0.0699)	(0.0746)	(0.0784)	(0.0684)	(0.0676)	(0.0682)	(0.0644)	(0.0802)	(0.0681)	(0.0486)	(0.0731)
Observations	27,370	28,943	27,641	28,186	27,777	28,616	29,848	28,002	26,808	27,815	28,516	28,131	28,371
R-squared	0.421	0.416	0.414	0.416	0.421	0.421	0.416	0.420	0.416	0.419	0.420	0.421	0.416

Note: All columns include municipality fixed effects, year fixed effects and household level controls (age, sex, ability to read, the number of household members and adult members, the electricity connection and main source of drinking water of the household) and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

Table 13: Health and education effects

	(1)	(2)	(3)	(4)	(5)	(6)	
Dep var:	has been sick or injured				in ongoing education		
Sample (split by age in years) :	above 16	6 to 16	0 to 5		above 16	6 to 16	0 to 5
Artisanal deposit	0.00831	-0.0167**	0.0171		-0.00605	0.0178	-0.0107
× gold boom	(0.0103)	(0.00794)	(0.0134)		(0.00460)	(0.0259)	(0.0176)
Artisanal deposit	-0.00187	0.00469	-0.0114		0.00437	-0.0108	-0.0268
	(0.00861)	(0.00773)	(0.0127)		(0.00426)	(0.0236)	(0.0187)
Industrial deposit	0.0230	-0.000309	0.0168		0.00292	0.0494	-0.0218
× active mines	(0.0170)	(0.0166)	(0.0198)		(0.00951)	(0.0371)	(0.0303)
Industrial deposit	0.0116	0.00348	0.00689		-0.00917	-0.00668	0.00603
	(0.0106)	(0.0119)	(0.0135)		(0.00636)	(0.0248)	(0.0209)
Observations	105,728	69,690	45,677		106,259	70,623	6,979
R-squared	0.032	0.030	0.052		0.056	0.162	0.154

Note: All columns include municipality fixed effects, year fixed effects and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.

Table 14: Effects on household characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		head characteristics			members characteristics		
Dep. Var. :	nb. members	sex	age	can read	sex	adult	can read
Artisanal deposit	-0.216	-0.00802	0.0143	0.00733	0.00506	-0.00234	0.00908
× gold boom	(0.234)	(0.0189)	(0.759)	(0.0251)	(0.00589)	(0.00777)	(0.0216)
Artisanal deposit	0.155	0.0143	-0.477	-0.00514	-0.00798	-0.00464	-0.0190
	(0.221)	(0.0162)	(0.762)	(0.0212)	(0.00597)	(0.00744)	(0.0185)
Industrial deposit	0.170	-0.0178	1.456	-0.00186	-0.000388	0.0106	0.00450
× active mines	(0.489)	(0.0327)	(1.335)	(0.0285)	(0.00933)	(0.0113)	(0.0258)
Industrial deposit	-0.154	-0.00165	0.0543	-0.0208	-0.00177	0.00720	-0.0205
	(0.384)	(0.0206)	(1.397)	(0.0247)	(0.00710)	(0.0122)	(0.0219)
Observations	30,823	30,823	30,793	30,753	226,929	228,652	154,595
R-squared	0.094	0.064	0.050	0.117	0.003	0.008	0.117

Note: All columns include municipality fixed effects, year fixed effects and a control for urban areas. Robust standard errors are clustered at the municipality level. *** p<0.01, ** p<0.05, *p<0.1.