Foreign capital, forest change and regulatory compliance in Congo Basin forests

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Abstract
Tropical forest change is driven by demand in distant markets. Equally, investments in tropical forest landscapes by capital originating from distant emerging economies are on the rise. Understanding how forest outcomes vary by investment source is therefore becoming increasingly important. We empirically evaluate the relationship between investment source and deforestation from 2000 to 2010 in the Republic of Congo. A Congolese forestry code was implemented in 2000 to mitigate degradation of production forests by standardizing all logging in the country according to sustainable forest management (SFM) guidelines. Following the implementation of this law, the majority (73%) of Congo’s production forests were managed by European (40%) and Asian (33%) companies. European concessions had the highest rates of total and core deforestation, followed by Asian concessions, indicating that the fragmentation of intact forests in Congo is strongly associated with industrial logging fueled by foreign capital. European concession holders were also far more likely to comply with SFM policies, followed by Asian concessions, suggesting that compliance with Sustainable Forest Management policies may not mitigate degradation in tropical production forests. Further evaluation of the relationship between investment source, regulatory compliance, and outcomes in tropical countries is essential for effective conservation of tropical forest ecosystems.

Keywords: conservation success, avoided deforestation, logging concessions, counterfactual, quasi-experimental matching

Online supplementary data available from stacks.iop.org/ERL/9/044007/mmedia

1. Introduction
Tropical forest change is largely driven by resource consumption in distant markets [1–3]. At the same time, increasing levels of foreign investment from emerging economies in the tropical forest landscape are changing how forests will be managed [4–6]. Indeed, management rights to millions of hectares of forest land have changed hands in the last decade and much of this change is driven by transnational capital investments [7–9]. These capital movements supplement substantial existing forest investments in forest concessions, particularly in Central Africa and Southeast Asia [10, 11]. The source of capital influences many aspects of firm behavior, including production practices, social invest-
ments, regulatory compliance and target markets [5, 12–15], but the effects of investment source on forest outcomes remains under-investigated.

The issue assumes greater importance in the context of Sustainable Forest Management (SFM): the process of managing permanent forest land for timber production without reducing inherent values and future productivity. SFM was identified during the 1992 Rio Summit as a key strategy to achieve positive social and economic benefits without compromising tropical forest ecosystem function [16]. SFM uses selective, rotational logging of natural forests, thus providing income for governments and people by allowing productive use of the forest, but also preventing forest clearing associated with intensive logging [17]. Since Rio, a growing proportion of tropical forests are managed under SFM principles [18, 19].

The global SFM community has developed both regulatory and market-based approaches for SFM implementation [16, 20–22]. National SFM-based forestry codes are key aspects of SFM establishment, but governance within tropical forest nations is often weak, limiting the capacity to enforce natural resource policies [23, 24]. International partnerships among governments, conservation organizations, development agencies and timber producers [25] have coalesced to support SFM implementation. These partnerships aim to strengthen government capacity, fight corruption (e.g. with ‘independent observers’), and develop market-based tools (i.e. green certification such as Forest Stewardship Council (FSC) [26]) to incentivize compliance with SFM policies [5, 22, 25, 27–29].

Our objective was to understand whether different investment sources influence behavior and outcomes in tropical production forestry guided by SFM policies. We focus on the Republic of Congo (Congo) (figure 1). In the 1990s, logging expanded rapidly throughout Congo [30] leading to precipitous wildlife declines [31–33]. In response, Congo passed a forestry law in 2000, designed in accordance with Sustainable Forest Management (SFM) principles. The law assigned 54% of all Congolese forests as forest management units to be harvested by industrial logging companies under long-term leases (i.e. logging concessions). The forestry law requires the development and implementation of a government-approved Forest Management Plan (FMP). A FMP is a detailed plan for rotational selective logging, and is designed to ensure adequate time for maturation of new harvestable specimens before the next logging cycle [34–36]. In addition, concessions are eligible to undergo market-based certification (i.e. FSC). FSC certification requires stricter biodiversity conservation measures and greater social obligations than the forestry law, but increases the demand for a concession’s timber as well as the variety of markets where the timber can be sold [26]. We used deforestation datasets derived from satellite imagery and a quasi-experimental matching approach to test if, in the 10 years following the passage of the overarching 2000 Congolese forestry law, concession-holder investment source influenced (a) deforestation rates, and (b) compliance with SFM policies.

2. Materials and methods

2.1. Data

2.1.1. Outcomes. Land cover data was derived from FACET land cover maps produced from automated classification of Landsat imagery [37, 38]. The FACET land cover maps characterize land cover and change in the Republic of Congo in two time periods: 2000–2005 and 2005–2010. FACET land cover maps are categorized into 12 classes, which for this analysis we further aggregated into the following 6 classes: (a) Forests, including primary, secondary, and swamp forests, (b) Non-forest, (c) Water, (d) Forest cover loss 2000–2005, (e) Forest cover loss 2005–2010, and (f) No Data. Deforestation represents any stand-clearing forest cover loss, including logging roads, timber extraction, and agricultural fields. The original spatial resolution of the land cover dataset was 60 m. We aggregated all data into 1 km grid cells to achieve a sample size that was computationally feasible, and consistent with similar analyses in the published literature [39, 40]. We calculated deforestation rates from (a) 2000–2005, (b) 2005–2010, and (c) 2000–2010 as the percentage of forest at the beginning of the time period that was cleared by the end of the time period. We classified cells beyond 1 km of a road, navigable river, settlement, or non-forest pixel as ‘core’ forest [30, 41]. We analyzed core deforestation separately from total deforestation rates.

2.1.2. Concession characteristics. We obtained concessionary boundaries and characteristics from the Forest Atlas of Congo V3 [42], which distinguishes the following categories of investment source: Congo, China, Malaysia, Europe, and Lebanon. For the purpose of our analysis, we aggregated China, Malaysia, and Lebanon into an ‘Asian’ category, according to standard continental geographic classifications. As an indicator of compliance, we used a concession’s management status achieved by 2011. The Forest Atlas of Congo V3 distinguishes the following categories of management status: (a) FSC-certified, (b) with Forest Management Plan (FMP), (c) FMP in progress, (d) no FMP, (e) inactive/unattributed, (f) Protected Area (PA), and Unassigned, i.e. not assigned to the permanent forest domain. Six concessions switched status between unattributed and no FMP during the 2000–2010 time period, so were categorized according to their majority status.

2.1.3. Covariates. We controlled for seven key confounders that we expected to influence the likelihood of treatment and the outcomes on a given forest parcel (i.e. 1 km grid cell) (see supplemental information for justification of the covariates available at stacks.iop.org/ERL/9/044007/mmedia). These include: (1) distance to a non-forest edge, (2) distance to the Congo/Oubangui River, (3) distance to nearest settlement, (4) travel time, (5) elevation, (6) slope, and (7) above-ground woody biomass. We obtained settlements, rivers, and roads data from the Forest Atlas of Congo. Distance to a non-forest edge, distance to Congo/Oubangui River, and distance to settlement were all calculated using Euclidean distances. We computed travel time estimates to major cities using the accessibility analyst [43], supplemented by improved roads, rivers and major cities data from the Forest Atlas of Congo and the FACET land cover data. We calculated slope and elevation from a Digital Elevation Model (DEM) recorded by the Shuttle Radar Topography Mission (SRTM). We used a 500 m resolution above-ground biomass dataset produced by
Woods Hole Research Center centered around 2007–2008 as a coarse measure of forest composition [44]. We projected all datasets into a customized Transverse Mercator projection and aggregated management regime, outcomes and covariates data into 1 km cells. Congo contained 335,822 cells, of which 287,025 (85%) contained forest in 2000.

2.2. Analysis

2.2.1. Concession-scale analysis. We summarized deforestation rates from 2000 to 2010 from the land cover data. We derived a 2000 roads dataset and a 2010 roads dataset by manually digitizing all roads visible on Landsat imagery (Landsat ETM 182/058 from February 9, 2001 and May 25, 2010; and Landsat ETM 181/058 from March 3, 2000 and March 31, 2010). We used annual allowable cutting zones where available until 2007 from the Forest Atlas of Congo [42].

2.2.2. Matching. Simple comparisons of the outcomes of different management regimes can be vulnerable to spatial biases in the allocation of management regimes within a landscape [45]. For our study area, we observed that certain management regimes were more likely to be situated in areas where deforestation was more likely to occur. To control for these important spatial confounders, we adopted a quasi-experimental matching approach. Our analytical strategy consisted of sampling forest parcels from areas under one management regime (‘A’) and matching these to forest parcels from areas subject to another management regime (‘B’) that were similar in terms of key confounders, such as accessibility, distance to settlements, topography and above-ground biomass (see materials and methods). We assumed that outcomes of this matched comparison group (‘B’) provided a counterfactual estimate for the treatment group (‘A’). In other words, we asked: What outcomes would we have observed on the forest parcels of regime ‘A’ had they instead been subject to regime ‘B’? We also switched control and treatment group to compute the reverse estimate (‘What would outcomes have been on forest parcels of regime ‘B’ had they instead been subject to regime ‘A’?’). We repeated this procedure for all 8 possible pairwise combinations of concessionary investment source.

We used Mahalanobis matching with replacement and bias adjustment for our pairwise comparisons of investment source. We randomly sampled 20% of the forest parcels from each management regime (treatment) and matched them to a sample of 20% of forest parcels in each other management regime (control). Our covariates include seven environmental and economic factors we assumed to influence the likelihood of both treatment and outcomes on any given parcel of land (see supplemental information for detailed description of covariates available at stacks.iop.org/ERL/9/044007/mmedia). We dropped treatment units for which no comparable control unit could be found within 1.0 SD of each covariate (calipers). We performed the analysis for all three time periods (2000–2005, 2005–2010, and 2000–2010). All analyses gave similar results, and we present here results from the 2000–2010 time period.

The performance of matching estimators is influenced by the quality of statistical support, i.e. the extent to which the pool of potential controls contains units that are sufficiently comparable to the treatment units. In our study area, concessions showed important differences in spatial location and properties, prompting the need for quality control of the resulting matching estimates. We therefore imposed the following quality thresholds to distinguish matching estimates of ‘high’ and ‘low’ comparability. For ‘high comparability’, (a) the sample size of the treatment group was not allowed to be more than three times larger than the size of the pool of potential controls, (b) matching needed to identify suitable

**Figure 1.** Concessions and investment sources in Republic of Congo.
control units for at least 50% of the treatment units (after imposing calipers) and (c) the mean absolute standard difference of all seven covariates between treatment and control group needed to be below 10 (covariate balance). Full results of the comparability assessments are included in tables S1–S2 available at stacks.iop.org/ERL/9/044007/mmedia.

3. Results

From 2000 to 2010, the majority of actively logged concessionary land in Congo was managed by foreign interests (73%), including European (40% of concessionary land, \( n = 15 \) concessions) and Asian (33%, \( n = 17 \)) companies. Congolese companies managed only 7% (\( n = 13 \) concessions) of the country’s production forests, and 20% (\( n = 18 \)) of concessionary land was inactive (i.e. not allocated to any firm for the majority of the time period).

We identified two distinct patterns of forest change in logging concessions (figure 2). First, a full 93% of deforestation occurred in edge areas (i.e. within 1 km from a public road, navigable river, or previously disturbed forest). Deforestation rates were 13 times higher in edge forests (1.1%) than in core forests (0.084%). Edge deforestation rates were highest close to settlements, existing roads, and agricultural fields.
Second, core deforestation (i.e. greater than 1 km from a non-forest edge) was typically contained within the annual allowable cut zones mandated by the logging contract, and aligned with new logging roads, indicating construction of new logging roads into intact forests.

We plotted deforestation rates as a function of distance to a non-forest edge, according to management status (figure 3). The plot indicates that European concessions experienced high deforestation rates in core and edge forests relative to other management units. However, simple comparisons of the outcomes of different management units can be vulnerable to spatial biases in the allocation of management regimes within a landscape. For instance, several of the Congolese concessions in our sample were located in areas with high density of roads and settlements, which complicated the attribution of observed outcomes to their management status.

The matching analysis compared samples that were similar in terms of deforestation pressure but were located within concessions with different sources of investment capital. Comparison of matched samples indicated that total and core deforestation rates varied significantly according to concession-holder investment source (figure 4). When assigning European concessions as the treatment (figure 4(a)), forest parcels in European concessions experienced higher total deforestation and core deforestation than matched samples in Asian, Congolese and inactive concessions. The impact of European concessions on total deforestation was confirmed when computing the reverse estimates (i.e. switching the treatment and control groups). Forest parcels in Congolese (figure 4(c)) and inactive concessions (figure 4(d)) experienced lower total deforestation rates than in European concessions. Forest parcels in Asian concessions had higher total deforestation rates than Congolese concessions in forward and reverse estimates (figures 4(b) and (c)), but core deforestation rates were not different between Asian and Congolese concessions.

Several comparisons classified as ‘low comparability’, indicating that some comparisons may still be biased despite the rigorous matching method (supplemental information, figure S1 and tables S1 and S2 available at stacks.iop.org/ERL/9/044007/mmedia). For example, the comparison between European concessions as the treatment and Congolese concessions as control failed two of the comparability criteria. European concessions cover a large proportion of the study area (40%), compared to Congolese concessions (7%), and thus (a) the sample size of the treatment group was more than 3 times larger than the control group, and (b) Congolese concessions did not contain an abundant pool of forest parcels that were statistically similar to European concessions, and thus high balance could not be achieved (i.e. the mean absolute standard difference of all seven covariates between treatment and control group were greater than 10). Our tests are the best available measure of treatment impact in this landscape, but caution must be taken when interpreting the results because of the low level of similarity among some treatment and control groups.

Figure 3. Deforestation rates from 2000 to 2010 in concessions with different management status as a function of distance from a non-forest edge.
Figure 4. Average differences in outcomes between treatment and comparison groups for each matched pairwise comparison with significant differences ($p < 0.05$). Positive values are in red, and indicate that treatment units experienced higher deforestation rates than the counterfactual comparison group. Negative values are in green, and indicate that the treatment units experienced lower deforestation rates than the counterfactual comparison group. Absent bars indicate no significant difference. See figure S1 and tables S1 and S2 in the supplemental information available at stacks.iop.org/ERL/9/044007/mmedia for full results, raw estimates and comparability criteria generated from the matching analysis.

Figure 5. Compliance with SFM policies in Congolese concessions. No FMP = Forest Management Plan process not initiated; FMP in Process = Forest Management Plan process initiated but not completed; FMP implemented = successful implementation of a Forest Management Plan; FSC certified = certification by the Forest Stewardship Council (requires SFM practices additional to those required by the Congolese forestry law).

We found systematic differences in SFM compliance depending on investment source (figure 5). European companies were by far most compliant with both state and market-based policies. By 2011, only 7 companies had successfully implemented FMPs (6 European and 1 Lebanese company), and only 3 had achieved FSC certification (all European). An additional 13 companies had initiated the FMP implementation process without completion (5 European and 7 Asian concessions). None of the 13 Congolese concessions had initiated FMPs or FSC certification.

4. Discussion

The main purpose of the Congolese forestry law of 2000 was to limit degradation of production forest ecosystems by standardizing logging practices according to SFM-based principles. However, our analysis revealed systematic differences in deforestation rates and SFM compliance based on investment source. Even when restricting results to matched samples with high comparability, total deforestation and core deforestation were all highest in foreign concessions as compared to Congolese or unattributed concessions. Furthermore, we found that while European concessions had the highest rates of SFM compliance, they also had the highest rates of total and core deforestation, indicating that the SFM-based policies may not be achieving their intended goal of limiting deforestation.

The higher total deforestation rates in European and Asian concessions compared to matched samples in Congolese and unattributed concessions may indicate higher rates of population growth and agricultural expansion. Concessionary logging is an economic development strategy in Congo Basin countries [19]. The 2000 Forestry Law includes ‘social contracts’ from logging companies, requiring them to generate employment for local people (for example, by building on-site timber processing facilities), maintain infrastructure, and provide basic services to local communities [21]. Settlements in and around logging concessions are expanding throughout
the Congo Basin as a result of increased economic activity and population growth stimulated by the timber industry [33], and our results suggest that rates of settlement expansion may be higher in European and Asian concessions compared to Congolese or inactive concessions.

Core deforestation rates were highest in production forests managed by European companies. Spatial patterns of deforestation indicate that the high rates of forest fragmentation observed in European concessions are associated with road construction for highly selective logging. European markets demand timber from only a few target tree species, and dense road networks are necessary to find those species [26, 35, 36]. Asian and Congolese markets demand a wider variety of less-valuable species [9, 10, 26]. Concessions serving those less-selective markets may have higher incentive to harvest more intensively in easily accessible forests, thereby saving money on road construction and maintenance, and avoiding penetration into core forests.

European concession holders were far more compliant with SFM policies. They were more likely to implement FMPs (as required by the Congolese forestry law), and the only concessions to achieve FSC certification. These observed differences confirm other studies in the Congo Basin which indicate that logging producers do not comply equally with SFM policies. Congolese concessions are likely challenged by the high investment cost of compliance and lack of technical capacity to implement SFM practices [19]. The low overall proportion (7%) of production forest managed by Congolese-owned companies may equally be attributed to the high investment cost of concessionary logging [19], coupled with low market incentive. Local Congolese markets are dominated by supply from the informal, artisanal, and illegal logging sectors, and thus there is little market incentive for Congolese companies to engage in the formal, industrial logging sector [22]. Compliance is also influenced by market incentives [5, 14], and European companies may have more incentive to adhere to the forestry law and to pursue certification, compared to Asian and Congolese companies. FMPs are designed to ensure long-term sustainability of the high-value target species that European markets consume. Furthermore, European markets are willing to pay more for sustainably managed timber [11], which may mitigate high costs of road construction and maintenance required for the highly selective logging required by FMPs. Finally, European companies are more accountable to international regulations, and more sensitive to negative publicity arising from poor management practices [28], compared to Asian and African markets [9, 10, 26].

We believe that our tests are the best available measure of impacts of investment source on forest outcomes in Congo, but we note several challenging aspects of impact assessment in this landscape, and the rationale for the methodology we employed. First, the placement of concessions with different investment sources is biased. We used matching analysis to deal with placement bias, and we implemented strict comparability criteria to identify those comparisons where low similarity between treatment and control groups may have influenced the impact estimates. Second, conservation outcomes and compliance can be measured using a variety of methods, and at multiple spatial scales. We used deforestation data as an indicator of conservation outcomes, and concessionary management status as an indicator of compliance, because these measures were consistently measured and covered the entire country. Our land cover dataset does not measure reforestation, forest degradation, actual biodiversity, or persistence of forest clearing, all of which are important indicators of sustainable forestry. Likewise, FMP and FSC implementation serve only as an indicator of SFM practices, and is not a direct field measure of the legality of timber extraction or harvest volumes. Further research that uses other on-ground measures of conservation and compliance, such as biodiversity surveys and timber extraction volumes, would enhance our understanding of the outcomes resulting from different management practices. Finally, forestry policy and logging operations were dynamic in Congo during the 10 years following the passage of the Congolese forestry law, influenced by global markets [46], increasing Asian presence [10], and growing monitoring and compliance [29]. Our results only characterize impacts from 2000 to 2010, and do not address the possibility that European/SFM logging strategies may have positive long-term implications (e.g. if highly selective logging practices result in higher-value timber stocks in the future). Continued monitoring is necessary to understand evolving relationships between investment source, outcomes and compliance in Congo Basin production forests, and to identify impacts that may occur at longer time scales.

Our findings indicate two priorities moving forward with the implementation of sustainable industrial logging in Congo Basin forests. First, the intention of Congolese forestry law is to standardize logging practices, but we found that deforestation and compliance with SFM policies systematically varied with investment source. Our findings demonstrate the need for continued efforts to strengthen governance and improve transparency of industrial logging operations in Congo [3]. Second, the overarching goal of SFM is to improve conservation outcomes of industrial logging in tropical forests, but our results suggest an unexpected association between SFM compliance and increased deforestation. This finding highlights an urgent need to empirically identify impacts of specific SFM policies (i.e. FMPs and FSC certification) within the context of the international Congolese industrial logging landscape.

5. Conclusions

Over 400 million hectares of tropical forests are now managed for timber production, comprising more than half of the remaining global permanent tropical forest estate [16]. A growing proportion of those forests are operating under SFM principles [18, 19]. We revealed a clear pattern of investment source impacts on forest change and SFM compliance, and our results point towards an urgent need for a better understanding of the processes underlying this pattern. Our results suggest that forest clearing and fragmentation of intact forests in the Congo Basin is driven by industrial logging made possible in
large part by international capital investments. They furthermore suggest that firms that were more compliant with SFM policies (i.e. European firms) had higher rates of total and core deforestation. If, in fact, SFM policy and certified timber markets are associated with increased forest cover change, this suggests that the growing global demand for legal and certified timber [25, 26] may have unforeseen consequences for intact tropical forest ecosystems. Our results call for continued monitoring of the outcomes of commercial logging practices in general, and different forest management practices in particular, to ensure the long-term future of tropical forests worldwide.

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