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The effects of extractive industries rent on deforestation in developing countries.

Harouna Kinda¹² Noel Thiombiano³⁴

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Abstract:

The extractive industries (oil, gas, and mining) play a dominant economic, social, and political role in the lives of approximately 3.5 billion people living in 81 countries across the world. However, the benefits come at a cost that is no longer limited to the problems of the ‘curse of natural resources’, but also includes the damage of greenhouse gas emissions, pollution, and biodiversity that extraction wreaks on the environment. This paper revisits the links between man-made and natural capital in developing countries, focusing on the case of forest cover loss⁵. Considering a theoretical model of income maximization, we assess through empirical observation the impact of extractive industries on forest cover loss. Based on a panel of 52 resource-rich developing countries, over the period 2001-2017, we adopt a dynamic specification with the two-step Generalized Method of Moments (GMM) system to address the inherent bias. Our main results show that the total rent from the extractive industries is detrimental to the forest. More specifically, mineral and gas rents accelerate forest cover loss. In contrast, oil rents contribute to reducing forest cover loss. In addition, we find that natural resource tax revenues contribute to reducing forest cover loss. Our results suggest substitutability between oil rents (natural resource tax revenues and forest natural capital), and complementarity between mineral rents (gas rents and forest natural capital). To promote corporate environmental management, stakeholders must overcome regulatory inefficiencies in exploration and exploitation contracts so that environmental compensation is at least equal to the marginal damage caused by the extractive industries.

Keywords: *Extractive Industries (oil, mineral, and gas) – Resource Taxation – Deforestation*

JEL Classification: *C33 ; H23 ; Q32 ; Q5 ; H5*

¹ Université Clermont Auvergne, CNRS, IRD, CERDI, F-63000 Clermont-Ferrand, France.

² Université Hassan II, Laboratoire de Modélisation Appliquée à l’Economie et à la Gestion, Casablanca, Morocco.

Email: hkinda40@gmail.com; harouna.kind@etu.uca.fr

³ Université Thomas Sankara, CEDRES - Laboratoire d’Economie de l’Environnement et de Socio-économétrie (LEESE), 03 BP 7210 Ouagadougou, Burkina Faso. Email: thiombianoel@yahoo.fr

⁴ Corresponding author: E-mail addresses: hkinda40@gmail.com (H. Kinda)

⁵ Following Hansen et al. (2013) we use the term “forest cover loss” to designate deforestation.

1. Introduction

In recent decades, natural capital has been recognized as playing a fundamental role in determining “the economic output and social well-being of developing countries (Corvalán *et al.*, 2005)”. Natural capital is defined as the stocks of natural resources, land, and ecosystems, it constitutes a more fundamental form of capital than man-made capital (i.e., human capital, social capital, manufactured capital, and financial capital) since it provides the basic conditions for human existence, biodiversity, food, clean water, and air, as well as essential resources (The World Bank, 2005).

However, the dependence of humans and their economic activities on natural capital can result in serious environmental consequences, such as land conversion, climate change, deforestation, and biodiversity loss (including the extinction of some animal and vegetal species). In the specific case of the extractive industries sector (oil, gas, and mining), the consequences are no longer limited to the problems related to the so-called natural resources “curse” or depletion but include the degradation of natural capital induced by the extractive industries. Some studies point to the specific case of the mining industry as a threat to biodiversity and particularly to deforestation (Siqueira-Gay *et al.*, 2020; Ranjan, 2019; Brusseau and Artiola, 2019; Bridge, 2004; Pepper *et al.*, 2011). Sonter *et al.* (2017) found that mining activities caused 11.67 km² of deforestation between 2005 and 2015 in the Amazon rainforest. The environmental damage caused by mining has often led to complaints from local communities and has raised questions about the opportunity to continue the mining activity (Evangelinos and Oku, 2006; Cook *et al.*, 2011; Khenisa, 2017). Moffat (2004) suggests that a forest established on sites reclaimed after mining has occurred is more susceptible to destructive agents, such as drought, insect attack, and infertility than undisturbed land. In the case of oil and natural gas, extraction poses environmental threats, such as leaks and spills during drilling and the extraction of wells, and air pollution from the burning of natural gas in oil wells (Cook *et al.*, 2011; Pepper *et al.*, 2011; Brusseau and Artiola, 2019).

In several developing countries, extractive resources account for a significant share of GDP (Hailu and Kipgen, 2017). The extractive industries play a dominant economic, social, and political role in the lives of nearly 3.5 billion people living in 81 countries across the world. The extractive industries sector accounts for at least 20% of exports and government revenues in twenty low- and middle-income countries (Halland *et al.*, 2015). Hailu & Kipgen’s Extractive Dependence Index (EDI) (2017) shows that all countries dependent on extractive resources are developing economies. Mining is mainly carried out by multinational companies. Thus, the extractive industries can have a significant impact on economic development because they generate income both for governments and foreign exchange earnings, and create jobs, directly and indirectly, in local communities. However, the extractive industries can also exacerbate or cause environmental and social problems, such as deforestation, pollution, conflict, depletion of nonrenewable resources, and disruption of ecosystems, endangering the health and safety of workers and the overall wellbeing of local communities.

Given the multiple effects associated with natural resource extraction, the debate on the opening of the Eagle mine (in the US state of Michigan) has focused on the trade-off between the economic benefits versus the potential environmental and social costs of the mine (Campbell and Roberts, 2010). Several studies show that economic development, demographic pressure, and institutions are

the main determinants of forest cover loss in the tropics (Delacote and Angelsen, 2015). Similarly, the expansion of both large- and small-scale agriculture has been identified as the main driver of forest loss and greenhouse gas (GHG) emissions. In contrast, the impacts of the extractive industry and infrastructure expansion, and the linkages between these two factors, have received less explicit attention.

Nowadays, empirical macroeconomic studies on deforestation data have yielded useful results regarding the factors that account for periodic deforestation rates. First, the literature has questioned the impact of economic development on deforestation, examining the existence of an environmental Kuznets curve for deforestation (see Culas, 2012). These studies provide contrasting results, as the meta-analysis of Choumert et al. (2013) shows. Second, institutional factors, such as corruption, internal conflict, the quality of land tenure, and, more broadly, the quality of governance in countries, have been found to be an important macroeconomic factor in deforestation (Barbier et al., 2001; Bhattarai and Hammig, 2001; Culas, 2012; Galinato and Galinato, 2016). Strong institutions seem to be environmentally friendly and thus contribute to the preservation of forests (Campbell and Roberts, 2010; Ferreira and Vincent, 2010). However, this effect seems debatable. (Besley, 1995) suggests that better quality institutions can encourage productive investments that potentially encroach on forested areas. The overall effect of institutions is therefore likely to be ambiguous. Other studies have found evidence that other macroeconomic factors are correlated with deforestation. These factors include the role of real exchange rates (Arcand et al., 2008), agricultural activity, access to capital, public policies (Benhin and Barbier, 2004; Combes Motel et al., 2009), population (Cropper and Griffiths, 1994), timber harvesting (Damette and Delacote, 2011), and the impact of plantations on forests (Heilmayr 2014).

This paper contributes to the literature on the relationship between man-made and natural capital in developing countries, with a specific focus on the impact of the benefits of extractive industries on deforestation. We empirically test the theoretical hypothesis of Combes et al. (2018) that man-made capital has heterogeneous impacts on economic sectors, using the specific case of the extractive industries. The extractive industries may contribute to forest cover loss because of the need for a large land area for industrial production and access to infrastructure. The hypothesis to be tested is that the access to rents from extractive industries can have a non-homogenous impact on forest cover, according to the type of rent. In other words, dedicating resource revenues for non-deforestation-related activities can reduce forest cover loss, and vice-versa. As deforestation and capital accumulation are long-term phenomena, this study is based on a sample of 52 resource-rich developing countries over a period spanning from 2001 to 2017. Such a timeframe is often used in the literature as it is considered necessary for the long-term effects to become apparent (Combes et al., 2018; Ranjan, 2019; Ouoba, 2020). To our knowledge, this paper is the first to perform a rigorous econometric analysis comparing the effect of extractive rents on forest cover loss. Our results suggest that access to extractive industry rents has non-homogenous impacts on forest cover in resource-rich countries, according to the type of rent accessed.

The paper proceeds as follows. In Section 1, we briefly present the context of our research question and the literature review. Section 2 describes the methodology and data. Section 3 presents the results obtained and discusses them in Section 4. The last part of the paper summarizes the main findings and offers concluding remarks.

2. Extractive industries and deforestation

The first theoretical analysis of the “curse of natural resources” was established by Sachs & Warner (1995), who indicate that countries rich in natural resources paradoxically appear to perform less well than countries without them. Indeed, this curse may stem from Dutch disease (Sachs and Warner, 1995), the volatility of natural resource prices (Arezki and Ploeg, 2007), or institutional factors (Robinson *et al.*, 2006; Torvik, 2002).

Although the abundance of extractive resources in developing economies and their dependence on them has been studied in the literature, the environmental repercussions still raise several questions. Deforestation, which can be defined as all the practices and processes that lead to an irreversible loss of forest area to economic activities, is due to both direct and indirect factors. The direct factors are those that cause the immediate conversion of forestland into land for other uses. These include infrastructure extension, agricultural expansion, wood extraction, and expansion of settlement areas and could be explained as a response to some indirect causes, such as strong population growth and increasing economic needs, technological factors, political and institutional factors, cultural and sociopolitical factors (see, for instance, Geist and Lambin, 2002; Madeira, 2008; Su *et al.*, 2011; Hosonuma *et al.*, 2012; Makunga and Misana, 2017). In addition, a large strand of literature examining the drivers of deforestation and forest degradation focuses on underlying (indirect) causes. Indeed, economic growth has long been considered an important driver of environmental destruction (see, for instance, Koop and Tole, 1999; Grossman and Krueger, 1995; Holtz-Eakin and Selden, 1995; Cropper and Griffiths, 1994; Shafik, 1994). Using a sample from 76 developing countries, Koop and Tole (1999) find no statistically significant empirical regularity between deforestation and GDP per capita. However, Shafik (1994) finds that forest cover loss exhibits a weak inverted-U-shape relationship with rising incomes. Cropper and Griffiths (1994) find an inverted-U-shape relationship between per capita income and the annual rate of deforestation in Africa and Latin America but not in Asia. Other indirect factors include the quality of political institutions (Barbier *et al.*, 2005; Galinato & Galinato, 2012; Nguyen Van & Azomahou, 2007) and exchange rates (Arcand *et al.*, 2008). For example, controlling corruption induces technological development, which can favor extensive agriculture if the technology is complementary to agricultural production (Galinato and Galinato, 2016). However, controlling corruption favors better institutions that are presumed to be environmentally friendly, which can preserve forests (Ferreira and Vincent, 2010). According to Koop & Tole (1999), when inequality levels are high in a country, the development will tend to exacerbate deforestation rates. Nevertheless, when distributions tend to be more egalitarian, the negative effects of economic development on forest cover are reduced. Additionally, the effects of public spending (Combes *et al.*, 2018; Galinato & Galinato, 2016; López *et al.*, 2011) and climatic factors, such as temperature and rainfall, are worth noting. The theoretical intuition of Combes *et al.* (2018) is that man-made capital accumulation (public credits and expenditure) can have non-homogenous impacts on natural capital, according to the sector of activity. Their empirical framework suggests that public credits and expenditure increase deforestation in developing countries. Thus, we enumerate two main channels that link extractive industries to forest cover, namely, the channel of industry (total rents to GDP) and the channel of public expenditure through the government’s share of rents (resource tax revenues to GDP).

2.1. Channel of industrial production

In recent decades, there has been a significant flow of foreign direct investment into developing countries. Foreign direct investment in Africa increased fivefold between 2000 and 2012, from \$10 billion to \$50 billion. The development of extractive industries is the main stimulus for investment in these countries. According to Morisset (1999), multinationals are motivated to invest in the presence of natural resources. The natural resources sector, mainly mining, attracts foreign direct investment (FDI) to developing countries, even to those with low schooling rates (Kinda, 2008). For example, in 2009 in Madagascar, the percentage of FDI in the extractive industries sector was estimated at 74% of all FDI and estimated at 2.3 billion US dollars (Raharinirina, 2013). This activity leads to deforestation, soil degradation, loss of biodiversity, and air and water pollution. In 2008, Burkina Faso had only ten industrial mining sites. These sites covered 1031.56 km² or 0.38% of the nation's area and 3% of the cultivated areas (Maradan *et al.*, 2011). In 2016, there were twelve sites in operation, ten of which were gold and the other two zinc and manganese mining, and several others were in the process of being set up. The rents from nonrenewable resources, (i.e., those from fossil fuels and minerals, as well as the rents from the overexploitation of forests) are indicators of the liquidation of a country's capital stock. Some studies in Mexico, Central America, the Brazilian and Western Amazon, and Indonesia suggest that extractive industries and infrastructure are often associated (Humphreys Bebbington *et al.*, 2018). The investment in both sectors and synergies between them lead to legal and institutional reforms that modify the management of forests. Notably, these reforms have contributed to reducing the status of protected areas, to weakening the protection of indigenous territories, to relaxing of environmental assessment procedures, and to increased violence against environmental defenders (Humphreys Bebbington *et al.*, 2018). Hall, (1991) focuses on the social costs, rural violence and intimidation, land grabbing, and forced population displacements caused by the Grande Carajás program which has worsened social and environmental conditions for most of the rural population and resulted in social conflict. The Grande Carajás project in Brazil is one of the world's largest reserves of copper (iron ore, manganese, and gold) and extends over 900,000 km² (Humphreys Bebbington *et al.*, 2018). The exploitation of this mine leads to annual deforestation of 6,100 km² through the conversion of wood from the surrounding forest into charcoal to feed the smelting plants (Moran *et al.*, 1994). Similarly, Ranjan (2019) shows that mining contributed to deforestation in 314 districts of India between 2001 and 2014. Charcoal, iron, and limestone-producing districts suffered 450 km² of additional forest cover loss, while the production of dolomite, quartz, fire clay, and manganese were not associated with forest loss. However, districts not producing any of these minerals had 350 km² less of forest loss.

These various works suggest that an increase in the area occupied by extractive industries leads to a loss of forest cover and, therefore, constitutes a threat to biodiversity conservation. However, the authors do not provide any answers regarding the effects of economic rents on deforestation in terms of public expenditure through natural resource tax revenues. Nevertheless, this review shows us that forest cover is encroached upon due to extractive activities.

2.2. Channels of public expenditure

Several development studies are investigating the impact of natural resource wealth on long-term economic growth, but the results are still controversial. Havranek *et al.* (2016) review the empirical literature and find that approximately 40% of the articles find a negative effect; however,

20% find a positive effect and 40% find no effect. According to López *et al.*, (2011), public expenditure accounts for 20% to 45% of GDP. However, natural capital has not recently been valued in the calculation of GDP. Currently, due to the adverse effects of climate change, leaders are beginning to develop an understanding of the importance of natural capital for economic development. Ideally, natural capital should be considered in all consumption and/or investment decisions.

The World Bank encourages better mobilization of national resources by strengthening transparency, which promotes inclusive growth that meets the vital needs of populations while simultaneously protecting the environment. Through an effective fiscal policy, revenues from extractive industries can contribute significantly to financing productive expenditures (Daniel *et al.*, 2013). This fact draws attention to the need to consider other factors, such as job creation in related activities and environmental and social effects, in addition to revenue objectives. Combes *et al.* (2018) used a theoretical analysis supported by empirical evidence and found a relationship of complementarity between natural and artificial capital. In their article, they argue that artificial capital derives from public credits and expenditure, the increase of which, due to a decrease in the cost of access, affects the activities related to deforestation in developing countries more than the activities not related to deforestation. They also hypothesize that countries that are heavily dependent on the agricultural sector and the exploitation of natural resources are likely to experience complementarity. This means that public expenditures in developing countries foster the loss of forest cover. While López *et al.* (2011) draw attention to the composition of public expenditure, they argue that increasing the share of revenue allocated to public and social goods reduces environmental pollution.

Economic rent is composed of the share of the producers' profit, the state's revenue, and the amount of reinvestment. From the channel of production, economic rents have a direct and negative impact on forest cover (i.e., a positive effect on deforestation) and the public expenditure has a heterogeneous impact, which explains the allocation of revenues to deforestation-related and non-deforestation-related activities. If the allocation of resource revenues from non-deforestation-related activities prevails, then we have a situation of substitutability between economic rents (artificial capital) and natural capital. Otherwise, we have a situation of complementarity between economic rents and natural capital. For example, the Grande Carajás project included the construction of a hydroelectric plant to power the mine, a railway, and a port to transport minerals. It also required the creation of some 800,000 hectares of protected areas and indigenous reserves to partially compensate for the damage caused (Humphreys Bebbington *et al.*, 2018).

3. Data and methodology

3.1. Data

We use a panel of 52 developing countries rich in extractive resources across several regions of the world (Table A4). Our data are annual in frequency and cover the period from 2001 to 2017. The main variables concern extractive rents (minerals, oils, and natural gas rents). Resource tax revenues are used as the interest variables and forest cover loss as the dependent variable. We wanted to extend the study to all resource-rich countries over a longer period, but unfortunately, there are problems regarding data availability for the dependent variable and many missing data points for

the variable of interest. Following Combes et al. (2018), the time horizon considered is quite consistent for our analysis.

To define countries rich in extractive resources, we used the Extractive Dependence Index (EDI) proposed by Hailu & Kipgen (2017). This index measures a country's dependence on the extraction of oil, gas, and mineral resources. This measure seems more complete at our level because it integrates the three essential components that express a country's wealth in extractive resources, i.e., the combination of the share of export earnings from extractive industries, their share in terms of income of the country's total income, and their value in terms of economic rents as a percentage of GDP. This measure considers the volatility of economic growth and affects its sustainability. Thus, our EDI is as follows:

$$EDI_{it} = \sqrt{[EIX_{it} \times (1 - HTM_{it})] \times [REV_{it} \times (1 - NIDC_{it})] \times [EVA_{it} \times (1 - MVA_{it})]},$$

where EDI_{it} is the Extractive Dependence Index of country i at time t ; EIX_{it} is the sum of export revenues from oil, gas, and minerals in the total export revenues of country i at time t ; HTM_{it} represents the export revenues of highly competitive and technology-intensive manufacturers of country i at time t as a percentage of the HTM_{it} exported worldwide; REV_{it} is the share of total income generated by the extractive industry in the total tax revenues of country i at time t ; $NIDC_{it}$ is the share in GDP of tax revenue from non-resource-related income, capital gains, and profits of country i at time t ; EVA_{it} is the share of total economic rents from the extractive industries in the GDP of country i at time t ; and MVA_{it} is the manufacturing/inhabitant value-added, used as a proxy for the industrial capacity of country i at time t . By considering the values in parenthesis, i.e., $((1 - HTM_{it}), (1 - NIDC_{it}), (1 - MVA_{it}))$, it is possible to take into account their influence on the values (EIX_{it} , REV_{it} and EVA_{it}).

In this study, we have selected those countries that had an EDI score above 10 in 2011. Additionally, the calculation takes time into account, and we notice that many countries have an almost constant EDI between 2000 and 2011 (see (Hailu and Kipgen, 2017)). Our proxy for annual deforestation or forest cover loss (**Forest Loss Year**) is from Hansen et al. (2013) and is available in the Global Forest Change dataset at Earth Engine (<http://earthenginepartners.appspot.com/science-2013-global-foreston>). This data set is based on Landsat satellite images between 2000 and 2019 and is available at 30 meters' spatial resolution. 'Forest cover loss' is a change from a forest to a non-forest state during the period. Inversely, 'forest cover gain' reflects an entire non-forest to forest change. 'Forest loss year' is a disaggregation of total forest loss at the annual scale. The dataset is mainly from the University of Maryland and was recently published and made freely available for use by Hansen et al. (2013). This dataset remains a potentially valuable source of information on forest cover, although it is criticized for inaccuracies in the distinction between forests and plantations at the local level (Tropek et al., 2014). This study considers a forest as any area with more than 20% trees in 2000, thus, excluding all areas with a lower percentage of trees.

For the variables of interest, we use the share of rents from extractive industries as a percentage of GDP (**RENTS**) and industry tax revenues. Natural resource rents are a measure of the sustainable development of extractive industries in the new millennium. As explained above, this variable represents the profit from the extraction of natural resources. It takes the form of economic rents since it is not produced. We use it because it captures the size of the extractive

sector in the national economy in monetary terms. Therefore, it depends on the size of the operation, the volume of production, the general level of prices, and many other institutional factors. More specifically, we consider mineral rents, oil rents, and natural gas rents (percentage of GDP).

The data on total natural resource revenues, including natural resource revenues reported as “tax revenue” or “non-tax revenue” of a given government (*Gov.Res-revenues to-GDP*), are from the ICTD website. We test the effect of this variable on forest cover. The goal is to determine if the use of this income considers the negative effects of the extractive industries on forest cover. This variable affects the national economy significantly in terms of capital and consumer spending. We expect a negative relationship between resource revenues and deforestation. The data on the *gross fixed capital formation (GFCF)* and *final consumption current (Consum)* permit the effects of public expenditures on forest loss to be considered. Other variables likely to influence deforestation are introduced to serve as controls, in order to allow us to obtain more robustness in our econometric results.

We thus test the endogeneity of these variables in our model. From the current literature, we retain the following: *GDP growth per capita* captures the effect of national wealth on forest loss. The works of Foster and Rosenzweig (2003) in India show that neither agricultural productivity expansion nor rising wages have increased local forest cover. Based on the level of a country’s development, the expected impact of the GDP growth on deforestation may be mixed.

Total population growth is a mid-year estimate of all residents of the country regardless of their legal status or citizenship. This variable can have an impact on the availability of natural resources, the size of the habitat, and farms. An increase in population fuels the demand for arable lands, fuelwood, and charcoal because the increases in basic needs such as food, energy, water, social services, and infrastructure can foster deforestation (Cropper and Griffiths, 1994). Foster & Rosenzweig (2003) find that the demand for forest products associated with population and income growth leads to forest growth. Therefore, the expected impact of population growth may be ambiguous.

Internal conflict is one of the major institutional shocks associated with extractive activities because of the infrastructure footprint on forests. An analysis exploring these issues in Mexico and Central America, the Brazilian and Western Amazon, and Indonesia indicates that resource extraction has induced more mobilization and protest from local communities than have road, railway, or waterway building projects (Humphreys Bebbington *et al.*, 2018). We consider the internal conflict index as a measure of the influence of political institutions. This is an assessment of the political violence in the country and its actual or potential impact on governance. A score of 4 points equates to Very Low Risk and a score of 0 points to Very High Risk. Internal conflict may generate higher or lower levels of deforestation (Larcom *et al.*, 2016).

The average rainfall shock, which is defined as the deviation of the mean annual rainfall from its long-term trend (mean rainfall from 1901 to 2016), is data extracted from the database of the Climate Research Unit (CRU) of the University of East Anglia. This climate variable is expected to control agricultural profitability as well as the natural causes underlying the loss of forest cover. Countries with low rainfall tend also to experience extreme temperatures. This can be detrimental to plants, leading to a loss of forest cover. It should be noted that high climate variability can also

lead policymakers to increase environmental standards, which can reduce deforestation. Thus, we can expect an ambiguous effect of rainfall shocks on deforestation.

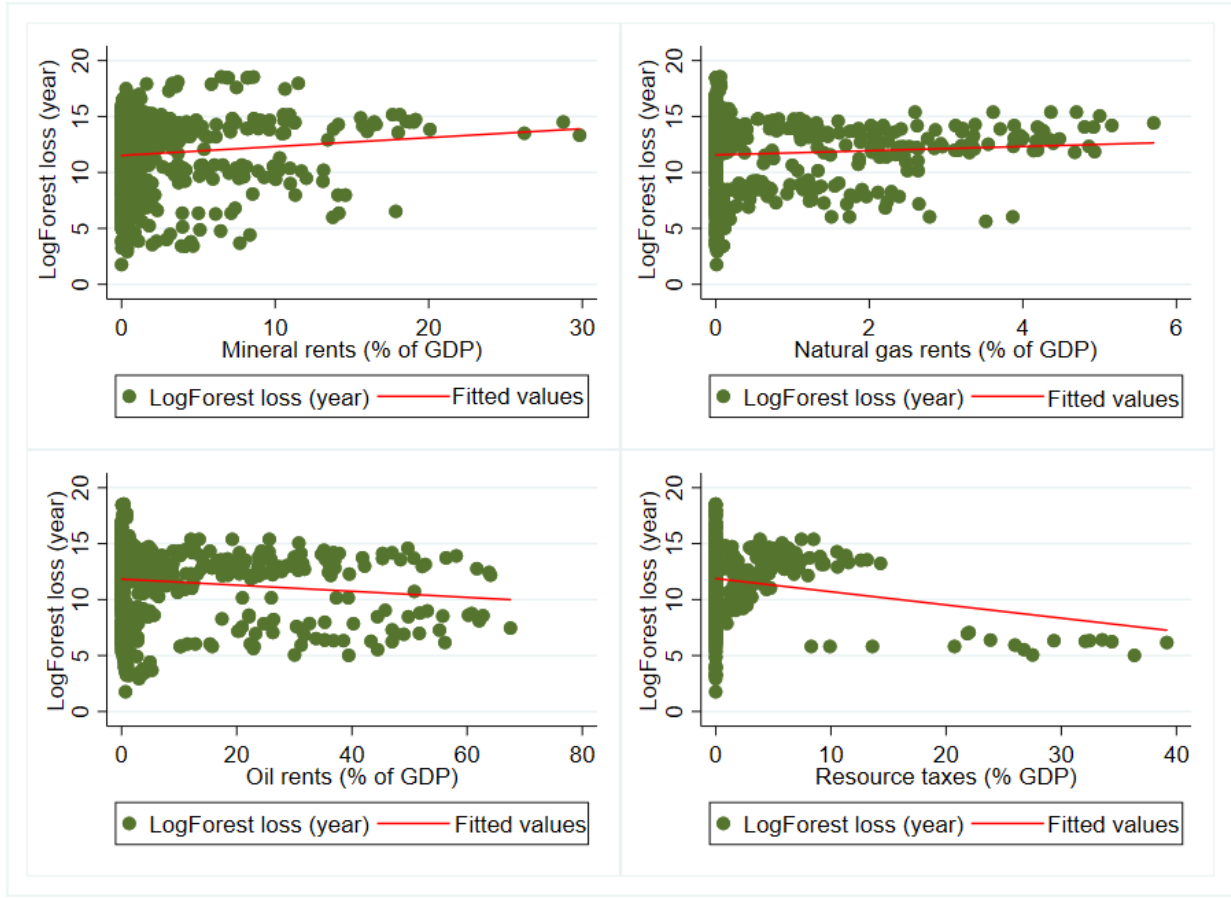
The *net official development assistance (ODA) received per capita* is purposefully promoting economic development and improving living conditions in recipient countries, according to the Development Assistance Committee (DAC) of the Organization for Economic Co-operation and Development (OECD). We expect a negative impact of the net ODA received on the loss of forest cover.

3.2. Descriptive statistics and stylized facts

Table A3 (Appendix) shows that the variables do not have the same number of observations, but this will be considered in our estimation. For all variables, we notice that the standard deviation is very high for the dependent variable compared to the explanatory variables. We use the variables in logarithm to minimize these deviations and to smooth the data that are widely spread out. This facilitates our interpretation of the econometric estimation results.

Figure 1 shows the relationship between natural resource rents (*oil, mining, and gas rents*) and forest cover, on one hand, and the linkage between resources tax revenue and forest cover loss, on the other hand. We can observe a negative relationship between oil rents and tax revenue from natural resources and forest cover loss. However, we can also observe a positive relationship between mineral and gas rents and forest cover loss. Our statistical analysis clearly shows that mineral rents and gas rents contribute to increasing deforestation, but oil rents and government revenue from extractive industries also contribute to reducing deforestation. To be able to draw conclusions from these results, we conduct an econometric verification, as the stylized representation of economic variables does not consider specific endogenous factors. In the following section, we use the dynamic panel method and the GMM system estimator in the analysis.

Figure 1: Extractive resource rents, resources tax revenue, and forest cover loss



3.3. Theoretical analysis

3.3.1. Main hypotheses

This section examines the channels through which maximizing economic rents from the extractive industries can affect forest cover loss. As a reminder, exploitation by the extractive industries requires the occupation of large areas, and thus, land use planning leads to a loss of forest area. Moreover, industrialists and the government of a given country are the main actors benefiting from the profits of the extractive industries. The increase in tax revenue through extractive resources leads to an increase in public expenditure, all other things being equal. While the value of the economic rent depends on several other factors such as costs and price levels, as well as other institutional and geographical factors, the quantity of production is likely to be crucial. An increase in tax revenue, therefore, depends not only on the tax system but also on the total value of rents.

Going back to our theoretical model, it should be noted that, in addition to the technological factor, an increase in the quantity produced by the extractive industries also depends on the size of the operations and/or the number of extractive industries (increase in the consumption of natural capital). We end up with a classic production function augmented by natural capital, where profit maximization will depend on the natural capital, in addition to the constraints cited above (production costs and price level), in the producer's program. The economic theory had historically ignored this reality of the role of natural capital in the production process, but in recent decades, it has increasingly become an indisputable truth. The 2012 Rio+20 summit has generated milestones

towards the integration of natural capital considerations into financial products and services. Natural capital is still a major limitation in the assessment of the gross domestic product (GDP).

$$MaxI(R) = B(D, Q) - c(D) - c(Q) \quad (1)$$

From equation (1), industry I maximizes the rent that depends on the level of capital $B(D, Q)$ also related to deforestation under the constraint of the costs of the natural factor $c(D)$ and other "traditional" factors of production $c(Q)$. This equation is very simplistic because it does not integrate the indirect deforestation D' likely to be generated by using tax revenue (public expenditure) and its cost $c(D')$. We, therefore, integrate public expenditure to analyze the case of developing countries where the State that owns the property rights collects the taxes and duties from the economic rents. According to the theory of optimal taxation, the rents can be taxed up to 100% since they are neutral in terms of investment and operating decisions (Ricardo, 2015). Surface royalties are paid each year in proportion to the area granted by the mining title, but they are not required in all countries. However, not all countries include surface taxes (Laporte *et al.*, 2015).

3.3.2. Theoretical demonstration of the assumptions with the integration of public expenditure

The remainder of our theoretical analysis is based on the theoretical model of Combes *et al.* (2018). The authors consider a country in which a representative agent maximizes its net income derived from economic activities that use natural capital D (deforestation) and artificial capital K . K requires both government appropriations and expenditures. The intuition is that K affects the economic sectors heterogeneously. $A(D, \delta K)$ is the income from activities related to deforestation and $O((1 - \delta)K)$ is the income from activities not related to deforestation, of which δ and $(1 - \delta)$ are the shares of the allocated K . Combes *et al.*, (2018), therefore, assume standard properties indicating second and first derivatives, such as the following:

$A_i \geq 0, A_{ii} \leq 0, \forall i = \{D, K_D\}$, $O_{K_o} \geq 0$; and $O_{K_o K_o} \leq 0$. The costs $c(D)$ of *Deforestation* and the costs $c(K)$ of *Capital access* K are increasing and convex, as follows: $c_i \geq 0, c_{ii} \geq 0, \forall i = \{D, K\}$. $c(K)$ are lower when forests are open access, higher when property rights are safe and well defined, higher when forests are a scarce resource. The authors consider the existence of a trade-off between consumption and investment in the cost functions, and thus, the optimized levels of D and K become steady-state variables, and their partial derivatives are responses to shocks. Hence, the following agent I maximization problem is as follows:

$$MaxI(D, K, \delta) = A(D, \delta K) + O((1 - \delta)K) - c(D) - c(Q) \quad (2)$$

The first derivatives D^* , K^* , and δ^* represent the level of deforestation, capital, and the share of capital allocated to economic activities related to deforestation, respectively, with the following:

$$A_D - c_D = 0 \quad (3)$$

$$\delta A_{K_D} + (1 - \delta)O_{K_o} - c_K = 0 \quad (4)$$

$$KA_{K_D} + KO_{K_o} = 0 \quad (5)$$

Note, Equation (3) indicates the equality between the marginal revenue from deforestation D^* and its marginal cost; equation (4) indicates that capital K^* is chosen for the equalization

between the marginal productivity and the marginal cost of capital, and equation (5) defines δ^* as the level of equalization between the marginal productivity of capital from deforestation-related and non-deforestation-related activities. Equation (3), (4), and (5) by substitution resulted in the following condition:

$$\frac{A_{K_D}}{c_K} = \frac{O_{K_D}}{c_K} = \frac{A_D}{c_D} \quad (6)$$

Equation (4) states that deforestation choices and capital allocation are made so that each activity equals the marginal benefit/marginal cost ratio. Thus, the authors show that the main argument is that an increase in government credit or spending would lead to a decrease in the marginal cost of capital. This will influence not only the agent's total capital but also the allocation of capital between deforestation-related and non-deforestation-related activities and, thus, the level of deforestation. Combes et al. (2018) thus go further in their demonstration to characterize cases of complementarity and substitution between artificial and natural capital (See their article for this demonstration). They use the implicit function theorem to derive three cases. The first case is that the decrease in the cost of artificial capital c_K increases the capital allocated to deforestation δK and the level of deforestation. In the second case, decreasing c_K increases δK but decreases the total level of deforestation. In the third case, decreasing c_K decreases both the capital allocated to deforestation and the total amount of deforestation. The authors therefore favor the case that they consider most likely with developing country characteristics. They believe that the experience of complementarity is more likely to be observed for countries highly dependent on agriculture and natural resources. This is explained by the tendency to allocate artificial capital to agricultural activities whose expansion is a source of deforestation.

Our theoretical model is based on Combes et al. (2018) but with the difference that in our model, deforestation comes not only from the allocation of artificial capital c_{d1} (between deforestation-related and non-deforestation-related activities) but also from the natural capital c_{d2} itself linked to its production, including $c_D = c_{d1} + c_{d2}$. As mentioned above, the representative agent receives only part of the artificial capital (taxes and taxes on the rent). However, he must bear the deforestation cost of producing artificial capital in addition to the cost of allocating his share between deforestation-related and non-deforestation-related activities. It should be noted that when the share of capital allocated to non-deforestation-related activities increases, it reduces the total amount of deforestation.

In our analysis, it is a question of the State putting in place a fiscal policy that allows it to maximize its revenues. It is also the case that increasing government revenues can exacerbate deforestation. Therefore, how do changes in rents and tax revenues affect deforestation? All other things being equal, an increase in the rent increases the total amount of deforestation. On the other hand, if the increase in rents is accompanied by an increase in revenues and is allocated to activities not related to deforestation, the total level of deforestation could decrease. We support this last sentence through equation (3) of Combes et al. (2018), which states that there is equality between the marginal income from deforestation D^* and its marginal cost. A strong hypothesis is that if the marginal income from deforestation is strictly directed into activities not related to deforestation (e.g., subsidies, reforestation, as well as moneys allocated to saving forests that are suffering from natural loss), this could partly lead to a decrease in the total amount of deforestation. The share of the rent accruing to the state in the form of revenue will be used as artificial capital. We, thus,

simplify the problem in order to be consistent with Combes et al. (2018). In the empirical part, we test the existence of situations of complementarity and/or substitutability between natural capital and artificial capital based on the rents and tax revenue.

3.4. Empirical strategy

Our theoretical analysis considers conditions under which maximizing artificial capital can foster deforestation. However, we argue that when the marginal income from deforestation is strictly invested into reforestation activities and safeguarding the natural loss of forests, a reduction in the total amount of deforestation may be observed. Thus, a situation of complementarity between natural and artificial capital is evoked when these maintain a positive relationship. In the case of a negative relationship, a situation of substitutability will then be envisaged (Combes et al., 2018; Delacote & Angelsen, 2015). Our empirical analysis includes economically verifying the existence of a case of complementarity and/or substitutability for developing countries with large stocks of forests and extractive resources.

3.4.1. Econometric model specification and estimation method

In this study, we adopt a dynamic panel specification that identifies the specific impact of two interdependent determinants of artificial capital, namely, total rent and tax revenue from extractive industries. It is an autoregressive model that distinguishes between the short-term and long-term impact of a variable. We argue here that increasing economic rents leads to increased deforestation and facilitates access to artificial capital. We consider the effects of a few control variables highlighted in the literature.

3.4.2. Specification of the dynamic panel model

The specification of the dynamic panel model allows us not only to study the relationship between artificial capital (total extractive industry rent and tax revenue) and the loss of forest cover but also to test the dynamic effect of the loss of forest cover. We thus adopt the method of Combes et al. (2018). From the analysis of the theoretical model, the static description of the allocation of deforestation capital corresponds to an equilibrium condition. This suggests the existence of a steady-state value of the logarithm of forest cover loss. The authors define $z_{it} = \ln Floss_{it} - \ln Floss_{it}^*$ as the difference between the logarithms of forest cover loss for country i in year t and its steady-state value. They assume that the dynamics of z described by $\dot{z} = -\beta z$, a homogeneous first-degree differential equation with $0 < \beta < 1$, i.e., the rate of convergence of the loss of forest cover to its steady-state value, decreases from β . The resolution results in the following basic dynamic specification of forest cover loss:

$$\ln Floss_{it} \cong \beta \ln Floss_{it}^* + (1 - \beta) \ln Floss_{it-1} \quad (7)$$

(See Combes et al., 2018 for more detail.)

We obtain the following specifications by integrating the variables of interest:

$$\ln Floss_{it} = \alpha_o + v_i + (1 - \beta) \ln Floss_{it-1} + \gamma_1 \ln Rents_{it} + X'_{it} \beta' + \varepsilon_{it} \quad (8)$$

$$\ln Floss_{it} = \alpha_o + v_i + (1 - \beta) \ln Floss_{it-1} + \gamma_2 \ln Gov.Res_revenues_{it} + X'_{it} \beta' + \varepsilon_{it} \quad (9)$$

In equations (8) and (9) $\ln Floss_{it}$ represents the present value of forest cover loss in hectares in country i in year t , v_i is the country fixed effect and ε_{it} is the idiosyncratic error term. Extractive

industry rents are represented by $Rents_{it}$, extractive resource tax revenues are denoted by $Gov.Res_rev_{it}$, $(1 - \beta)$ is the estimated coefficient of the lagged explained variable, and γ_1 and γ_2 represent those of the interest variables. X'_{it} represent the vector of control variables and β' is the vector of estimated coefficients. The vector of the control variables includes GDP per capita, total population, corruption as an indicator of the institutional quality of the country, and rainfall as an indicator of the potential effect of climate variability on forest cover.

3.4.3. Dynamic panel estimation by the GMM system estimator

The presence of the lagged endogenous (dependent) variable characterizes the dynamic panel model. Its appearance among the explanatory variables makes the OLS estimator non-convergent since the lagged endogenous variable is positively correlated with the error term due to the presence of the specific effect. The OLS estimator is biased because of the correlation of the lagged endogenous variable with the error term (Nickell, 1981). We then use the two-step GMM system estimator (SYS-GMM) proposed by Blundell & Bond (1998) with Windmeijer's (2005) small sample robust correction, which combines two instrumentations designed to overcome some of the limitations of the DIF-GMM (Arellano and Bond, 1991). This approach includes the use of lagged variables in levels and lagged variables in differences as instruments. It has the advantage of addressing both the problem of endogeneity and the problem of unobserved heterogeneity. In addition, the GMM system is preferred to the standard first difference GMM because if the dependent variable is close to a random walk process, then the level variables are poor instruments of the difference variables. The System-GMM solves the problem of weak instruments and significantly improves the accuracy of the estimators. It also reduces the bias in short period samples (T small). Indeed, the GMM considers the inertia that may exist in the determination of the dependent variables and will therefore reduce the potential reverse causality bias of the explanatory variables by systematically using predetermined and exogenous variables as instruments. We assume in the regression that the lagged dependent variable and the economic rents variable of interest are endogenous and that the other explanatory variables are weakly endogenous, except "population", which is assumed strictly exogenous. Of course, we check the Sargan/Hansen incremental test for the validity of the additional moment restrictions required by the SYS-GMM and the Chi-square test (Arellano and Bond). Since our panel is unbalanced, in this case, the flexible GMM framework takes into account this problem and that of multiple endogenous variables. Their use is atomized in the *STATA-15* software used in this study (Arellano and Bond, 1998; Roodman, 2006).

Other studies use the Dynamic Ordinary Least Squares (DOLS) of Kao & Chiang (2001) for cointegrated panel data with a homogeneous covariance structure. When the variables are nonstationary and cointegrated, this method allows a cointegration regression to be obtained between the dependent variable and the regressors. It considers the problem of endogeneity, and the possible non-sphericity of the residuals and is asymptotically unbiased. We do not use it in this work since this method requires a greater number of individuals and a longer time horizon ($N \rightarrow \infty, T \rightarrow \infty$).

4. Main results

4.1. Econometric hypothesis tests of the dynamics of forest cover loss

First, we test for heteroscedasticity, although its presence in the model does not violate the estimator's convergence hypothesis, as it is no longer at minimum variance. This requires the correction of the variance-covariance matrix to make the perturbations spherical. The presence of the matrix has the advantage of requiring only consideration of Hansen's test for assessing the validity of the instruments since Roodman (2006) shows that Sargan's test is biased when considering the “robust” option in the Stata `xtabond2` command.

For the set of estimates, Hansen's over-identification test tells us that there is no correlation between the instruments and the error term. The instruments are therefore valid. Similarly, there is not enough evidence to reject the null hypothesis of no second-order serial correlation of the error term at the 5% threshold, which requires maintaining the assumption of serial independence in the error term ε_i in equations (8) and (9). The second difference explanatory variables can therefore be used as appropriate instruments for their level values because there is no correlation with the error term. For all estimates, the number of instruments is smaller than the number of groups (number of countries). According to Roodman (2009), this eliminates the problem of the proliferation of instruments, which is often underestimated in the application of the first difference model.

Our basic estimates of equations (8) and (9), reported in Tables 1 and 2, respectively, present the characteristics of the dynamic process of forest cover loss. For all regressions, we always find a coefficient β of the lagged dependent variable significantly different from zero. The associated Chi2 statistic verifies that $\beta < 1$ and is positive. Our results also show that forest cover loss is governed by the stationary *AR* (1) process, *ceteris paribus*. According to Combes et al. (2018), this reinforces the ubiquitous nature of the gross forest cover loss concept invented by Hansen et al. (2013). Considering the most complete specifications (column 6 in Tables 1 and 2), the results show that a past 1% increase in forest loss induces an approximate 0.6 percent increase in current forest loss in developing countries.

We cannot provide an interpretation in terms of forest gains since the data only measure the gross loss of forest cover. Following Combes et al. (2018), these results also suggest that forest loss is converging towards a steady-state value.

4.2. The effects of control variables

The determinants of deforestation are multiple. Several studies have attempted to identify the drivers of deforestation. On the one hand, there are direct factors whose effects have a direct impact on forests, namely, climatic conditions, occupation of forest areas, and logging. On the other hand, there are underlying factors that can amplify the effect of the so-called direct factors. These include macroeconomic and institutional factors.

We note a mixed effect of GDP growth per capita on forest cover loss for the basic model (Table 1, Table 2). This result is consistent with several theoretical and empirical studies and is relative to the level of a given country's development. According to Crespo Cuaresma et al. (2017), “theory predicts that economic growth in poor countries increases environmental depletion, but the

effect disappears in developed economies". This may well illustrate the case of this study, even more so since all the countries in the sample are still in the first phase of development. Similarly, Kuznets' environmental curve shows that in the first phase of a country's economic development, the level of pollutant emissions is low because production is low, but subsequently, there will be an increase in pollution due to industrialization, which imposes significant pressure on the environment. The increase in the per capita income levels in countries rich in extractive resources could therefore be explained by industrial development, which is a source of deforestation. Population growth has a mixed effect on deforestation. This seems to support the idea of forest destruction caused by the expansion of agricultural land to meet people's food needs. Ehrlich & Holdren (1971) argue that environmental degradation is positively correlated with population size. The ecological footprint is sensitive to the population size since it decreases the bio-capacity. The net development assistance received (ODA) contributes to reducing the loss of forest cover in developing countries. Therefore, the average rainfall shocks contribute to accelerating the deforestation process in developing countries. Previous empirical studies such as Kirby et al. (2006) suggest that roads, high population densities, low annual rainfall, and long dry seasons also increase the likelihood that a site will be deforested.

4.3. The effects of the basic models (economic rents and tax revenue)

Economic rents, according to our theoretical model, affect the forest cover directly or indirectly. The results in Table 1 show that economic rents have a positive impact on the loss of forest cover and are significantly different from zero. This reinforces the results of Combes et al. (2018), i.e., that mining rents positively impact deforestation. Our results are in line with the intuition that extractive industries are invasive and can, therefore, destroy forest areas. Considering Table 2, when economic rent increases by one percentage point, then deforestation increases by 0.13% to 0.34% (columns 6 and 2). This measures the overall effect of economic rents on deforestation. The positive impact suggests a complementarity between total economic rent and natural capital in resource-rich developing countries.

Table 2 shows that government revenue has a negative and significantly nonzero impact on deforestation. It can be interpreted that a one-percentage-point increase in government revenue from extractive industries is linked to a decrease in deforestation of 0.43% to 0.56% (columns 5 and 4). If we control for the presence of internal conflict, the effect remains negative but not significant. The result seems controversial in relation to Combes et al. (2018), who found that public spending increases the forest cover loss. However, our results are in line with the objective of the World Bank in terms of domestic resource mobilization to meet the needs of populations while protecting the environment. Similarly, the time horizon of our data coincides with the implementation of the Extractive Industries Transparency Initiative (EITI) in 2003. This initiative includes almost all the countries in our sample. López et al. (2011) draw attention to the effect of the composition of tax expenditure on the environment and argue that a reallocation of the composition of public expenditure towards public and social goods reduces pollution.

Table 1: Estimated impact of the total extractive rents on deforestation

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log forest loss (-1)	0.712*** (0.0554)	0.611*** (0.0710)	0.625*** (0.0688)	0.534*** (0.0775)	0.557*** (0.0827)	0.628*** (0.0809)
Log total rents	0.225*** (0.0767)	0.342*** (0.123)	0.328*** (0.126)	0.328*** (0.124)	0.299* (0.153)	0.133** (0.0529)
GDP per capita growth		-0.161*** (0.0420)	-0.157*** (0.0417)	-0.148*** (0.0414)	-0.141*** (0.0415)	0.0657* (0.0346)
Population growth			-0.148** (0.0753)	-0.174* (0.0934)	-0.124 (0.0863)	0.293* (0.153)
Log rainfall shocks				0.0126*** (0.00297)	0.0124*** (0.00313)	0.0099*** (0.00289)
Log NET ODA per capita					-0.285*** (0.0962)	-0.331*** (0.121)
Log internal conflict						0.302 (0.594)
Constant	3.028*** (0.596)	4.643*** (0.843)	4.715*** (0.852)	4.511*** (0.812)	5.111*** (0.960)	3.212** (1.423)
Nb. of observations	748	747	747	747	715	582
Hansen (p-value)	0.067	0.872	0.798	0.881	0.423	0.932
AR (1) p-value	0.000	0.042	0.047	0.039	0.034	0.078
AR (2) p-value	0.849	0.854	0.767	0.82	0.264	0.125
Nb. of instruments	5	7	8	9	10	11
Countries	49	49	49	49	48	39

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. GMM-System - Generalized method of moment's estimator with country fixed effects for the study period 2001-2017. Delayed forest loss is a predetermined endogenous variable; rents are contemporaneously endogenous; population growth, GDP per capita growth rate, Net ODA per capita, internal conflict, and average rainfall are assumed to be weakly exogenous.

Table 2: Estimated impact of government revenues from extractive industries on deforestation

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log forest loss (-1)	0.723*** (0.0823)	0.707*** (0.0992)	0.673*** (0.103)	0.558*** (0.117)	0.615*** (0.135)	0.588*** (0.0856)
Gov. res-revenues	-0.0481*** (0.0178)	-0.0459** (0.0204)	-0.0499*** (0.0186)	-0.0565*** (0.0180)	-0.0431** (0.0190)	-0.0222 (0.0197)
GDP per capita growth		-0.00407 (0.0122)	-0.00364 (0.00840)	-0.00971 (0.0151)	-0.0150 (0.0206)	-0.00560 (0.00910)
Population growth			0.312* (0.182)	0.0714 (0.265)	0.0775 (0.285)	0.268 (0.253)
Log rainfall shocks				0.00920** (0.00382)	0.00774** (0.00382)	0.011*** (0.00278)
Log NET ODA per capita					-0.0844 (0.132)	-0.141** (0.0704)
Log internal conflict						-0.0519 (1.194)
Constant	3.820*** (1.171)	4.070*** (1.385)	3.857*** (1.367)	4.842*** (1.585)	4.485*** (1.637)	4.081* (2.426)
Nb. of observations	301	301	301	301	292	259
Hansen (p-value)	0.137	0.114	0.221	0.256	0.18	0.541
AR (1) p-value	0.001	0.002	0.002	0.002	0.003	0.009
AR (2) p-value	0.706	0.691	0.674	0.626	0.319	0.341
Nb. of instruments	6	7	8	9	12	17
Countries	25	25	25	25	25	23

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. GMM-System - Generalized Method of Moment's estimator with country fixed effects for the study period 2001-2017. Delayed forest loss is a predetermined endogenous variable; res-revenues are contemporaneously endogenous; population growth, GDP per capita growth rate, NET ODA per capita, internal conflict, and average rainfall are assumed to be weakly exogenous.

4.4. Robustness check

4.4.1. Sensitivity related to the composition of the total extractive rents.

We estimate individually the effect of each type of extractive rent on deforestation. The results show that mineral rents and gas rents have positive and significant impacts on deforestation (Table 3 and Table A1). However, oil rents have a negative impact on deforestation (Table A2). This effect could be explained by the size of oil rents compared to mineral rents and gas rents. Additionally, the government share of revenue for an oil project is higher than that of other extractive projects. According to Baunsgaard and Sunley (2001), the extractive industries' tax regime predicts that oil regimes are higher than mining regimes, and anticipates higher profits for the former. This effect may be caused by the fact that oil projects require less surface area than mining projects. All other things being equal, we can argue that even oil rents contribute significantly to reducing forest cover loss. The robustness estimation shows that our theoretical predictions are not affected by a problem of multicollinearity. We also note that when considering only mining rents, growth in GDP per capita contributes significantly to forest cover loss. In contrast, for the individual oil and gas rent specifications, growth in GDP per capita contributes to a reduction in forest cover loss. This would imply that, unlike the oil and gas industries, income growth based on mining is detrimental to forest cover. The same is true for the effects of population growth. The effects of ODA and climate shocks remain unchanged.

Table 3: The effects of mineral industry rents on forest cover loss

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log Forest loss (-1)	0.661*** (0.0652)	0.692*** (0.0814)	0.690*** (0.0822)	0.601*** (0.0848)	0.602*** (0.0784)	0.628*** (0.0809)
Log mineral rents	0.204*** (0.0401)	0.137*** (0.0455)	0.135*** (0.0454)	0.150*** (0.0419)	0.200*** (0.0495)	0.133** (0.0529)
GDP per capita growth		0.0396* (0.0213)	0.0398* (0.0217)	0.0563* (0.0292)	0.0292 (0.0430)	0.0657* (0.0346)
Population growth			0.00725 (0.112)	0.0472 (0.113)	0.0407 (0.0931)	0.293* (0.153)
Log Rainfall shocks				0.0102*** (0.00358)	0.0110*** (0.00292)	0.0099*** (0.00289)
Log NET ODA per capita					-0.338*** (0.115)	-0.331*** (0.121)
Log Internal Conflict						0.302 (0.594)
Constant	4.108*** (0.766)	3.582*** (0.932)	3.584*** (0.983)	3.487*** (0.757)	4.658*** (1.112)	3.212** (1.423)
Nb. of observations	671	671	671	671	647	533
Hansen (p-value)	0.568	0.14	0.138	0.106	0.379	0.439
AR (1) p-value	0.00	0.00	0.00	0.00	0.00	0.00
AR (2) p-value	0.698	0.522	0.518	0.518	0.969	0.887
Nb. of instruments	6	11	12	13	12	13
Countries	46	46	46	46	45	36

Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. GMM-System - Generalized method of moment's estimator with country fixed effects for the study period 2001-2017. Delayed forest loss is a predetermined endogenous variable; Rents are contemporaneously endogenous; population growth, GDP per capita growth rate, NET ODA per capita, Internal Conflict, and average rainfall are assumed to be weakly exogenous.

4.4.2. Sensitivity related to the composition of public expenditure.

Table 4 shows that gross fixed capital formation (GFCF), final consumption, and household expenses have positive and significant impacts on deforestation. Following Combes et al. (2018), these results further confirm the hypothesis of complementarity between artificial and natural capital. However, the resource revenues to GFCF ratio and military expenditure contribute to reducing deforestation. This confirms the hypothesis of substitutability between artificial and natural capital. The government resource revenues to final consumption ratio are found to be insignificant. Although military expenditures do not have a direct impact on deforestation, their negative impact can be explained by the decrease in the volume of expenditures related to deforestation. The negative impact of the resource revenues to GFCF ratio confirms that government revenue from extractive industries takes into account the negative impact of the extractive sector on forest cover. In other words, the share of resource revenues in capital investments fosters forest conservation.

Table 4: The effects of the composition of public spending on forest cover loss

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log forest loss (-1)	0.537*** (0.0832)	0.683*** (0.122)	0.503*** (0.111)	0.618*** (0.140)	0.479*** (0.0953)	0.553*** (0.122)
GDP per capita growth	0.158*** (0.0581)	-0.00538 (0.0576)	0.000372 (0.0199)	-0.0100* (0.00563)	0.104** (0.0525)	-0.112*** (0.0321)
Population growth	0.252* (0.143)	0.236 (0.170)	0.202 (0.146)	0.231 (0.230)	0.424** (0.189)	-0.0839 (0.184)
Log rainfall shocks	0.0123*** (0.00294)	0.00853*** (0.00330)	0.0129*** (0.00360)	0.0115*** (0.00288)	0.0155*** (0.00444)	0.0091*** (0.00314)
Log NET ODA per capita	-0.230* (0.137)	-0.0811 (0.0688)	-0.0546 (0.127)	-0.0673 (0.131)	0.162 (0.211)	-0.277** (0.118)
Log internal conflict	1.358* (0.764)	0.0247 (0.912)	0.893 (1.031)	0.881 (1.070)	1.722 (1.112)	-0.199 (0.793)
Log GFCF	0.266*** (0.0872)					
Gov. res-revenue/GFCF		-0.466** (0.232)				
Log Consum.			0.400*** (0.117)			
Gov. res-revenue/Consum.				-1.195 (1.225)		
Log household expenses					0.760*** (0.285)	
Military expenditure						-0.351*** (0.113)
Constant	-5.969* (3.063)	2.885 (1.881)	-6.383** (3.164)	1.546 (1.371)	-18.89** (8.647)	6.799** (2.773)
Nb. of observations	594	255	589	234	522	572
Hansen (p-value)	0.501	0.259	0.148	0.199	0.227	0.213
AR (1) p-value	0.026	0.014	0.00	0.01	0.00	0.001
AR (2) p-value	0.338	0.284	0.898	0.425	0.356	0.230
Nb. of instruments	11	13	13	14	11	13
Countries	41	23	41	21	39	41

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. GMM-System - generalized Method of moment's estimator with country fixed effects with study period 2001-2017. Delayed forest loss is a predetermined endogenous; res-revenue is contemporaneously endogenous; population, consumption, GFCF, household expenses, military expenditure, GDP per capita growth rate, NET ODA per capita, internal conflict, and average rainfall are assumed to be weakly exogenous.

5. Discussion

This paper revisits the links between extractive industries and natural capital in developing countries. Certainly, many aspects of natural capital (such as biodiversity, clean air, land, and water) can be influenced by the extractive industries. However, this article focuses on the aspect relating to forest losses. Our main assumption was that the access to extractive industry rents could have non-homogenous impacts on forest cover, according to the type of rent. This assumption is confirmed by the results of the empirical analysis. First, the total economic rents from extractive industries significantly increase deforestation, confirming a situation of complementarity between rents and natural capital (forest cover). Second, the indirect effect of rents on deforestation shows

that the increase in government resources tax revenue reduces deforestation, thus reflecting substitutability between the share of government rents (artificial capital) and deforestation (natural capital). Third, mineral rents and gas rents contribute significantly to accelerating forest cover loss, unlike oil rents, which have contributed significantly to reducing forest cover loss. Previous studies such as Gifford et al. (2010) indicate that about 70% of gold mining comes from developing countries, where the consequences related to environmental damage are often greater for the sustainability of local communities. Ranjan (2019) shows that mining contributed to deforestation in 314 districts of India in 2001-2014. However, districts not producing any of the main minerals had 350 km² less of forest loss.

A discussion could be held on the net effect of extractive industries on deforestation according to the type of rent and because of the non-homogeneity assumption. In other words, a negative effect suggests that the impact of rents in favor of forest gains outweighs the damage they cause in terms of forest losses, and vice versa. First, the extractive industries require the occupation of large areas for local installation and infrastructure such as hydroelectric plants, railways, and roads that lead to deforestation. Kirby et al. (2006) also found that road development is a key driver of the deforestation process. The relocation of local communities to new housing sites, and the development of new agricultural fields leave significant environmental footprints. Second, economic rents can contribute to accelerating deforestation if the government's share of rents (i.e., resource taxes, fees, and shareholder participation) is funded to deforestation-related activities such as extensive agriculture and infrastructure. By contrast, economic rents can contribute to mitigating deforestation if the government's share of rents is used to fund non-deforestation-related activities. Compliance with environmental legislation and the inclusion of social, environmental, and economic concerns in the management systems of companies would compensate for the damage caused and contribute to forest restoration. For example, the Grande Carajás mine required the creation of some 800,000 hectares of protected areas and indigenous reserves to partially compensate for the damage it caused (Humphreys Bebbington et al., 2018). E. Barbier (2011) addresses the funding challenge of bridging the shortfall between the global benefits that humanity receives from ecosystems and what it is willing to pay to maintain and conserve them.

Finally, we find that government revenue from extractive industries contributes to mitigating forest cover loss. Thus, the positive effect of mineral rents and natural gas rents on deforestation shows that the mechanisms of compensation for damages caused are not effective. This may be the result of ineffective tax systems, the under-valuation of environmental damage in tax regimes, or the reallocation by governments of part of the rehabilitation funds intended for deforestation-related activities. For example, the tax regime predicts that oil regimes are higher and anticipate higher profits than mining regimes (Baunsgaard and Sunley, 2001). The economic theory had historically ignored the reality of the role of natural capital in the production process. Its full value is not well recognized in political trade-offs and economic choices, despite its fundamental importance for well-being. At the microeconomic level, market prices do not reflect the full costs and benefits of a product, and at the macroeconomic level, environmental values are not reflected in national accounts (European Environment Agency, 2015).

Furthermore, the theoretical model indicates that the cost of access to natural capital is higher when property rights are safe and well defined. We use internal conflict to approach the influence of institutions and the management of property rights on deforestation. Our results show an ambiguous effect of internal conflict on deforestation. Larcom et al. (2016) found that internal

conflict might generate higher or lower levels of deforestation. The poor social and environmental conditions brought about by the Grande Carajás project on the rural population have led to social conflict (Humphreys Bebbington *et al.*, 2018). Given the stakeholders in the extractive industries (central government, local communities, companies), this could be close to Vincent and Elinor Ostrom’s concept of polycentric governance, which includes the notions of “commons” and “natural resource systems” (Carlisle and Gruby, 2019) and “socio-ecological system” (Folke *et al.*, 2005). The polycentric governance concept connotes a complex system of governance with multiple semiautonomous decision-making centers. In the case of extractive industries, the final decision to implement the mining projects rests with the central government, based on the profitability of a given project, the socio-economic and environmental damage that may be faced by local communities, and an equitable share of the revenue.

This study is limited to the aspect related to the loss of forest cover, although it is certain that several other natural capital factors are also affected in one way or another by the exploitation of extractive industries. In the spirit of complementing this study, future research should address the extinction of plant and animal species, air and water pollution, and the health of local communities. To simplify this study, we include only a few control variables that could influence forest cover, based on validated econometric tests. However, several other variables not included in our specifications also contribute significantly to changes in forest cover. Finally, the impacts of institutional factors, such as governance, transparency, and property rights, have not been the subject of consistent analysis.

6. Concluding remarks

This paper contributes to the empirical literature on the relationship between extractive industries and deforestation, the source of the “curse of natural resources”. The analysis focuses on the direct and indirect effects of economic rents on forest cover loss with a focus on comparing these effects according to the nature of the rents and the composition in terms of investment expenditure and final consumption. Previous studies have mainly analyzed the relationship between resource dependence and capital accumulation, with little attention paid to resource funds, which should be an effective tool for such accumulation, particularly in oil-producing countries. To our knowledge, this paper is the first to present a rigorous econometric analysis comparing the effect of extractive rents on forest cover loss. Our results suggest that access to extractive industry rents has non-homogenous impacts on forest cover in resource-rich countries, according to the type of rent.

Our results can be interpreted as indicating a “polluter pays” situation, where part of the natural resource benefits is obligatorily earmarked to compensate for forest encroachment by extractive industries. If this is the case for mineral and gas rents, since they significantly contribute to damaging forest cover, the share of revenues destined for compensation (e.g., area taxes) must be at least equal to the marginal damage. It is, therefore, necessary to strengthen tax regimes to obtain an equitable share of economic rents in order to improve forest protection. Public spending should target as much economic activity as possible in order to generate the least adverse environmental impacts. Companies and governments must ensure that exploitation by extractive industries results in real and positive social, economic, and environmental gains for affected communities, as also suggested by the Extractive Industries Transparency Initiative (EITI) standard (<https://eiti.org/document/eiti-standard-2019>).

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Appendix

Table A1: The effects of oil rents on forest cover loss

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log forest loss (-1)	0.675*** (0.0995)	0.689*** (0.0939)	0.674*** (0.0967)	0.837*** (0.174)	0.657*** (0.0887)	0.576*** (0.0971)
Log oil rents	-0.306*** (0.0917)	-0.282*** (0.0906)	-0.295*** (0.0897)	-0.459** (0.197)	-0.234** (0.0964)	-0.0376 (0.130)
GDP per capita growth		-0.00880*** (0.00297)	-0.00819** (0.00370)	-0.0110** (0.00549)	-0.00923*** (0.00248)	-0.0111*** (0.00265)
Population growth			0.0162 (0.101)	0.113 (0.150)	-0.0543 (0.0796)	-0.116 (0.253)
Log rainfall shocks				-0.0166 (0.0164)	0.00986*** (0.00313)	0.0097*** (0.00364)
Log NET ODA per capita					-0.349*** (0.109)	-0.285*** (0.105)
Log internal conflict						1.135** (0.513)
Constant	4.048*** (1.205)	3.827*** (1.096)	4.055*** (1.215)	3.680*** (1.155)	4.341*** (1.062)	2.769* (1.563)
Nb. of observations	535	534	534	534	502	426
Hansen (p-value)	0.244	0.37	0.278	0.552	0.336	0.122
AR (1) p-value	0.00	0.00	0.00	0.004	0.00	0.003
AR (2) p-value	0.502	0.432	0.433	0.394	0.197	0.143
Nb. of instruments	6	9	8	10	10	17
Countries	36	36	36	36	35	30

Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. GMM-System - Generalized Method of Moment's estimator with country fixed effects for the study period 2001-2017. Delayed forest loss is a predetermined endogenous variable; rents assumed are contemporaneously endogenous; population growth, GDP per capita growth rate, NET ODA per capita, internal conflict, and average rainfall are assumed to be weakly exogenous.

Table A2: The effects of gas rents on forest cover loss

	<i>Dependent variable: log forest loss</i>					
	(1)	(2)	(3)	(4)	(5)	(6)
Log Forest loss (-1)	0.804*** (0.0744)	0.753*** (0.0864)	0.746*** (0.0651)	0.675*** (0.0838)	0.689*** (0.0726)	0.651*** (0.0524)
Log gas rents	0.0105 (0.0203)	0.0164 (0.116)	0.0260 (0.112)	0.113 (0.0776)	0.154* (0.0843)	0.185* (0.112)
GDP per capita growth		-0.126*** (0.0263)	-0.00936** (0.00429)	-0.00756*** (0.00274)	-0.00748*** (0.00256)	-0.0104*** (0.00319)
Population growth			-0.145** (0.0707)	-0.162** (0.0738)	-0.128* (0.0677)	-0.00483 (0.142)
Rainfall shocks				0.0115*** (0.00391)	0.00979*** (0.00322)	0.0122*** (0.00310)
Log NET ODA per capita					-0.134 (0.0915)	-0.114 (0.0814)
Log Internal Conflict						1.392*** (0.513)
Constant	2.256*** (0.847)	3.206*** (1.116)	3.211*** (0.894)	3.202*** (0.796)	3.608*** (0.897)	0.831 (1.093)
Nb. of observations	480	479	479	479	447	388
Hansen (p-value)	0.108	0.122	0.122	0.117	0.19	0.251
AR (1) p-value	0.00	0.077	0.00	0.00	0.00	0.01
AR (2) p-value	0.781	0.452	0.467	0.32	0.103	0.134
Nb. of instruments	12	11	13	9	10	13
Countries	32	32	32	32	31	27

Robust standard errors in parentheses. * p < 0.10, ** p < 0.05, *** p < 0.01. GMM-System - Generalized method of moment's estimator with country fixed effects with study period 2001-2017. Delayed forest loss is a predetermined endogenous variable; Rents are assumed contemporaneously endogenous; population growth, GDP per capita growth rate, NET ODA per capita, Internal Conflict, and average rainfall are assumed to be weakly exogenous.

Table A3: Descriptive statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max	Source	Description
Forest loss year_20	884	1469435	5040906	0	5.86E-07	Hansen et al. (2013). Data available online: http://earthenginepartners.appspot.com/science-2013-global-forest	Hectares of tree cover loss, by country, from 2001 to 2018, categorized by percentage of canopy cover, canopy cover > 20%
Total extractive rents	876	8.890443	13.24438	0	68.7483	WDI-World Bank	Mineral rents + Oil rents + Gas rents (% GDP)
Mineral rents	880	1.889859	3.795242	0	29.82654	WDI-World Bank	Mineral rents (% GDP)
Oil rents	876	6.512433	13.02709	0	67.5278	WDI-World Bank	Oil rents (% GDP)
Natural gas rents	876	0.4796556	1.033261	0	5.704	WDI-World Bank	Natural gas rents (% GDP)
GDP per capita growth	882	3.091272	7.296149	-62.37808	121.7795	WDI-World Bank	GDP per capita growth (annual %)
Population growth	884	1.714659	1.333731	-9.080638	7.78601	WDI-World Bank	Population growth (annual %)
Net ODA received	859	57.95048	65.60888	-26.65224	819.2875	WDI-World Bank	Net ODA received per capita (current US\$)
Gross fixed capital formation	846	7.38E-13	4.15E-14	1.78E-08	4.37E-15	WDI-World Bank	Gross fixed capital formation (current LCU)
Final consumption	839	1.98E-10	5.51E-10	3.22E-07	4.88E-11	WDI-World Bank	Amount of general government final consumption expenditure (in current US\$)
Total resource revenues	321	13.36433	14.3983	0.0447867	72.35043	https://www.ictd.ac/dataset/grd/	Total natural resource revenues, including natural resource revenues, reported as “tax revenue” or “non-tax revenue”
Rainfall shocks	884	96.795	67.03309	1.977812	287.8786	Climatic Research Unit, University of East Anglia and CERDI https://data.cerdi.org/	Deviation of the yearly average of rainfall levels (mm) from its 1901 to 2019 trend
Internal conflict	705	8.673499	1.443335	2.916667	11.91667	International Country Risk Guide (ICRG)	Internal Conflict index from the ICRG database. This is an assessment of political violence in the country and its actual or potential impact on governance. A score of 4 points equates to very low risk and a score of 0 indicates very high risk.

Table A4: List of developing countries included in the dataset.

South Asia	East Asia & Pacific	Middle East & North Africa	Europe & Central Asia	Latin America & Caribbean	Sub-Saharan Africa
3	4	7	9	10	19
Afghanistan	Indonesia	Algeria	Albania	Argentina	Angola
Bhutan	Lao People's Democratic Republic	Egypt	Armenia	Belize	Botswana
India	Mongolia	Iran	Azerbaijan	Brazil	Burkina Faso
	Myanmar	Iraq	Belarus	Colombia	Cameroon
		Jordan	Bosnia and Herzegovina	Cuba	Central African Republic
		Libya	Bulgaria	Ecuador	Congo, Republic of the
		Morocco	Georgia	Guatemala	Ivory Coast
			Kazakhstan	Guyana	Equatorial Guinea
			Kyrgyzstan	Honduras	Ethiopia
				Mexico	Gabon
					Gambia, The
					Ghana
					Guinea
					Guinea-Bissau
					Lesotho
					Liberia
					Madagascar
					Mali
					Mozambique