Three Essays on the Effectiveness of Voluntary Forest Certification

by

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Dedication

To my husband, my rock,
Joshua Simister

Acknowledgments

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Abstract

Finite contracts, weak local forest law, and poor monitoring erode incentives for firms to manage forests responsibly. In response, voluntary, independent certification of forest management practices has emerged as a policy tool. If firms choose to participate, in return for certified compliance with the standard they earn a price premium. Currently 9% of the world's production forests are certified by a credible voluntary standard, Forest Stewardship Council's Forest Management Certification (FSC). The effectiveness of voluntary environmental policies remains poorly understood, particularly in the developing world. My dissertation examines whether voluntary forest certification is effective at improving sustainable forest management. I focus on FSC certification in Central Africa, home to a highly intact tropical forest second in size only to the Amazon. In Central Africa, 66% of all forested land is gazetted for commercial forestry.[1] In three chapters, I evaluate FSC effectiveness by asking the following research questions (chapter titles follow in italics):

1. Do FSC participants improve the environmental quality of their harvesting behavior?

   Chapter 1: *Gaming the Baseline: Certified Timber Production in Cameroon*

2. Does the net effect of FSC activities improve development outcomes for locals?

   Chapter 2: *Unintended Impacts from Forest Certification: Evidence from Congolese Households*

3. Which forests participate in FSC and why? Do the highest priority forests participate?

   Chapter 3: *Drivers of Participation in Voluntary Forest Regulation and their Implications for Conservation*

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[1] Nasi, R., B. Cassagne, et al. (2006). "Forest management in Central Africa: where are we?" International Forestry Review 8(1): 14-20.

To answer these questions, I use multiple data sets and identification strategies. The data range from primary data collected from Congolese households along a certified forest border to a national panel of timber outcomes in Cameroon to a regional biogeographical dataset spanning Gabon, Cameroon, and Congo.

Across the three chapters, I find FSC to be relatively ineffective due to three policy design features: a relative standard for harvesting practices, process indicators for a multidimensional standard, and voluntary selection into the policy.

FSC standards for harvesting practices are not the same for all forests. For each forest, the auditor sets a management standard relative to that forest's unique baseline management practices. In *Gaming the Baseline*, my job market paper, I show that firms game this design feature by distorting their production when the auditor establishes this baseline. At certification, auditors document a change in harvesting practices, but on net, I do not find evidence that harvesting practices become more sustainable. These empirical results fit theoretical predictions from a principal-agent model with asymmetric information between the auditor and firm. Relative standards are not limited to forest management or FSC; consider time-shifting of electricity usage or carbon additionality policies. During policy design, policymakers must account for strategic firm behavior and should remain skeptical of documented change, however precisely measured.

FSC signals to consumers "responsible forestry," a standard that encompasses sustainable development for local forest users and protection of biodiversity, such as elephants and gorillas. FSC relies on process indicators to assess whether firms address social and environmental needs in their forest. Auditors can easily verify implementation of rural development activities, like building a road, and environmental protection activities, like financing eco-guards to patrol for poachers. The net effect on local forest users may be positive or negative, depending on the activities and a forest user's original endowment. Activities may also beget negative externalities, like local deforestation. My second chapter, *Unintended Impacts*, evaluates how FSC activities change forest dependent households' consumption, production, and wealth. The main FSC activities, a new road connection and controlled hunting protocols, result in worse nutrition outcomes for certified households. Consumption of animal protein falls by one third and indigenous households switch to an inferior starch source, in terms of calories, as wild protein and farmed starch are exported. Farmer households both intensify and extensify agricultural production. Extensification of fields comes from reduced fallow periods instead of increased field clearing. Farmer households use their wealth to improve their dwellings. This set of impacts reminds us that, when evaluating multidimensional policies, we should expect to find tradeoffs across social and environmental goals; there will be winners and losers. Policymakers must be prepared to explicitly prioritize among policy goals.

Finally, voluntary policies differ from traditional regulation in their reach: firms participate only if doing so improves their profits. In the third chapter, *Drivers of Participation*, I show that selection into legality and forest management certification depends on how each policy increases costs, which varies across forests. Whether or not the most important forests participate depends on how costs correlate with forest characteristics. In the case of FSC, high conservation value forest was not more or less likely to select into the policy. In the case of legality certification, I find that forests with higher production costs are more likely to participate.

CHAPTER 1

Gaming the Baseline: Certified Timber Production in Cameroon

1 Abstract

Forestry firms lack incentives to leave trees behind to regenerate and replenish timber stock. Firms can volunteer to adhere to a forest management standard defined by Forest Stewardship Council (FSC) and invite an auditor to visit and verify their compliance. In return, they label their timber as certified and receive a price premium. This paper asks, does certification improve the environmental quality of participating firms' harvesting practices? Using a panel dataset of timber production for all Cameroonian firms, I exploit variation in event timing and each species' local regeneration risk to identify changes in harvesting practices. I find that firms systematically distort production when the FSC auditor establishes their baseline. The firm fells younger, smaller trees at the baseline for poorly regenerating species only; species with the worst regeneration prospects see average tree size fall by 20 percentage points at the baseline audit. On net, I find no evidence that certification improves firm harvesting practices.

2 Introduction

In Cameroon, the government leases one third of the forest to firms for industrial timber production (Nasi et al., 2012). Once the lease ends, firms no longer have access to trees within the forest. When prices are high, firms fell too many trees and risk local extinction of commercial species. Knowing this, the Cameroonian government legally restricts access to young trees to ensure regeneration. If enforced, firms would incur new costs from more comprehensive inventories and additional roads as they leave behind profitable small trees and seek out large trees. However loopholes in forest legislation and weak monitoring make these restrictions de facto unenforced (Vandenhaute and Doucet, 2006). Forest Stewardship Council's (FSC) voluntary forest management certification may resolve the challenge of exploiting valuable timber in a way that sustains it for the future when local monitoring and enforcement is weak. Independent auditors certify that participating firms comply with FSC's standard. Once certified, firms receive a price premium for their timber from consumers willing to pay more for sustainably harvested timber.[1]

FSC is the largest and most credible sustainable forest management standard yet it remains empirically untested.[2] More generally, theoretical predictions for voluntary regulation's effectiveness are ambiguous when local monitoring is poor. The mechanism that drives changes in firm behavior from voluntary regulation appears to be improved targeting of a local regulator's monitoring and enforcement resources (Blackman, 2010). Furthermore, FSC relies on third-party auditors selected by firms to enforce harvesting restrictions. Yet auditors interested in garnering future contracts have poor incentives to truthfully report firm compliance (Duflo et al., 2013). In this paper, I investigate whether FSC certification improves the sustainability of timber harvesting and explore the mechanisms that determine FSC's effectiveness. I ask: Do we see greater protection for species at risk of local extinction and if not, why not?

Drawing on the dynamic contracting literature, I build a principal-agent model between auditors and firms to better understand FSC effectiveness and to frame my empirical results. My model extends the theoretical voluntary policy literature by explicitly modeling asymmetric information.[3] In the FSC process, auditors make a baseline assessment, define harvesting constraints relative to this baseline, and then certify compliance with harvesting constraints. Auditors balance improving regeneration by restricting access to trees against maintaining incentives for the firm to continue to participate in FSC. The menu of contracts they can

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[1] Estimates of the price premium for FSC-certified timber range from 5-30%, with most estimates around 10-15%. (Kollert and Lagan, 2007)(Nebel et al., 2005)(Aguilar and Vlosky, 2007). This magnitude is similar to the estimated price premium for Marine Stewardship Council's certified seafood (Roheim et al., 2011).

[2] As of October 2014, FSC certified forests are found in seventy-nine countries (FSC, 2014).

[3] For early surveys of the theoretical framing of voluntary policy, see (Khanna, 2001), (Lyon and Maxwell, 2002), and (Alberini and Segerson, 2002). A separate but related literature on payment for ecosystem services, a voluntary program, recognized the importance of modeling asymmetric information early in its development; see, for example (Wu and Babcock, 1995). This literature has since moved toward conservation auctions as a way to address the mechanism design problems inherent to voluntary policies (Ferraro, 2008).

offer is limited by FSC's price premium, determined exogenously in the marketplace. Under a broad set of conditions, the model predicts that firms distort production at the baseline assessment in order to weaken harvesting constraints. Based on the distorted baseline, the firm's opportunity cost from a harvesting constraint appears large to the auditor. At the baseline, firms produce away from the profit-maximizing level, creating a second-order profit loss, but gain a first-order increase in certified profits from the weaker constraint. Based on the model, we predict that at the baseline firms will fell more of the trees the auditor wants to protect: young trees of species at risk of local extinction.

Empirically, I investigate whether FSC improves harvesting practices by comparing production at FSC events to production in the pre-event period. More specifically, I compare changes at events for species at risk of extinction to changes for abundant species. To do this, I create a new dataset that links the Cameroonian Forest Ministry's production records to each species' local extinction risk. From 2003 to 2009, I observe all industrial forest production in Cameroon, FSC participants and non-participants alike. Using a difference-in-differences regression model, I investigate how each species' felled size and quantity changes at certification events. If certification improves the sustainability of harvesting practices, it should restrict access to young, poorly regenerating tree species previously exploited. We would expect at-risk tree size to increase once certified, a prediction I investigate using a triple difference-in-differences model.

Instead, I find evidence that firms distort production at the auditor's baseline assessment. As dynamic contracting theory would predict, I find a large and significant decrease in tree size in the baseline period for at-risk species only. On average, poorly regenerating species tree size decreases by 7% in the baseline period. I also exploit variation in the intensity of extinction risk among poorly regenerating species. Within each forest, some species have very high extinction risk and any timber exploitation is unsustainable. For these species, the question is not whether or not the auditor will constrain access to young trees, but by how much. We expect these species' incentives for distortion to be particularly strong and I find a commensurate decrease in tree size, 21%, in the baseline period. I find no evidence that FSC improves the sustainability of harvesting practices for species at risk of local extinction.

Relative to production before FSC participation, tree size for at-risk species is unchanged at certification. When considered from the auditor's perspective, however, certified tree size for high risk species appears improved relative to the baseline assessment.

I find further evidence that firms distort production in order to inflate their expected cost of compliance. At the baseline, firms abruptly and temporarily increase the quantity of trees felled for all species along extensive and intensive margins. Unlike costs related to seeking out large trees, which depend on a species' particular distribution of trees across space, felling cost parameters are common across species. A firm can inflate the opportunity cost of restrictions by making felling look less costly in general. For any species, the likelihood that the firm fells at least one tree increases by 12% at the baseline audit. The firm fells 60% more trees and total production for the forest increases by the same magnitude. Production returns to the pre-event average immediately after the baseline audit. Total firm production is unchanged in baseline audit years, suggesting that firms shift production across forests in order to accommodate distortion. Consistent with a higher certified price, I do find a large and significant increase in total firm production when certified: 36% more trees are felled in certified years.

The regulation and dynamic contracting literatures have long predicted firms would behave strategically in order to game a regulator's baseline (Weitzman, 1980; Laffont and Tirole, 1988, 1993). Empirical evidence is scant because reforms implementing incentive regulation were often accompanied by other changes, such as broader deregulation (Joskow, 2013). We do have empirical evidence of regulatory cycles, where public utilities make less effort to minimize costs before rate adjustment hearings (Casarin, 2014; Joskow, 2013; Di Tella et al., 2008; Bottasso and Conti, 2009). Given their empirical strategies, these papers document suggestive correlation between changes in costs and regulatory events. My paper uses a different identification strategy –difference-in-differences– to show a causal change in firm behavior at the regulator's baseline. Moreover, the changes I estimate may be better characterized as "pure" or "strategic waste," as described by Sappington (1980). In rate cases, firms lack incentives for cost minimization, whereas I find firms choose to incur additional costs now in order to increase future profits.

I contribute to the empirical voluntary policy evaluation literature in two ways. First, this paper is among the first to credibly evaluate voluntary policy effectiveness with a very weak local regulator. In developed countries, voluntary policies are most effective when they accompany mandatory regulation and strong monitoring and enforcement (Lyon and Maxwell, 2002). In developing countries, absent local compliance pressure, predictions about voluntary policy effectiveness are ambiguous (Blackman, 2010). To date, empirical evidence primarily comes transition economies with strong monitoring capacity relative to other developing countries (Rivera, 2002; Tambunlertchai et al., 2013; Foster and Gutierrez, 2013; Blackman et al., 2010). According to Foster and Gutierrez, who study impacts on air pollution from Mexico's Clean Industry Program, the program improved air quality by acting as a signal for the local regulator to more efficiently allocate scarce auditing resources. Second, this is the first study to credibly evaluate voluntary policy effectiveness in forestry (Blackman and Rivera, 2011). Forest certification has emerged as a global governance tool and FSC forest certification can be considered emblematic of a trend toward non-state, market-driven governance (Cashore et al., 2004; Earnhart et al., 2014). In contrast, most empirical evaluation of voluntary policy effectiveneses comes from toxics, ISO 14001, energy or air pollution policy and evaluates policies that are locally circumscribed (Kim and Lyon, 2014; Gamper-rabindran and Finger, 2013; Delmas et al., 2010; Morgenstern and Pizer, 2007; Khanna and Damon, 1999; King and Lenox, 2000).

The implications of this work extend beyond forest management to two areas of environmental policy. First, we gain evidence that even if FSC auditors are corrupt, oversight from a meta-auditor and public comment creates real pressure to report change from certification. This finding differs from the pattern found among Indian auditors, who reported firm compliance regardless of pollution emissions levels (Duflo et al., 2013). FSC ineffectiveness appears driven by policy design features that encourage strategic behavior instead of auditor rubber-stamping. Second, policymakers are experimenting with offsets in a variety of sectors, such as time-shifting in electricity demand ("Nega-watts") or carbon sequestration in avoided deforestation. In these policies, participants are rewarded for reducing their electricity consumption or deforestation relative to a reference level.[4] Scholars have expressed concern that offsets fail additionality, e.g. they would have happened even without the policy intervention. My work draws attention to a different problem with offsets, which must be measured relative to a baseline: agents may behave strategically, manipulate the baseline and fail to make any improvements at all.

The rest of the paper is outlined as follows. Section two describes the timber sector in Cameroon, the FSC certification process, and how regeneration risk is calculated. The theoretical model and its empirical predictions are section three. Section four describes the dataset, section five the empirical framework. Results from the empirical analysis are presented in section six. Section seven concludes.

3 Institutional Context

3.1 Timber Production in Cameroon

The second largest tropical forest in the world spans Central Africa. From Figure 1, we can see the extent of the forest, much of which is earmarked for timber production. In Cameroon, the government leases rights to selectively log timber sections of permanent forest domain, primarily through auction. These contracts give firms the right to fell timber within the boundaries of a forest management unit over thirty years.[5] As of 2009, there were 89 forest management units spanning six provinces, and the average forest management unit size was about 72,000 hectares.

The number of active forest management units changes over the course of the panel due to forest management units entering and exiting production. Beginning in 1999, the Cameroonian government began auctioning rights to forest management units through a closed bid

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[4] For example, in 2005 the City of Anaheim Public Utilities experimented with a billing schedule to address excess electricity demand on hot days. Consumers were rebated 35 cents/KWh for the amount they reduced their consumption during peak periods relative to their reference level consumption. See Wolak (2007) for more on this experiment.

[5] Note that forest management units are not the only way firms may harvest timber in Cameroon. The government also allocates Petits Titres and Sales Standing Volume for short-term, small-scale timber production. Firms also trade timber locally amongst themselves. For now, I ignore these other forms of timber procurement.

process. With the exception of less than 10 forests, which were grandfathered into the current system, all forests in the analysis were allocated through auction. Auctions occurred in 1999, 2001, 2002 and 2005.

Cameroonian forest management units harbor hundreds of different species of tree. Between 2003 and 2009, firms felled 147 different tree species. The set of commercial species found in any one forest management unit varies from unit to unit, as does each species' abundance. The average number of species felled in a forest management unit in a year is about 22, with a standard deviation of 10.4 species. Natural forests harbor trees of different ages classified by diameter measured at breast height (DBM) using ten centimeter bins. Across all species, tree size ranges from saplings of a few centimeters wide to very old trees with a diameter greater than 250 cm. Minimum exploitable tree size ranges depend on Cameroon's minimum diameter requirement for that species and, potentially, additional constraints required for sustainable management. In the 1994 Cameroon Forest Law the smallest minimum harvesting diameter is 50 cm and the largest is 100 cm.

Multiple species and heterogeneous age distributions drive many of the positive externalities associated with natural forests. These features also complicate management. Greater species and age diversity are associated with greater biodiversity and resilience to climate change and other shocks. Variation in tree age makes each species' population dynamics more complex. Events in the past, like storms or felling, shape a tree species' current local distribution and its risk of local extinction. Current felling shapes a species' future distribution. Forest management decisions are thus locally determined and vary across species and across space. For this reason, I use a tree species within a forest management unit, e.g. a forest-species pair, as the unit of analysis.

3.2 Forest Stewardship Council Certification in Cameroon

Forest Stewardship Council (FSC) describes Forest Management Certification as a "voluntary, market-based approach to improve forest practices worldwide."[6] Forest Stewardship Council is a not-for-profit organization currently based in Bonn, Germany that is considered among the

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[6] Source: https://us.fsc.org/our-history.180.htm Accessed October 25, 2014.

most credible of eco-labels. The FSC Forest Management Standard was originally defined in 1994 and revised in 1996, 1999, and 2001, which is FSC International Standard Version 4. The standard was revised in 2011 and in 2012 Version 5 was approved. Ten FSC Principles and Criteria must be applied in any forest management unit for certification making the standard multidimensional. The ten broad principles and criteria reach beyond forestry, writ small, to include worker protections and rural development. My focus is narrow: I consider FSC principles six, Environmental Impact, and seven, a forest's Management Plan. Principle six requires the firm to maintain or enhance "forest regeneration and succession," among other goals. Principle seven requires "rationale for rate of annual harvest and species selection" and a plan for "the identification and protection of rare, threatened, and endangered species."

If a firm chooses to participate, they select an FSC-approved auditor from a list on the Accreditation Services International website.[7] FSC-approved auditors are investigated by a meta-auditor of sorts, Accreditation Services International, who confirms that "a certification body is able to thoroughly assess clients ... and issue certificates in an impartial manner."[8] I observe two auditors in my dataset, Bureau Veritas and Rainforest Alliance, used by three and two firms, respectively. Firms with multiple forests participating in FSC could use different auditors across forests if they desired. In practice, I observe firms using the same auditor for all of their participating forests. The role of the FSC auditor is really a hybrid between regulator and auditor, as will become more clear in the discussion below of the FSC process.

This paper focuses on how firms change their felling at two events within the FSC regulatory process. This first event is the baseline event, when the auditor first visits the forest and assesses the firm's harvesting practices. At this moment the firm invites an FSC auditor to visit their forest at their preferred date and time for a "pre-audit." The firm pays for the audit – salaries, per diem, materials, transportation, etc. – at a typical cost of around $40,000-60,000. Following the visit, auditors share a list of "corrective actions" which the

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[7] http://www.accreditation-services.com/archives/standards/fsc Accessed October 25, 2014

[8] http://www.accreditation-services.com/archives/what-is-the-difference-between-certification-and-accreditation Accessed October 25, 2014

firm must fix in order to become certified.[9] Corrective actions are relative to the auditor's baseline, established at the pre-audit.

The second event in the FSC regulatory process is the certification event, when the firm is awarded certification and can sell timber with the FSC logo. Firms take on average two to three years to respond to the auditor's corrective actions before inviting the auditor to return for an "initial audit," the certification event. During the initial audit, the auditor evaluates the firm's response to corrective actions. Soon thereafter, the auditor awards or denies FSC certification. Once certified, the firm may sell their timber stamped with the FSC logo for the next five years.[10] About ten years pass between the baseline event and the expiration of the FSC certificate. Most studies find an FSC price premium of 10-15% for exported timber (Nebel et al., 2005)(Aguilar and Vlosky, 2007), though estimates for certified timber in Sarawak were much higher (Kollert and Lagan, 2007). A price premium of 10-15% is similar in magnitude to the estimated price premium for Marine Stewardship Council's certified seafood (Roheim et al., 2011).

Regeneration and succession refer to a species' population dynamics. For some species, FSC auditors are concerned that firms fell too many young trees, threatening the species' regeneration and sustainable timber harvesting. FSC auditors use the ratio of future to current trees to control current felling and ensure future felling. For managed species in Cameroon, this ratio must be at least 50%: accounting for growth and mortality, the number of trees available at the next timber harvest must be at least half of the number currently available.[11] Firms calculate the ratio by pairing a tree's age distribution with a vector of parameters, e.g. growth, mortality, and minimum felling age, in a simple population growth model. FSC requires firms to increase the minimum felling age, proxied by diameter, until they reach a ratio of future to current trees of 50%. If the FSC standard was a uniform standard,

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[9] Unlike the initial audit, corrective actions from the pre-audit are private information between the firm and auditor. They are only published if the firm continues on to certification. Initial audit results are always published, even if a firm fails certification.

[10] Firms are periodically audited over the five year period, always at their own expense.

[11] A harvest rule that takes the oldest trees first is optimal when managing a forest to maximize biomass only, not taking into account old-growth forest's amenity value. When amenity value is considered, the harvesting rate for older trees would be slower (See Amacher et al. (2009) pages 330-339 for more information). The 50% harvesting rule comes from managing the forest for biomass, only.

the harvesting constraint would be mechanical: the minimum felling diameter would increase until the ratio between current and future trees was 50%. Instead, the standard is relative to the firm's opportunity cost from restricted access to trees. Auditors compare changes in the harvest ratio against the firm's opportunity cost from reduced access to small trees.

A special class of forest-species pairs brings the tradeoff between improved regeneration and a firm's opportunity cost into greater relief. Within some forests, past events shaped a species' local age distribution in such a way that even for the most stringent minimum felling diameter the species fails the 50% future-to-current tree ratio. These forest-species pairs have the "Worst Regeneration" among all species in any forest. Legally, firms continue to exploit these trees by declaring them "unmanaged."[12] However, FSC requires all species to be managed in order to satisfy principles six, enhancing regeneration, and seven, protection of rare species. If the FSC standard was a uniform one, auditors would prohibit felling of these species. Instead, FSC auditors increase the minimum felling diameter so that the harvest ratio increases to at least 35%-40%. An example makes this concrete. In response to corrective action 7.1.9 concerning the exploitation of some species where "renewal is not secured," the auditor writes that the proposed increases in harvesting diameter "represent a significant sacrifice for the company, especially as regards Okan, which is a premium hydraulic wood" (p. 80) (Veritas, 2013). The "sacrifice" here is the opportunity cost to the firm of no longer felling smaller Okan trees. Notably, in this case the proposed diameter increase for Okan is still insufficient to satisfy the 50% criteria.[13]

4 Theoretical Model

I use a two period principal-agent model of auditors and firms to describe FSC certification in order to reveal firm incentives to distort production at the baseline event. The firm and the FSC auditor maximize total discounted profit and utility, respectively. I make two initial

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[12] According to Cameroonian law, at least 75% of a forest's timber must be "managed," which allows 25% of a forest's timber to be extracted at very high rates. The loophole is even bigger then it seems, because it is assessed on potential timber resources, not those extracted. In practice, for uncertified forests the future to current harvesting ratio requirement does not legally bind (Vandenhaute and Doucet, 2006).

[13] Acknowledging this, the auditor writes that the firm will focus on "increase[ing] the number of stalks in phonological monitoring mechanisms and in the production of seedlings in tree nurseries." (p 80)

simplifications. First, I simplify the firm's problem to a choice of average felled tree size. I endow forests with a single species of tree that regenerates poorly. Second, I model the auditor's beliefs as naive. This set up reveals firm incentives to distort at the baseline.

I then enrich the model in two ways to generate more detailed empirical predictions. First, I allow firms to choose a second input, tree quantity, which is an imperfect substitute for average felled tree size. Second, I endow the forest with a second tree species with low local extinction risk. Finally, I compare FSC's relative standard to a uniform standard and investigate how predictions change with different auditor frameworks.

4.1 Model Set Up

The timber firm and FSC auditor maximize total discounted profit and utility over two periods. The firm manages a single forest endowed with a single tree species that has a high risk of local extinction. Firms maximize profits by choosing the felled tree size z_t given price p_t and their cost function. Costs are a function of a firm's private parameter β drawn from the distribution $F(\beta)$, which is common knowledge. Auditors seek to maximize utility, which is a function increasing in certified tree size.

4.2 Timber Firm Profit-Maximization Absent Certification

The firm's forest harbors trees of a single species of different ages. The firm seeks out specific trees for felling. Large trees offer more volume but firm incur additional costs in order to access them, in the form of more comprehensive inventories and a denser road network. The average tree size in period t, z_t, reflects logging selectivity, which grows increasingly costly. Firms differ in their tree search technology. The interaction of a firm's technology and a species' local distribution determines search costs for that species. We can model the firm's problem, absent certification, using a quadratic search cost term.

$$\max_{z_t} \qquad p_t z_t - \left(\frac{1}{\beta}\right) z_t^2 \tag{1}$$

Search costs are scaled by a parameter β which reflects the interaction between the firm's technology and the species' local distribution. Absent certification, the firm's optimal tree size and profit are linear in type and vary with price in period t:

$$z_t^* = \frac{p_t}{2}\beta \qquad \pi_t^* = \frac{p_t^2}{4}\beta \tag{2}$$

Less productive firms have a low β, lower profits, and smaller optimal tree size because they find search costly. Higher prices encourage search and increase profits.

4.3 FSC Auditor's Utility Maximization Problem

The auditor's utility strictly increases in certified tree size for species with high risk of extinction. This very simple representation of auditor utility has two distinctive features. First, incentives to increase tree size are paid for by a direct transfer from consumers, not a government subsidy, eliminating the cost of raising revenue through distortionary taxes from the auditor's utility maximization problem. Second, the marginal benefits from increasing tree size are linear and constant. When combined with the absence of costs, this implies that the auditor will try to maximize tree size up to the maximum tree size possible.[14]

I model auditor beliefs as naive. Formally, naive beliefs imply that the auditor believes that observed period one tree size, $z_1(p, \beta)$, is the firm's profit-maximizing tree size, z^*. Using these beliefs and the firm's optimal size $z^* = \frac{p}{2}\beta$, the auditor infers type from observed tree size. This is possible because optimal tree size is linear in unobserved type. If the firm chooses a first period tree size different from the optimum, the auditor will infer a different firm type $\tilde{\beta}$, $z_1(p, \beta) = z^*(p, \tilde{\beta})$.

A compelling alternative would be a corrupt auditor. For corruption to fit the institutional features of the FSC process, e.g. public auditor reports open to comment, the auditor must document change between the baseline and certification and must do so in a way consistent with reported production to the Forest Ministry. Later, I discuss a corrupt auditor trying to

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[14] Another way to conceptualize the auditor's problem is as a cost-effectiveness problem. Unlike benefit-cost criteria, which would compare marginal benefits from increasing tree size to marginal costs, cost-effectiveness aims to increase benefits as must as possible given a budget constraint.

maximize the likelihood of a future contract given the need for documented change between the baseline and certification. Predictions are consistent with those of a naive auditor.

Because participation is voluntary, the FSC auditor faces a constraint when maximizing utility. The auditor chooses a certified tree size that satisfies the firm's individual rationality constraint. Firms only participate in FSC certification if certified profits exceed uncertified profits: $\pi(z_c|\gamma p) \geq \pi(z_2|p)$. Selecting a policy's stringency conditional on firm participation sets voluntary policies apart from traditional regulation. As pointed out in the voluntary policy literature (Alberini and Segerson, 2002), the key difference between voluntary and and mandatory policies is the regulator's ability to force firms to incur unwanted costs, which limits a voluntary policy's scope.

Formally, we can write the auditor's utility maximization problem as:

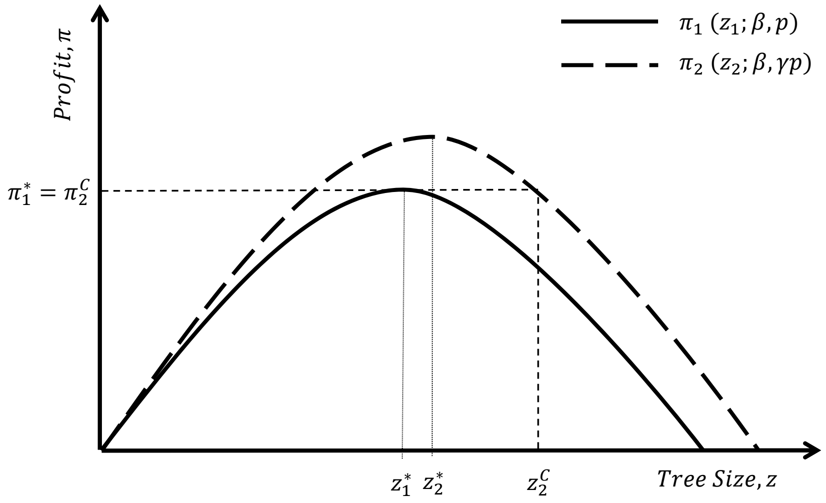
$$\max_{z_c} \qquad z_c$$

subject to

$$\pi(z_c|\gamma p) \geq \pi(z_2|p) \tag{3}$$

The optimal certified tree size, given beliefs is a function of the price premium and linear in observed type, making it linear in observed tree size: $z_c = \Gamma z_1$, where $\Gamma = \gamma + \sqrt{\gamma^2 - 1}$.

A graphical look at the auditor's utility maximization problem makes two results concrete. Given convex search costs, the profit function is concave. The solid line maps profit at uncertified prices for different sizes of tree. The dashed line maps profit at certified prices. First, note the FSC-certified price premium increases the profit-maximizing tree size, independent of the auditor, to $z_2^* > z_1^*$. In this model, firms respond to an increase in price by seeking out larger trees with greater volume. Later, in a richer model, firms will be able to respond by felling more small trees.



Second, with perfect information the auditor pushes the firm beyond the profit-maximizing tree size given certified prices, z_2^*, to the largest tree size possible while maintaining firm participation. This occurs where the firm is indifferent between certification and uncertified production, z_2^c.

4.4 Game Timing

The forest certification process has three periods. Periods 1 and 2 are conditional on participating in the baseline audit. Recall that tree size is z and a firm's marginal cost of increasing tree size is scaled by the private firm parameter $\frac{1}{\beta}$. In the model, each firm manages one forest and each forest has one species. Thus a "firm" refers to a firm-forest-species triad.

- **Period 0:** State of Nature
    - Firm draws its type β from $F(\beta)$
    - Firm decides whether or not to participate in Baseline Audit
- **Period 1:** Baseline Audit
    - Firm chooses tree size, z_1 given p
    - Auditor observes size, updates beliefs

  - Auditor chooses certified tree size constraint z_c, offers contract $\{z_c, p^c\}$
  - Firm accepts or rejects contract

- **Period 2:** Post-Baseline Audit Phase
  - If accept and certify:
    - Firm chooses profit-maximizing size z_2 given p^c and constraint z_c
    - Auditor verifies that tree size meets requirement, $z_2 \geq z_c$
  - If reject and abandon certification:
    - Firm chooses unconstrained profit-maximizing tree size z_2 given p

4.5 Firm Incentives to Distort

Suppose the firm maximizes total profit, the sum of profit in period one and discounted profit in period two: $\Pi = \pi_1 + \delta\pi_2$. If the firm participates in certification, tree size choice in period one affects second period tree size via the auditor's tree size constraint rule. Firm total profit maximization becomes:

$$\max_{z_1, z_2} \qquad \pi(z_1|\beta, p) + \delta\pi(z_2|\beta, \gamma p) \tag{4}$$

$$s.t. \qquad z_2 \geq z_c = \Gamma z_1$$

Where $\Gamma = \gamma + \sqrt{\gamma^2 - 1}$. Solving for the optimal distorted tree size, we get:

$$z_1 = \left(\frac{1 + \gamma(\delta\Gamma)}{1 + \Gamma(\delta\Gamma)}\right)\frac{p}{2}\beta \tag{5}$$

Recall that $z^* = \frac{p}{2}\beta$. We can compare the distorted size to the optimal tree size given perfect information. Since $\Gamma > \gamma$, distorted tree size is smaller than the optimal tree size, $z_1 < z^*$.

The auditor observes distorted and certified tree size, z_1 and z_c, where $z_c = \Gamma z_1$. Harvesting practices appear improved when comparing tree size across the two events, $z_c - z_1$. The firm does not distort so much at the baseline such that the certified tree size is equal to the unrestricted optimal tree size given a price of γp. The unconstrained optimal tree size is linear in price; given the certified price premium, it would be $z_c^* = \frac{\gamma p}{2}\beta < z_c$.

What is the intuition behind the firm's distortion? How far will it distort the baseline size? The firm's profit at the baseline from choosing tree size $z_1 = z^* + dz$ is:

$$\pi_1(z^* + dz) = \pi^* + \frac{\partial \pi_1}{\partial z} dz \tag{6}$$

$$\pi_1 = \pi^* + (p - \frac{z^*}{\beta}) dz \tag{7}$$

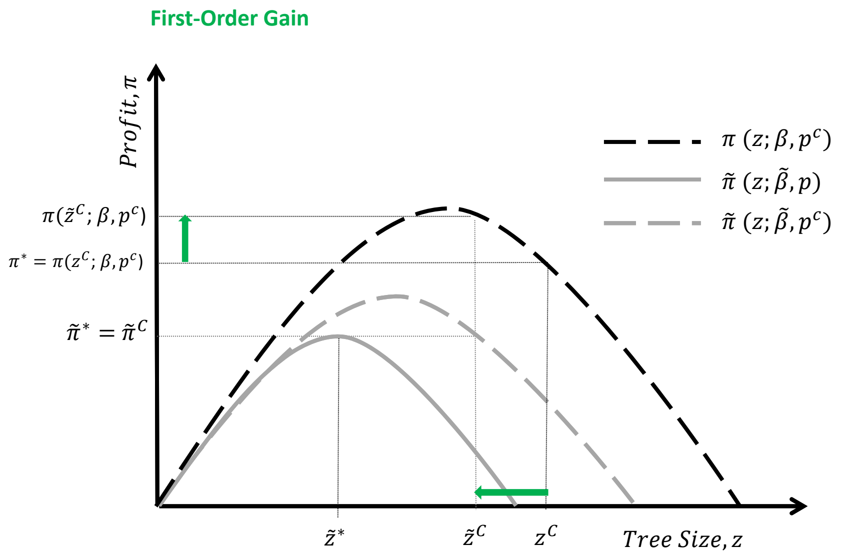
Here, the firm is choosing a deviation around the optimal tree size $z^* = \frac{p}{2}\beta$. The second term in the expression is zero at the optimum. Profit loss from distortion has a second order impact only. Compare this to the gain in profit from a weaker constraint:

$$\pi_c(z_c + dz) = \pi_c + \frac{\partial \pi_c}{\partial z} dz \tag{8}$$

$$\pi_c = \pi_c + (\gamma p - \frac{z_c}{\beta}) dz \tag{9}$$

We know that $z_c \geq \frac{\gamma p}{2}\beta$, so the second term is positive and increasing in the change in tree size. Distortion relaxes the constraint, making $dz < 0$, which has a first-order effect on certified profits. The firm trades off between these competing effects from distortion, a second-order loss in the baseline period and a first-order gain when certified, to find the optimal level of distortion.

We can see how distortion works graphically. Like the previous figure, the firm's uncertified and certified profit given type β are the solid and dashed black lines, respectively. In grey are the uncertified and certified profit for some type $\tilde{\beta}$ the auditor infers from observed z_1, the distorted tree size in period one.



Weaker Certified Size based on less productive type

The figure shows how tree size changes at each event. At the baseline event, tree size falls from z_1^* to z_1^D. At certification, tree size increases to z_2^D, which falls short of the unobserved perfect information certified tree size, z_2^C.

In addition to limiting policy scope, voluntary participation weakens the dynamic contract in a surprising way. The firm's outside option is its uncertified profit. When modeling dynamic contracting, the most basic construction has the outside option identical across types. In this case, we would still predict that firms would distort at the baseline to relax the harvesting constraint (Laffont and Tirole, 1988). Here, the firm's outside option is a function of unobserved type. Distortion now relaxes the harvesting constraint along two pathways: directly, by making search look costly, and indirectly, by making exit look more lucrative.

Consider another feature of FSC's policy design limits effectiveness. The auditor can offer a limited menu of contracts because the price premium is set exogenously in the marketplace. If the market-clearing price is p, the certified price is $p^c = \gamma p$, where $\gamma > 1$ and fixed. Typically, we would induce productive firms to expend effort using a menu of contracts. A fixed price precludes the use of a menu.

We can use this simple model to make some general predictions on FSC effectiveness. We see that the larger the price premium, the larger the change in the certified tree size, even with distortion. However, the marginal change in certified tree size given a marginal change in the price premium is very small, because of distortion.

4.6 Comparison to a Static Contract

Suppose the FSC auditor used a static contract instead of a dynamic contract. How would this change effectiveness? A static contract would mean a uniform forestry standard; the auditor could not tailor the contract requirements to the firm. In this case, the auditor would choose certified tree size based on the least efficient firm that would satisfy the auditor's criteria, $\underline{\beta}$ within the distribution of search costs, $F(\beta)$. The certified tree size would be $\Gamma z_1^*(\underline{\beta})$ Given the price premium γ, firms would either accept or reject the contract. All firms at least as productive as $\underline{\beta}$ would choose to participate. All types $\beta \in [\underline{\beta}, \hat{\beta})$ would expend some effort when certified, meaning their certified tree size would be greater than the profit-maximizing tree size given the certified price: $z_c > \frac{\gamma p}{2}\beta$. The type at which the constrained tree size is equal to thee profit-maximizing tree size given the price premium is the threshold type $\hat{\beta}$. More productive search types will increase their tree size beyond the criteria, but only up to their profit-maximizing level.

We can compare this to the naive auditor prediction, which has all firms increasing tree size beyond their profit-maximizing level in the second period. Which policy dominates depends on the distribution of types, $F(\beta)$. If types are very heterogeneous, the dynamic contract will outperform the static contract.

4.7 Enriching the Model

4.7.1 Tree Quantity and Tree Size: Imperfect Substitutes

The previous model simplified firm choice to just tree size but we know that firms choose both tree size and the quantity of trees to fell. We can think of tree quantity and tree size input choices as imperfect substitutes when producing timber volume, $V = qz$, to sell on the open market. The quantity of trees felled changes the cost function in two ways. First, we introduce a convex *felling cost*, $\frac{1}{\phi}q^2$, which reflects the labor and material cost of felling a tree. These costs are independent of search costs. Second, we scale search costs by the number of trees felled, making search costs now $\frac{1}{\beta}qz^2$.

How does the FSC auditor's problem change with the firm's enriched production function? The auditor's utility function is unchanged and remains a function of tree size only; changes are restricted to the auditor's information set. Suppose the felling cost parameter ϕ is private information to the firm and the auditor knows only the distribution, $G(\phi)$.[15] We enrich auditor beliefs to be *naive but consistent*. The auditor still believes observed production is profit-maximizing for both parameters, e.g. $z^* = z_1$, $q^* = q_1$. The auditor still controls second period tree size via the contract, $z_2 \geq z_c$. Consistency refers to the auditor's beliefs about the new felling parameter. The firm must maintain the auditor's expected felling cost parameter across the baseline and certified periods, $\phi(q^*) = \phi(q_2)$. Otherwise, the auditor concludes the firm has distorted production and refuses to grant certification.

The auditor's problem becomes:

$$\max_{z_c} \qquad z_c$$

subject to

$$\pi(z_c|\gamma p) \geq \pi(z_2|p) \tag{10}$$

$$\phi(q^*) = \phi(q_c) \tag{11}$$

The auditor's constraint assignment rule remains the same as before, $z_c = \Gamma z_1$, however the firm's total profit-maximization problem changes.

$$\max_{z_1,z_2,q_1,q_2} \Pi = q_1(pz_1 - \frac{q_1}{\phi} - \frac{z_1^2}{\beta}) + \delta q_2(\gamma p z_2 - \frac{q_2}{\phi} - \frac{z_2^2}{\beta})$$

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[15] We can imagine an alternative scenario. Suppose the auditor's information set is unchanged from the single input scenario, namely only β is private information to the firm. In this case, the auditor is empowered by the second input because the auditor can use optimal quantity q^* to triangulate the search cost parameter.

subject to

$$z_2 = \Gamma z_1 \tag{12}$$

$$q_2 = q_2^*(q_1) \tag{13}$$

If we re-write the profit-maximization problem in terms of type, the firm chooses the types it would like to mimic, $\{\tilde{\beta}, \tilde{\phi}\}$ given the auditor's beliefs, which determines $\{z_1, q_1, z_2, q_2\}$.

As before, the firm always distorts the search cost parameter to make seeking out large trees appear more costly, $\tilde{\beta} < \beta$. If the firm distorts the felling cost parameter, it will make felling appear less costly, $\tilde{\phi} > \phi$. The intuition is that the firm now has two margins along which it can distort the expected opportunity cost of the harvesting constraint. Distorting tree size around the optimum always pay off because the gain in certified profit outweighs the second-order profit loss in the baseline period. Quantity is unregulated, so the firm will only distort the auditor's expected felling cost parameter in order to relax the tree size constraint. A cheaper felling cost parameter implies a greater opportunity cost from restricted access to small trees. But whether the firm deflates expected felling cost depends on the relative cost of distorting quantity versus tree size. If felling costs are low relative to search, the firm will find it profitable to distort along both margins, decreasing tree size and increasing tree quantity in the baseline period.

In the case where the firm chooses to make felling appear cheaper, $\tilde{\phi} > \phi$, the extra margin for distortion makes the difference between the optimal and distorted tree size worse than in the previous model without quantity, e.g. $z_1 < z_1^q$, which in turn weakens the certified tree size, $z_c << z_c^q$. Distorted felling brings with it costs in the second period - the firm must maintain the expected felling cost parameter - but the gains from more revenue in the baseline period and a weaker certified tree size dominate.

We can summarize model predictions for observed outcomes. With the richer model, we expect that felling increases at the baseline, $q_1 > q^*$. We still expect to see smaller tree size at the baseline, $z_1 < z^*$. Tree size and quantity both should weakly increase at certification, from the price premium and the constraint, $z_c > z^*$, $q_c > q^*$.

4.7.2 Mix of Safe and At-Risk Tree Species

We can enrich the model further to describe a forest with two tree species, one which regenerates poorly P and one that is abundant A. Keeping our focus on the role of information asymmetries, suppose production costs are independent across the two species but they share the same felling cost parameter, ϕ. Their search cost parameters differ, $\beta_P \neq \beta_A$, because search is determined by each species underlying distribution. The auditor's utility function remains a function of the poorly regenerating species tree size, z_P, only. Like in the previous case, we broaden auditor beliefs to include consistency across species: $\phi(q_P) = \phi(q_A)$.

In this case, the direction of our predictions for the poorly regenerating species do not change: the firm continues to distort tree size and tree quantity. How does the firm change production outcomes for the abundant species? For the firm's joint profit-maximization problem, the linkage between the species is the auditor's expectations of the felling cost parameter. We know from the previous section that if the firm distorts the felling cost parameter, it will make felling look cheap in the one-species case. Thus, given our consistency requirement, the firm will also make felling look cheap for the abundant species. Any changes in tree size for the abundant species are marginal and occur only in response to the change in quantity. Our predictions for the abundant species would be an increase in production of similar magnitude to the poorly regenerating species, and a very weak decrease in tree size.

An extreme example makes predictions for the abundant species more concrete. Consider the case where the abundant species price is low enough that, absent certification, the firm does not find it profitable to cut any abundant species trees. In order to distort the felling cost parameter, the firm would now cut abundant species trees, a change along the extensive margin.

4.8 Model Extensions: Auditor Beliefs and Utility Maximization Problem

So far, the FSC auditor has been modeled as naive or naive and consistent. These beliefs, while restrictive, are a simple way to investigate whether and how the revelation principle fails. They may also be more appropriate given the context, where instead of a government regulator we have a well-intentioned NGO. But how robust are model predictions to other ways of framing the principal-agent problem? Here I discuss how predictions change for three of the most likely alternatives: a constrained auditor, a corrupt auditor, and a sophisticated auditor.

As discussed in the institutions section, the FSC auditor is periodically audited by a meta-auditor. We can re-frame the FSC auditor as not naive but constrained, working within a nested principal-agent contract with the meta-auditor. In order to satisfy the meta-auditor's contract, the FSC auditor must show that tree size changes between the baseline and certification. The FSC auditor's utility function changes from $U = z_c$ to $U = f(z_c - z_1)$, where $f' > 0$. Now the meta-auditor's beliefs constrain the firm. If the meta-auditor is naive, which may be a more realistic assumption, the FSC auditor' problem collapses to the naive auditor case.

Instead of a naive or constrained auditor, we can imagine a corrupt FSC auditor. We can imagine two broad forms of auditor corruption: cheap talk or in cahoots. For the former, auditors would always report that the firm satisfies FSC criteria at the baseline and certification audits and we would predict no change in harvesting practices at either event.[16] This framework fits the FSC process poorly because audit reports are open to public comment, auditors are themselves audited by an accreditation service, and we observe a change in felled tree size between the baseline and certification events using independent Ministry data. A more nuanced model would have auditors reporting changes in harvesting practices in audit reports while firm harvesting remains unchanged. This would require reporting felling that differs from that recorded by the Ministry and is unlikely given that the Ministry also comments on FSC audit reports.

Instead, suppose the auditor creates a side contract with the firm to manipulate the public comment process. The contract specifies a change in harvesting at the baseline. The auditor would like to maximize the likelihood of a future contract with the firm but is constrained by the risk of being detected as corrupt. The higher the firm's total profits, the more likely

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[16] This framework explains empirical evidence from auditors in India, for example (Duflo et al., 2013).

the FSC auditor will gain a future contract. Auditor utility is thus a function of firm profits, $U(\Pi)$. The risk of detection increases as the documented change from certification falls: $Pr(D) = g(z_c - z_1)$, where $g' < 0$. In this set up, the auditor's utility maximization problem is a transformed version of the firm's total profit-maximization problem with a naive auditor. We would predict similar incentives to distort tree size at the baseline.

Finally, I briefly consider a sophisticated FSC auditor, a framework that merits future work. The auditor is aware of firm incentives to distort tree size at the baseline. Using a proof structure based on Laffont and Tirole (1988), we can show that if types are continuous a fully separating equilibrium is impossible. Like in the case of the naive auditor, I use the envelope theorem to show that the firm always has an incentive to deviate in the baseline and mimic a less efficient type, the "ratchet" effect described by Weitzman (1980). This is conditional on the auditor having a minimum standard, a threshold type below which firms cannot be certified. Around the optimum, the firm will always trade a second-order loss in marginal revenue in the baseline period for a first-order gain in avoided search costs from a relaxed constraint in the certified period. It is worth noting that in this case, a static contract outperforms the dynamic contract because both have a uniform standard but the static contract avoids first period distortion.

5 Data

5.1 Forest Production Data from the Cameroonian Forest Ministry

In Yaoundé, Cameroon in 2012, the Director General of the Cameroonian Ministry of Forestry agreed to share Ministry data with me with the explicit goal of analyzing how Forest Stewardship Council certification changes forest production in Cameroon. The Ministry shared production data for all forest concessions active between 2003 and 2009. The Ministry of Forestry compiles forest production data in their Système Informatique de Gestion de l'Information Forestière (SIGIF). The SIGIF houses production data collected from DF-10 forms strictly controlled by the Ministry. From 2000-2005, the government contracted with Global Witness, a non-governmental organization, to serve as an independent forest monitor. From 2005 to

2009 the NGO Resources Extraction Monitoring took over forest monitoring. Although forest monitoring is broader than ensuring SIGIF's data integrity, both NGOs did include comparing DF-10 forms to site records, among other activities.

For each year t, in the SIGIF dataset I observe an owner identity g, the number of trees cut S_{gfst} and the total volume harvested V_{gfst}, in meters cubed, for tree species s in forest management unit f.[17] Summary statistics are reported in Table 1. Between 2003 and 2009, I observe non-zero trees felled for 9,215 forest-species pairs in the SIGIF dataset.[18] The SIGIF reporting process changed in 2003 from a June-July year to a January-December year. Total production for 2003 appears low in Figure 2 for two reasons: it captures half a calendar year of timber harvesting and only 70 forests were active. When a firm does not fell trees, there is no record on the DF-10 form. I infer zero production for missing forest-species pairs that are observed at least once between 2003 and 2009. Table 2 gives a sense of patterns along the extensive margin. We see zero production increase sharply in 2009 in response to the global recession. Another sharp jump occurs in 2006, likely reflecting newly awarded forest management units' slow start. Table 2 shows 9,215 observations non-zero of forest-species pairs and 8,915 inferred zero production observations, for a total of 18,130 observations.

In order to estimate fixed effects for each forest-species unit, I drop forest-species pairs only observed once. I also drop 18 observations with average size less than 1.5 meters cubed and 9 observations with average size greater than 50 meters cubed. Using the generic allometric equation for trees in Cameroon, a tree with 1.5 meters cubed would have a diameter of about 40 cm; the smallest legal diameter is 50 cm. Together, this restriction results in 7,986 observations.[19] Figures 3 and 4 show each outcome variable's distribution using the restricted population. The large spike in the quantity graph comes from the number of forest-species pairs with a single tree reported cut. For some specifications I include a forest-level trend, which requires a third observation per forest-species pair, resulting in 6,642 observations total.

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[17] Forest certification events occur at the forest management unit level. A forest concession may be made up of more than one forest management units.

[18] Among the non-zero observations, 139 reported positive volume but were missing the number of trees cut. The volumes harvested are very small, much smaller than the amount generated by one tree. I suspect the missing values occur because firms reported a fraction of a tree cut and the report format used by the Ministry when sharing the data did not support non-integers.

[19] All results are robust to including these 27 observations.

Between 2003 and 2009, 89 distinct forest management units f actively harvested timber for at least one year. Of the 89 forest management units, 11 change ownership over the period, for a total of 98 forest-firm pairs gf. In the empirical analysis, when a forest changes ownership I treat each firm-forest pair as independent forests. In effect, I create a new index f that corresponds to a firm-forest pair gf [20] Among the 98 forest-firm pairs, 85 have at least two years of positive production, making the effective number of clusters 85 for regressions with fixed effects. Table 3 shows the breakdown of firms and forests by participation status. Units listed under "Baseline" experienced at least a pre-audit, the baseline event, between 2003 and 2009. Of 33 firms, five participate in forest certification. These five firms enroll 19 forests in at least the baseline event. Participating firms manage a portfolio of forest management units that includes both certified and uncertified forests. Figure 5 shows variation in participation across Cameroon. Not shown is firm variation across space; firms tend to concentrate in one or two regions.

For each forest, I observe quantity of timber harvested by species. The dataset includes 147 unique species; the average forest management unit reports positive production for 34.7 (SD 15.2) unique species. The analysis relies on change across years within a species-forest unit. There are a total of 3,353 forest-species units. Table 4 imposes panel and size threshold requirements and we are left with 2,136 forest-species pairs remaining, which is the number of estimated fixed effects. I construct two variables to assess changes in quantity of trees felled. First, I use the natural log of trees felled, $q_{fst} = ln(Q_{fst})$. Production levels vary greatly: the median number of trees felled across all forest-species units is 15 trees felled, while the mean is 96.9 trees felled. Much of this variation comes from different levels across species because some tree species are more abundant than others. For example, the average number of trees felled for Acajou de Bassam (*Khaya ivorensis*) is 29 trees, whereas the average for Ayous (*Triplochyton scleroxylon*) is 710 trees. Because my empirical framework uses changes within a forest-species unit at forest certification events in order to identify firm distortion, using trees felled in levels may mute or overstate group-level changes at certification events. The second variable I construct is a binary variable, $1[q_{fst} > 0]$ equal to one if I observe non-zero

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[20] There is one case where the SIGIF has entries for the former and new owner in the same period. Observations from both units were retained for the analysis.

number of trees felled.

Next, I construct three measures of a forest-species' average tree size. To calculate the unit's gross average tree size, I divide the total volume felled by the total number of trees cut, $A_{fst} = V_{fst}/S_{fst}$. Next, I use an allometric equation estimated in Cameroon that relates tree diameter to tree volume. I invert the allometric equation, using the average tree size, to find the equivalent diameter, D_{fst}. Finally, I create a diameter gap measure to reflect the distance between the average tree diameter and the minimum felling diameter, which varies by species: $DG_{fst} = D_{fst} - D_s^{min}$.

As noted in the institutions section, timber auctions occur during the panel, changing the number of active forests. Table 2 shows a large jump in the number of forests from 2005 to 2006, from 72 to 85, reflecting an auction in 2005. Trends across the panel change in 2005, perhaps in response to this auction. In Figure 6, we see average tree size increase slightly after 2006 across all size percentiles except the lowest percentile. Table 6 shows the annual average number of trees felled per forest-species pair, log-transformed. The overall average is 2.755, which is 12.8 trees. The average number of trees felled falls across the sample. In Figure 2 we see total sector production is highest in 2006, passing 1.8 million meters cubed. To summarize, we see a general trend of fewer, larger trees felled on average. I will use different regression specifications with a species time trend to as a check on whether changes at events are driven by this broader trend in tree size.

5.2 Forest Management: Ownership, Event Timeline, and Forest Characteristics

Forest management data was paired with production statistics. I coded information on subcontracting arrangements and forest certification event dates from three main sources. Several timber corporations in Central Africa are composed of multiple smaller firms and joint ventures with different names. This makes it difficult to link subcontractors to the firm exploiting timber or to link joint-ventures to their parent corporation. For each forest management unit, the SIGIF database identified the permit-holder, not the corporation. I used World Resources Institute's Global Forest Watch Forest Atlas for Cameroon (2012) to link permit-holders to subcontractors and to match smaller firms to their parent corporations.[21]

To identify the 18 forests that participated in a baseline audit between 2003 and 2009, I used the Forest Stewardship Council Certification's online database.[22] Variation in baseline event timing is shown in Figure 7. From the database, I accessed public audit reports published by FSC auditors for the 15 forests that elected to continue the certification process, nine of which certify before 2010. Certified forests per year are plotted in Figure 8, where we see nine forests certified in 2009. I was able to establish baseline audit timing for the three forests that drop out of certification using either documentation from certified forests or the company's website.[23] From each audit report, I coded the month and year of the auditor's first visit to the forest and the timing of the certification event. For the certification dummy variable, I use the year the forest is certified and able to sell timber with the FSC label, not the year of the initial audit.[24] Likewise, some forests scheduled a second "pre-audit" before certification. The timing of the second pre-audit event often occurred very close to the certification audit. Second pre-audits are not included in the analysis.

One forest has an unusual history with FSC that deserves mention. After certifying in 2007, the auditor stripped the forest of FSC certification between 2007 and 2008. The auditor restored FSC certification in 2009, which explains the gap in certified forest in 2008 in Figure 8. Results in the empirical analysis are robust with or without this forest.

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[21] From the SIGIF database, I do not officially observe entry and exit. I only see positive production for a firm-forest pair. The Center for International Forestry (CIFOR) shared information on changes in forest ownership over time. This data enabled coding of shut-down years at the end of the panel which would otherwise looked like exit. It also served as a check on the SIGIF and WRI databases for linkages across firms and firm-forest linkages. Note that the regression analysis does not include shut-down years.

[22] Info.fsc.org: Accessed in 2011 and again in 2014.

[23] It is ambiguous whether forest management unit 10-040 had a baseline audit in 2009. I do not include FMU 10-040 among the 18 participants for three reasons. First, SIGIF reports production by the uncertified owner in 2008 and 2009. Second, the firm's public audit report does not discuss corrective actions or forest history for 10-040. Third, I lack a management plan for 10-040 and could not code local regeneration risk. Estimates from difference-in-difference specifications, which do not require local risk, are unchanged by including 2009 as an audit year for FMU 10-040.

[24] A few times the initial audit occurred at the end of the year and certification was awarded the following year.

5.3 Regeneration Risk Data

The Cameroonian Forest Ministry shared with me all forest management plans they received until about 2010. Legally, the forest management plan must include a *table de peuplement*, a table with the estimated number of individual trees in the forest management unit for each 10 cm diameter class between 20 cm and 150 cm, inclusive. Estimated tree counts come from a coarse, large-scale inventory across 1-3% of the total surface of the forest management unit, a process detailed in Arrêté 222. For all forests that participated in the baseline event, I coded tree counts for all species and all diameter classes.[25] To construct the "At-Risk" or "Poor Regeneration" flag, I paired the management plan table de peuplement with each species' growth rate and minimum diameter. I use Arrêté 222 of May 24, 2001 from the Ministry of Environment and Forestry for these species parameters. The Arrêté lists which species must be managed, their legal minimum harvesting diameter, and their average annual diameter growth rate in millimeters. Minimum diameters vary between 40 and 100 cm, growth rates between 0.35 to 0.9 mm/year. Mortality rates are assumed 1%, assessed annually, and a one-time 7% loss captures tree damage during felling. I then wrote an algorithm that replicates the simple population model used by the Ministry and FSC auditors to calculate the harvest ratio at different minimum diameter thresholds. The algorithm simulates population dynamics at different minimum diameter thresholds. Forest-species pairs failing the 50% recruitment rate threshold for any minimum felling diameter were tagged as "Worst Regeneration." Table 7 reports variation among FSC participants in regeneration classification for the seventeen species classified at least once as having the worst regeneration.

6 Empirical Strategy

My research question seeks to identify whether participants in FSC improve their harvesting behavior once certified. If not, I wish to investigate whether strategic distortion of the auditor's baseline can explain this failure. Normally, random assignment of FSC would serve as

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[25] Some management plans reported densities instead of counts. In these cases, I converted the density to a count using total forest area. Some forests updated their management plan after certification and included a new Table de Peuplement. In these cases, I used the Table from the first management plan.

an empirical benchmark. However, I am interested in policy effectiveness given endogenous selection by firms into the voluntary policy. My goal is to estimate harvesting changes at certification events conditional on participating in FSC.

One approach would be to explicitly control for endogenous treatment status using predicted participation. However, Doremus (2014) found that, with the exception of forest size, observable characteristics did not consistently predict FSC participation. Instead, I make an identifying assumption that unobserved trends are the same for participants and non-participants and use a difference-in-differences framework to identify deviations at FSC events. By including fixed effects at the forest-level, I estimate deviations from within-unit averages and accommodate changes in the composition of treated and control units over time. For outcomes for forest-firm f in province p in year t, the basic regression specification is (14):

$$\begin{aligned} y_{fpt} = \beta_{BL} Baseline_{ft} + \beta_{Int} Interim_{ft} + \beta_{Cert} Certified_{ft} \\ + \beta_{Drop} Dropout_{ft} + \alpha_f + \rho_{pt} + \epsilon_{fpt} \end{aligned} \tag{14}$$

Where y_{fpt} is a production outcome, either a measure of tree quantity or size. Forest fixed effects α_f control for forest-specific effects and province-year fixed effects ρ_{pt} control for omitted variables which might be correlated with FSC that are shared among forests in each of the five provinces in a given year. For example, if a major road linking a province to the port is resurfaced, transport costs would fall for forests in that province. Likewise, production outcome reporting is controlled by region, so measurement error likely varies by province. My identifying assumption is that, absent FSC, non-participating and participating forests have parallel trends. The error term ϵ_{fpt} is clustered by firm-forest pair and there are eighty-five clusters after imposing size thresholds and panel requirements.

The reference period includes all observed years before the baseline audit.[26] The dummy $Baseline_{ft}$ is equal to one during the first baseline audit. Unlike the baseline event, a forest

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[26] The length of the reference period varies across participants. The longest reference period is six years, the shortest is zero years. In this case, the forest has a baseline audit the first year I observe it in the Ministry's production database. I include this forest in all regressions to help identify changes at certification. Eliminating it improves the precision of the baseline coefficient estimate but does not appreciably change the magnitude.

certification "event" may occur more than once within the panel if the forest is certified for multiple years. The treatment variable denoting forest certification, $Certified_{ft}$, is a dummy variable equal to one each year the forest can sell timber labeled FSC. For example, if a forest certifies in December 2008 and is active in 2009, all species within that forest will have $Certified_{ft}$ equal to one in 2008 and again in 2009. Years between the first baseline audit and certification are lumped into the $Interim_{ft}$ period.[27] For forests that drop out of the certification process, years after the baseline audit are tagged with $Dropout_{ft}$ equal to one.

6.1 Event Changes Common to All Species Within the Forest

Certification events are common to all species felled in that forest. Estimation of (14) is straightforward for outcomes we can meaningfully aggregate across species, such as the number of trees felled in a forest. However, other outcomes, like average tree size and changes along the extensive margin, are better evaluated for each species within a forest. Since we identify FSC event coefficients using changes across time, individual data improves precision if we control for additional time-varying omitted variables. Species-year fixed effects, γ_{st}, control for year-specific omitted variables shared across species, such as demand shocks. In addition to adding species-year fixed effects and clustering the standard errors, I add a species-forest pair's fixed effects to (14). My identifying assumption is similar to before. I use cluster-robust standard errors grouped at the firm-forest level, which requires the weaker assumption that shocks are independent across clusters as well as addresses serial correlation in the error term.

6.2 Identifying Assumptions

In order to estimate causal changes in forest production at FSC events common across species, I make two assumptions necessary for identification in any difference-in-differences regression model: I assume that participating and non-participating forests share common unobserved time trends and that the change from certification is additive and constant across participants.

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[27] The length of the interim period varies across forests. For the forest stripped of FSC certification in 2008, this year was coded as "interim." Regression results are robust to dropping this special forest: magnitudes and directions stay about the same and precision improves on the baseline coefficient estimate.

Here, I investigate the two most likely violations of the common trends assumption: different trends at the firm level and different trends at the forest level.

Variation in baseline event timing and heterogeneity in non-participating firm type address potential concerns over different trends for participating and non-participating firms. The timing of the baseline event varies across years and firms, as shown in Figure 7. Baseline events occur as early as 2004 and as late as 2009. During the period of inquiry, we observe foreign-owned firms increasing the number of forests they manage. All FSC participants are foreign-owned, thus we might be concerned that unobserved, broad sectoral changes that vary with ownership status drive changes across time. However, foreign-owned firms are found among non-participants, including the largest timber producer in Cameroon. Finally, participating firms have portfolios that include non-participating forests.

We might be concerned that participating forests have different unobserved trends than non-participants. Two violations seem plausible: a shock that drives FSC participation and anticipatory behavior by participants. For the former, any shock that drives participation in the baseline audit should be persistent because FSC certification is a ten year process; if firms are rational, temporary changes in demand or productivity should not drive participation in FSC. A persistent change is incompatible with our theoretical prediction, a temporary, discontinuous change in production. To look for persistence, I investigate how unregulated outcomes, like tree quantity, change after the baseline event.

Two types of anticipatory behavior would violate the common trends assumption: anticipatory demand for “greener” timber and firms responding to future constraints. Anticipatory demand for “greener” timber, if it existed, would be forest-specific and persistent; firms would use their public baseline audit in a way similar to the FSC logo to signal their movement toward sustainable timber production and attract additional orders. This change would persist into the interim period and thus is incompatible with the model’s predicted temporary distortion. Institutions make raiding and stockpiling trees in anticipation of future constraints unlikely. The only reason to raid and stockpile trees is if participating in the baseline event changed access to these trees as compared to the pre-event period. By Cameroonian law, every year firms are restricted to felling within a demarcated zone. At the end of the year, they move on to the next zone. Incentives to raid that year's zone, which are few considering stockpiling logs is costly and strongly discouraged by the Ministry, are unchanged by the baseline event. Moreover, the FSC auditor regulates tree size, not the quantity of trees.

I investigate these potential violations in three ways. First, I investigate alternative regression specifications with firm- and forest-time trends. Second, I investigate patterns around events graphically, looking for evidence of trends. Third, I use a triple difference-in-difference specification, which has a much weaker common trends assumption.

6.3 Differential Change for At-Risk Species

Incentives to distort a species' search cost parameter depend on the local distribution of that species in that forest, which varies across species-forest pairs. To estimate differential changes in production for at-risk species, I use the following triple difference-in-differences specification (15):

$$y_{fst} = \rho_{BL,AR}\left(BL_{ft} * AtRisk_{fs}\right) + \rho_{Int,AR}\left(Interim_{ft} * AtRisk_{fs}\right) + \rho_{Cert,AR}\left(Cert_{ft} * AtRisk_{fs}\right) + \rho_{Drop,AR}\left(Dropout_{ft} * AtRisk_{fs}\right) + \alpha_{fs} + \lambda_{ft} + \gamma_{st} + \epsilon_{fpst} \quad (15)$$

There are two key differences between this regression specification and the regression estimating changes common across species. First, I include forest-year fixed effects λ_{ft}. This controls for changes common across all species in the forest at certification events and, unlike before, allows these common changes to vary across participating forests. Next, event dummies, which vary at the forest level, are interacted with a dummy coded for forest-species' pair fs's regeneration risk. $AtRisk_{fs}$ is an indicator variable equal to one if the species fails regeneration criteria in that forest. Coefficients on interaction terms, $\rho_{EVENT,AR}$, estimate average differential change for at-risk species at events.

The triple difference-in-differences regression framework specified in (15) allows us to relax the identifying assumption we needed to estimate the double difference-in-differences framework of (14). There, we had to assume that firms did not choose to participate in FSC based on time-varying shocks or trends. Now, we must assume that participation is not driven by shocks or trends unique to at-risk species, a much weaker assumption.

7 Results

7.1 Firms Change Harvesting Behavior at Baseline for At-Risk Species

Table 8 reports differential changes in tree size at FSC events for species that fail FSC's regeneration criteria and are at risk of poor regeneration over time using a triple difference-in-differences specification. The dependent variable is a measure of tree size, and the unit of observation is a species in a forest in a given year. Each regression has forest-year and species-year effects as well as fixed effects for each forest-species pair. Standard errors are clustered at the forest-level. The table has two panels, one for each class of at-risk species: poor regeneration and worst regeneration.

The broadest class of species where firms may have incentives to distort have "Poor regeneration;" These species fail FSC's regeneration criteria, even if by a small margin. For some species-forest pairs in this group, firms have already increased the diameter threshold in order to satisfy Cameroon's Forest Law. In this case, there is no payoff to the firm of distorting tree size. Other forest-species pairs in this group are at risk of additional constraints from the FSC auditor. Thus incentives to distort vary across units in this group. "Worst Regeneration" forest-species pairs fail FSC's regeneration requirements for any diameter constraint. Incentives to distort tree size exist for each of these units.[28] If FSC is effective at increasing protection of at-risk species from local extirpation, we should see increased average tree size at certification for both groups. We might also expect to observe increases in tree size during the interim period as firms implement changes in order to satisfy FSC requirements.

Certification does not appear to change average tree size for either at-risk species classification, for any measure of tree size. There are three measures of tree size, raw average tree size in meters cubed, the estimated diameter based on tree size, and the difference between the diameter and the minimum legal diameter. Estimated changes at certification are noisy

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[28] The "Worst Regeneration" species are a subset of the "Poor Regeneration" class.

and less than zero for any of the measures. Similarly, interim coefficients are also noisy and less than zero. We do find large changes in tree size – at the baseline audit event. For poor regenerators, tree size falls by 0.8 meters cubed or a fall in diameter of 3.3 centimeters. For species with the worst regeneration prospects, tree size falls even more, by 2.5 meters cubed. The change in diameter is ten centimeters, a 21% decrease in the difference between average diameter and the legal minimum diameter. Ten centimeters is one diameter class and a significant change from the auditor's perspective because felling restrictions are done in ten centimeter bins.

We can investigate whether the decrease in tree size at the baseline audit reflects an unobserved downward trend in tree size using an event study specification. Figure 9 plots timeline coefficients for years leading up to and after the baseline event using the following regression specification:

$$size_{fst} = \sum_{\tau - 1} \beta_\tau \tau_{ft} * HighRisk_{fs} + \alpha_{fs} + \gamma_{st} + \lambda_{ft} + \epsilon_{fst} \tag{16}$$

Where τ_{fst} is equal to zero at the baseline audit. The reference period is the year before the audit. Species-forest fixed effects and forest-year fixed effects are included. Errors are clustered at the forest-level. In Figure 9 we see a sharp, temporary decrease at the baseline event. Before the baseline event, there appears to be an upward trend in tree size, making the decrease in tree size at the baseline event more striking. This upward trend is consistent with general trends observed across the panel (see Figure 6). Tree size returns to the pre-event trend immediately after the event. Tree size returns to the pre-FSC average around the time when most firms certify, two to four years after the baseline audit.

7.2 Broader Evidence of Baseline Distortion to Inflate Opportunity Cost of Constraint

Table 10 characterizes common changes in the quantity of trees felled at FSC certification events and shows the robustness of the estimated increase in production at the baseline audit across specifications. The unit of observation is a species-forest pair and the outcome variable is the natural log of the number of trees felled, $ln(q_{fst})$. The reference period for event changes includes all years prior to the baseline audit period.[29] Regression specifications 1 through 4 include fixed effects for each forest-species pair. Moving from left to right adds different controls. Regressions 2 and 3 include a time trend for each forest and species, respectively. The time trend restricts the dataset to forest-species pairs observed for at least three years and reduces the number of observations.[30]. Standard errors are clustered at the forest-level for each regression, with 85 clusters for regressions without the time trend and 72 clusters with the time trend.

Across specifications, I find a large, precisely estimated increase in production at the baseline audit. Depending on the specification, the magnitude of the increase ranges from 52% to 81%. Most estimates of the change in trees felled at the baseline are around 81%, what would appear to be an extremely high response. The high magnitude reflects the skewed shape of production data, reflected in Figure 3 . Almost ten percent of forest-species pairs have production of just one tree; another six percent have two trees felled. An increase of a few trees will appear comparatively large for many species. Later regressions use production in levels and total production for the forest and find an increase of about 60%.

The large increase in production at the baseline audit is temporary and abrupt. In the regressions, the Interim coefficient is noisy and weakly positive and the Dropout coefficient is noisy and weakly negative. If the change in production at the baseline audit reflected a trend in increased productivity among participants, we should see positive production among Dropouts. This is true for the Interim period, too - institutionally, the auditor does not issue corrective actions to limit the quantity of trees felled.

We can investigate whether the increase at the baseline reflects an underlying trend of increased production using an event study specification. Figure 10 plots timeline coefficients

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[29] The reference period length varies by forest. Forests that join later may be different than forests that join earlier. As long as firms decide to participate based on a time-invariant forest characteristic, this is not a problem for identification but it can make the estimate of the change at the baseline event less precise. Including a dummy variable for 3 or more years before the baseline audit restricts the comparison of the baseline audit year to the two years prior. The magnitude of the baseline audit coefficient is roughly identical, but standard errors fall by about 10%.

[30] Running regressions 1, 4, and 5 with this smaller sample improves the precision of the baseline coefficient estimate. Magnitudes stay without 5% of those reported here. Standard errors for the certification coefficient increase slightly for regression 4 but decrease for regressions 1 and 5

for years leading up to and after the baseline event using the following regression specification:

$$ln(q_{fpst}) = \sum_{\tau-1} \beta_\tau \tau_{ft} + \alpha_{fs} + \rho_{pt} + \epsilon_{fpt} \tag{17}$$

Where τ_{ft} is equal to zero at the baseline audit. The reference period is the year before the audit. Species-forest fixed effects and province-year fixed effects are included and errors are clustered at the forest-level. In Figure 10 we see a sharp increase at the baseline event but no trend prior to the event. Production returns to the pre-event trend immediately after the event.

Figure 10 confirms the temporary change, and shows further that it is abrupt. There is no trend prior to the baseline audit driving the increase in production and production returns to the unit average after the baseline event. Production increases at around the time when most firms certify, but the estimate is noisy.

We can investigate the common trends assumption via regression specifications 2 and 3, which include a forest and species time trend, respectively. With a forest-trend, coefficient estimates for the baseline, interim, and certification decrease. The change at the baseline audit remains positive and significant but decreases from 81% to 52%. Production during the Interim and among Dropouts is negative, giving further evidence that the change at the baseline is temporary. The production increase at certification, though imprecisely estimated, remains about the same magnitude as without the trend. If an unobserved trend drove participation in FSC, we would expect the change at certification to disappear when we include forest-trends.

Among the regression specifications in Table 9, the regression with the best fit has species-year and province-year effects, Regression 5. I repeat this specification in column one of Table 10. Table 10 looks at how quantity and tree size change at FSC events using this specification. The table features three different transformations of the quantity of trees felled across four regressions: the natural log of the number of trees felled, $ln(q_{fpst})$ as in Table 9 (Spec 1), the raw number of trees felled q_{fpst} (Specs 2 and 3), and a binary variable equal to one if there is at least one tree felled, $1[q_{fpst} > 0]$ (Spec 4). Unlike with log-transformed quantity, we can include observations with zero trees felled when using the raw quantity.

Specification 2 includes only observations with positive production to facilitate comparison with the log-transformed quantity. Specification 3 includes observations with zero trees felled, which increases the number of observations to over ten thousand. The last two regression specifications estimate common changes in tree size using two measures: a gross tree size average and tree diameter based on the gross tree size average.

Our theoretical model predicts that firms will distort production to make felling appear less costly. Empirically, we would expect to find an increase in the number of trees felled across all species at the baseline audit. Likewise, for species infrequently felled at all due to low market price, we would expect the likelihood of felling to increase at the baseline audit. We saw in Table 9 that the increase in log-transformed quantity was robust across specifications, including a forest time trend. Here we see that the increase in felling is common across species, whether infrequently or frequently felled. The raw quantity regressions estimate an increase of 68 trees felled for non-zero observations and 54 trees when zeroes are included, an increase of 57 percentage points in either case. Unlike in the log-transformed quantity case, these estimates reflect the arithmetic mean, which is more sensitive to outliers, yet the coefficient is very similar to the 65% increase estimated increase in the log-transformed case with identical controls. This gives us further evidence that changes are common across species. Changes occur along the extensive margin as well: a species is 12% more likely to be felled in the year of the Baseline audit. Changes in quantity and likelihood of felling are very similar when aggregated to the forest-level, as shown in Table 11.

Recall that we expect to find differential changes in distorting search costs. When estimating common changes in tree size, theory predicts the average change across species will be noisy and weakly negative. Specification 5 reports the change in gross average size, which falls by .5 cubic meters but is insignificant. Using the diameter measure in specification 6, we find an insignificant decrease in tree diameter of 4 cm at the baseline audit. Changes in tree size from search may be better reflected by how tree diameter changes relative to the legal minimum diameter, which varies by species. The final specification uses this outcome and finds a fall of 4.8 cm relative to an average gap of 49 cm, for a 10% fall in diameter. We can compare this to the change in gross average tree size, which corresponds to a fall of 7.8%

when compared to the average tree size of 3 meters cubed. Table 11 reports the forest-level average using the harmonic mean of tree size and tree size falls on average about 11%. It appears that firms may seek out fewer large trees at the baseline audit, but the change is not consistent across species.

Another way to investigate whether changes at the baseline audit are part of a broader unobserved productivity trend is to look at how firm-level production changes at FSC events. Firms manage a portfolio of forests, some that participate in FSC and others that do not. If firms increase their total production in baseline event years, this could be evidence of an unobserved productivity shock at the firm-level. Table 12 presents regression results for firm-level production. The unit of analysis if a firm-species pair in specification 1 and total firm production, regardless of species identity, in specification 2. Both regressions include fixed effects at their respective unit of analysis. Standard errors are clustered at the firm level. Since there are only 33 firms, there are few clusters and we should be wary when interpreting the precision of our estimates. Events are coded such that if a firm has at least one forest experiencing a baseline audit or is certified, that variable is equal to one. If the firm experiences both a baseline audit and a certified forest at the same time, their interaction is coded as one. Specification 1 includes species-year effects while specification 2 has year effects. Immediately we see that the estimated coefficient for baseline audit years is nearly zero. This is in contrast to production when at least one forest is certified, which increases by 36% on average for each species or 48% overall. We saw in Tables 9, 10, and 11 that certified timber quantity increased at certification by as much as 80%, though the estimate was noisy. Together with this table, it appears that firms may shift production among their forests to accommodate overly inflated felling in the baseline period for participating forests. At certification, the price premium legitimately increases total production, a response that makes sense since certification is persistent, spanning several years.

When paired with Figure 10, regression results across specifications and outcomes provide evidence that changes at the baseline audit fit predictions of participants changing production to distort felling and search costs. Changes do not appear to be driven by anticipatory behavior, unobserved trends, or a selection effect.

Table 13 investigates differential changes in the quantity of trees felled for at-risk species. The regression specifications are identical to the investigation of tree size in Table 11. Two quantity outcomes are included for each at-risk classification, the natural log of trees felled and a binary variable equal to one if at least one tree is felled. Our theoretical prediction is that firms will not differentially change quantity for at-risk species. For both at-risk classifications, we find no differential change in the likelihood of felling or the quantity of trees felled at the baseline audit or any FSC events.

8 Conclusion

Finite contracts and high prices create incentives for firms to overexploit commercial timber species. An innovative policy tool, FSC, addresses this problem by linking consumers willing to pay more for sustainable timber with firms willing to incur opportunity costs from leaving behind trees at risk of local extinction.

This paper investigated whether local biodiversity protection improved for Cameroonian forests participating in FSC. A principal-agent model of firms and auditors yielded insights in to FSC effectiveness. Auditors cannot incite firm effort because the FSC price premium is common across firms and exogenously determined. We learn from the model that firms have incentives to distort their production at the auditor's baseline assessment. They trade a second-order profit loss in the baseline period for a first-order gain in profits once certified. These predictions are robust to different auditor frameworks, including a corrupt, constrained, naive, or sophisticated auditor.

Empirically, I investigate these predictions using a dataset I created that links forest production to local extinction risk. Using a difference-in-differences framework, I investigate whether certification affords at-risk species greater protection. I find that firms distort production at the auditor's baseline assessment, felling smaller, younger trees for at-risk species only. For species with the highest risk of local extinction, tree size decreases by 20% at the baseline before returning to the pre-event average at certification. Firms inflate the opportunity cost of restricted access to small, rare trees. I find no evidence that firms leave behind more small, high-risk trees once certified as compared to production before participating in FSC.

Firms can inflate opportunity costs by distorting production along another margin, their general felling productivity. I find a temporary, abrupt increase in production for all tree species at the baseline assessment, consistent with firms exaggerating the opportunity cost of harvesting restrictions. Total production for participating forest increases by 60%. Production at the firm-level is unchanged in years with a baseline audit, suggesting that firms shift production across forests at the baseline in order to accommodate distortion. In contrast, total firm production increases by 36% once certified, consistent with a response to an FSC price premium.

These empirical results contribute to two literatures, empirical work on dynamic contracting and regulation and studies evaluating voluntary policies in developing countries. FSC has policy design features that amplify the incentive problems known to plague dynamic contracts. Many eco-labels rely on an exogenously determined price premium to incentivize changes in firm behavior, and this work draws attention to how this limits effort extraction by the auditor. Dynamic contracting is found in other policy arenas, such as time-shifting of electricity demand and offsets for avoided deforestation. From this work, we learn that there are strong incentives for firms to manipulate their baseline with a net result of no change in behavior.

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Table 1: Summary Statistics

Table 1: Summary statistics

Variable	Mean	(Std. Dev.)	Min.	Max.	N
Trees Cut	96.912	(285.918)	1	4877	9215
ln(Trees Cut)	2.755	(1.895)	0	8.492	9215
Raw Size, m3	11.897	(6.187)	0.667	104	9215
Diameter, cm	109.386	(26.216)	28.017	321.186	9215

Table 2: Number of Observations by Forest-Species Pair and Year

	Year							
	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
	N	N	N	N	N	N	N	N
Firms								
	28	28	26	25	28	27	27	189
Forests								
	70	71	72	85	84	81	80	543
Individuals								
Zero Production	1,262	961	1,089	1,224	1,353	1,404	1,622	8,915
Positive Production	975	1,325	1,295	1,610	1,491	1,390	1,129	9,215

Table 3: Number of Units by Participation Status

	Participation Status		
	Never	**Baseline**	**Total**
Firms			
	28	5	33
Firm-Forest Pairs			
	80	18	98
Forest-Species Pairs			
	2,673	731	3,404

Table 4: Dropped Forest-Species Pairs

Num obs in panel	**Forest-Species Pairs** **Size under 1.5**	 **Size [1.5,50] m3**	 **Size over 50**	**Total**
	N	N	N	N
1 obs only	5	1,202	53	1,260
2 obs only	4	670	1	675
3 or more obs	1	1,466	2	1,469
Total	10	3,338	56	3,404

Table 5: Dropped Observations

Num obs in panel	**Observations** **Size under 1.5**	 **Size [1.5,50] m3**	 **Size over 50**	**Total**
	N	N	N	N
1 obs only	5	1,202	2	1,209
2 obs only	4	1,344	2	1,350
3 or more obs	9	6,642	5	6,656
Total	18	9,188	9	9,215

Table 6: Cross-Sectional Variation: Outcome Variables by Year

	ln(Trees)					**Size (m3)**				
Year	Mean	SD	Min	Max	N	Mean	SD	Min	Max	N
2003	2.840	1.874	0.00	8.06	975	11.9	5.32	1	47	975
2004	2.895	1.895	0.00	8.26	1,325	11.7	5.78	1	51	1,325
2005	2.873	1.913	0.00	8.03	1,295	11.5	5.80	1	54	1,295
2006	2.732	1.915	0.00	8.01	1,610	11.4	6.16	1	70	1,610
2007	2.704	1.868	0.00	7.89	1,491	12.1	6.44	2	57	1,491
2008	2.663	1.933	0.00	8.49	1,390	12.5	7.12	1	104	1,390
2009	2.597	1.835	0.00	8.31	1,129	12.2	6.15	1	53	1,129
Total	2.755	1.895	0.00	8.49	9,215	11.9	6.19	1	104	9,215

Table 7: Worst Regenerating Species

		Participate FSC		
Scientific Name	**Do Not Participate**	**Not Vulnerable**	**Vulnerable**	**Total**
Afzelia bipindensis	57	18	1	76
Afzelia pachyloba	39	11	2	52
Aningeria altissima	32	6	1	39
Autranella congolensis	27	7	1	35
Baillonnella toxisperma	46	15	4	65
Ceiba pentandra	28	4	5	37
Cylicodiscus gabonensis	52	6	12	70
Detarium macrocarpum	38	6	5	49
Entandrophragma angolense	61	16	1	78
Entandrophragma candollei	70	15	3	88
Entandrophragma utile	75	11	7	93
Erythropleum ivorense, E. suaveolens	75	12	7	94
Khaya grandifoliola	11	2	1	14
Khaya ivorensis	61	16	1	78
Lophira alata	32	7	2	41
Piptadeniastrum africanum	45	12	2	59
Total	749	164	55	968

Table 8: Tree Size Falls for At-Risk Species

	Poor Regeneration		Worst Regeneration	
	(1)	(2)	(3)	(4)
	Raw Size, m^3	Diameter, cm	Raw Size, m^3	Diameter, cm
Fixed Effects	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc
Baseline Audit	-0.809*	-3.346*	-2.515*	-9.128*
	(0.389)	(1.661)	(1.137)	(4.270)
Interim	-0.171	-0.153	-0.888	-2.037
	(0.611)	(2.351)	(1.715)	(5.900)
Certified	-0.495	-2.167	-1.373	-4.427
	(0.957)	(3.123)	(1.680)	(5.812)
Dropout	-0.185	-1.028	1.868	8.753
	(0.915)	(3.564)	(1.302)	(4.714)
Constant	11.44***	107.7***	11.61***	108.3***
	(0.0910)	(0.378)	(0.0719)	(0.310)
Species-year	Yes	Yes	Yes	Yes
Forest-year	Yes	Yes	Yes	Yes
Observations	7986	7986	7986	7986
R^2	0.288	0.305	0.289	0.306

Standard errors in parentheses. Standard errors clustered at the forest-level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: Changes in Quantity at Auditor's Baseline

	(1) Quantity	(2) Quantity	(3) Quantity	(4) Quantity	(5) Quantity
Fixed Effects	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc
Baseline event	0.595^{***}	0.422^{**}	0.595^{***}	0.591^{***}	0.502^{**}
	(0.140)	(0.152)	(0.136)	(0.143)	(0.155)
Interim	0.249	-0.0818	0.254	0.220	0.0178
	(0.345)	(0.294)	(0.368)	(0.380)	(0.429)
Certified	0.597	0.486	0.594	0.636	0.600
	(0.330)	(0.890)	(0.336)	(0.364)	(0.342)
Dropout	-0.317	-0.158	-0.351	-0.324	-0.284
	(0.326)	(0.536)	(0.360)	(0.361)	(0.424)
Constant	3.005^{***}	3.793^{***}	3.585^{***}	3.005^{***}	3.002^{***}
	(0.0839)	(0.196)	(0.229)	(0.0857)	(0.0810)
Year	Yes	Yes	Yes	No	No
Forest trend	No	Yes	No	No	No
Species trend	No	No	Yes	No	No
Species-year	No	No	No	Yes	Yes
Province-year	No	No	No	No	Yes
Observations	7986	6642	6642	7986	7986
R^2	0.027	0.103	0.073	0.143	0.172

Standard errors in parentheses. Errors clustered at forest-level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10: Changes in Production Outcomes at Auditor's Baseline

	Felling Outcomes				**Size Selection Outcomes**	
	(1)	(2)	(3)	(4)	(5)	(6)
	Ln(Trees Cut)	Trees Cut	Trees Cut	$1[q > 0]$	Size, $\frac{m^3}{tree}$	Diameter, cm
Fixed Effects	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc
Baseline event	0.502^{**}	68.21^{**}	54.21^{***}	0.116^{*}	-0.894	-3.969
	(0.155)	(20.94)	(14.45)	(0.0451)	(0.647)	(2.793)
Interim	0.0178	-4.947	0.176	-0.0575	0.252	1.191
	(0.429)	(62.32)	(42.40)	(0.0664)	(0.938)	(3.795)
Certified	0.600	55.56	44.89	0.0687	0.536	2.579
	(0.342)	(69.51)	(49.00)	(0.0450)	(1.035)	(4.136)
Dropout	-0.284	-41.73	-33.97^{*}	-0.0354	0.869	3.122
	(0.424)	(21.05)	(16.76)	(0.0338)	(0.490)	(1.990)
Constant	3.067^{***}	119.9^{***}	93.64^{***}	0.770^{***}	11.48^{***}	108.0^{***}
	(0.0674)	(8.538)	(6.571)	(0.0189)	(0.155)	(0.655)
Province-year	Yes	Yes	Yes	Yes	Yes	Yes
Species-year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7986	7986	10223	10223	7986	7986
R^2	0.172	0.106	0.088	0.191	0.160	0.176

Standard errors in parentheses. Standard errors clustered at the forest-level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: Forest-level Changes

	(1) Quantity	(2) Quantity	(3) Share Species	(4) Harmonic Size
Baseline event	1545.3***	0.692***	0.109*	-1.138*
	(369.4)	(0.157)	(0.0467)	(0.567)
Interim	220.9	-0.00167	0.0246	0.307
	(838.0)	(0.477)	(0.0540)	(0.796)
Certified	1172.5	0.708	0.113*	0.203
	(1030.8)	(0.380)	(0.0459)	(0.943)
Dropout	-477.6	-0.212	-0.0196	0.675
	(540.0)	(0.253)	(0.0599)	(0.543)
Constant	2490.9***	7.638***	0.637***	10.17***
	(162.1)	(0.0818)	(0.0222)	(0.168)
Year	Yes	Yes	Yes	Yes
Observations	395	395	395	395
R^2	0.143	0.136	0.076	0.056

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12: Firm-level Changes at Baseline Audit and Certification

	(1) ln(Q)	(2) ln(Q)
Unit of Observation	Firm-Species	Firm
Baseline event	0.0219	0.0677
	(0.115)	(0.205)
Certified	0.309^{*}	0.388^{*}
	(0.122)	(0.148)
Baseline & Certified	-0.149	-0.0977
	(0.207)	(0.238)
Constant	3.451^{***}	8.341^{***}
	(0.0405)	(0.0905)
Year	Yes	Yes
Species-year	Yes	No
Observations	4531	163
R^2	0.236	0.203

Table 13: No Differential Change in Quantity

	Poor Regeneration		Worst Regeneration	
	(1)	(2)	(3)	(4)
	Trees Cut	$1[q > 0]$	Trees Cut	$1[q > 0]$
Fixed Effects	Forest-Spc	Forest-Spc	Forest-Spc	Forest-Spc
Baseline Audit, Poor regen	0.0578	-0.0481	0.333	-0.0240
	(0.160)	(0.0406)	(0.221)	(0.0899)
Interim, Poor regen	-0.0191	0.0183	0.284	0.113
	(0.198)	(0.0613)	(0.376)	(0.139)
Certified, Poor regen	-0.159	-0.0285	0.672	0.0183
	(0.197)	(0.0740)	(0.450)	(0.126)
Dropout, Poor regen	0.220	0.0622	0.752	0.0357
	(0.270)	(0.0613)	(0.663)	(0.0397)
Constant	3.406***	0.751***	3.070***	0.766***
	(0.0271)	(0.00439)	(0.0249)	(0.00446)
Species-year	Yes	Yes	Yes	Yes
Forest-year	Yes	Yes	Yes	Yes
Observations	7986	10223	7986	10223
R^2	0.371	0.284	0.372	0.284

Standard errors in parentheses. Errors clustered at the forest-level.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

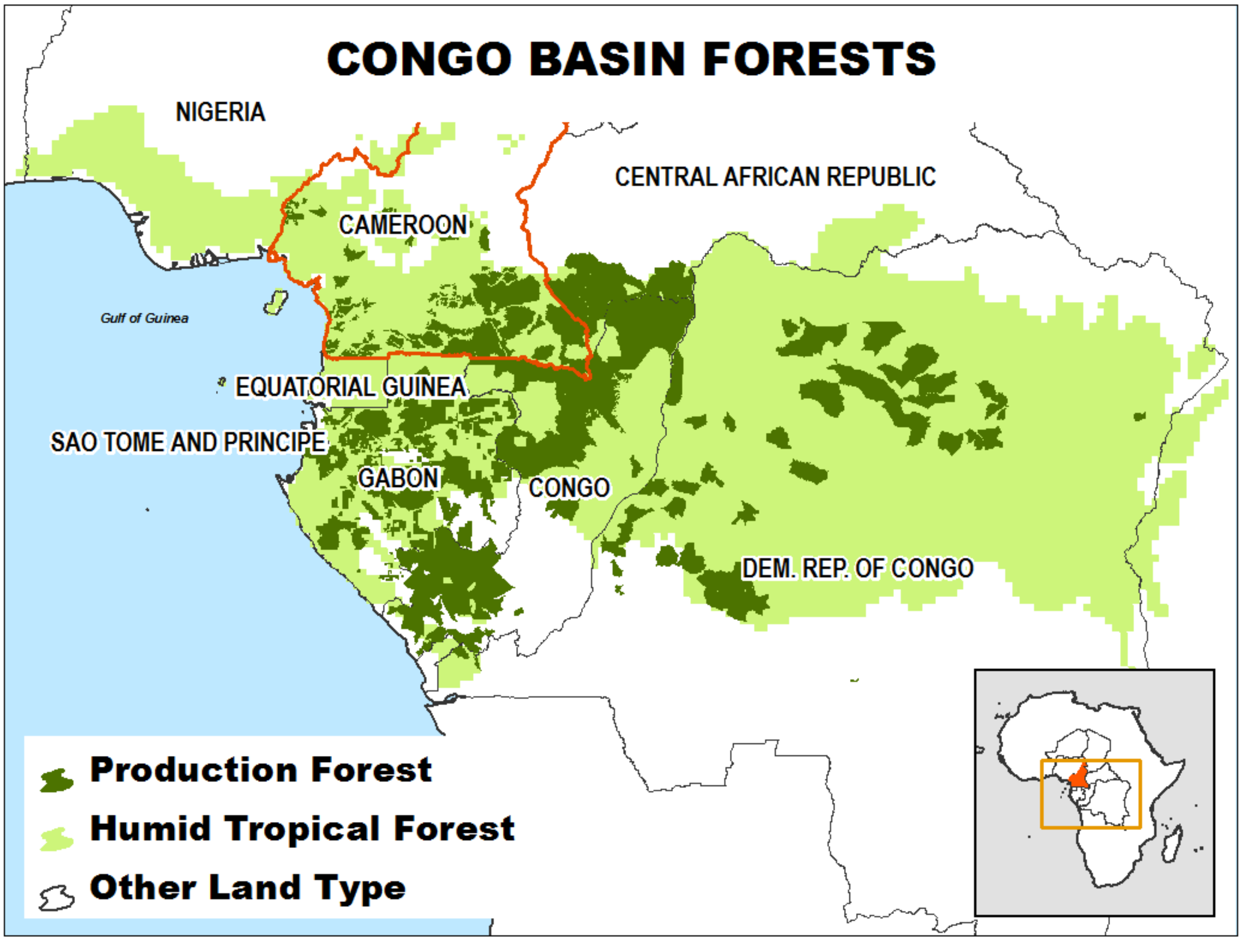

Figure 1: Forest Allocated for Timber Production in Central Africa

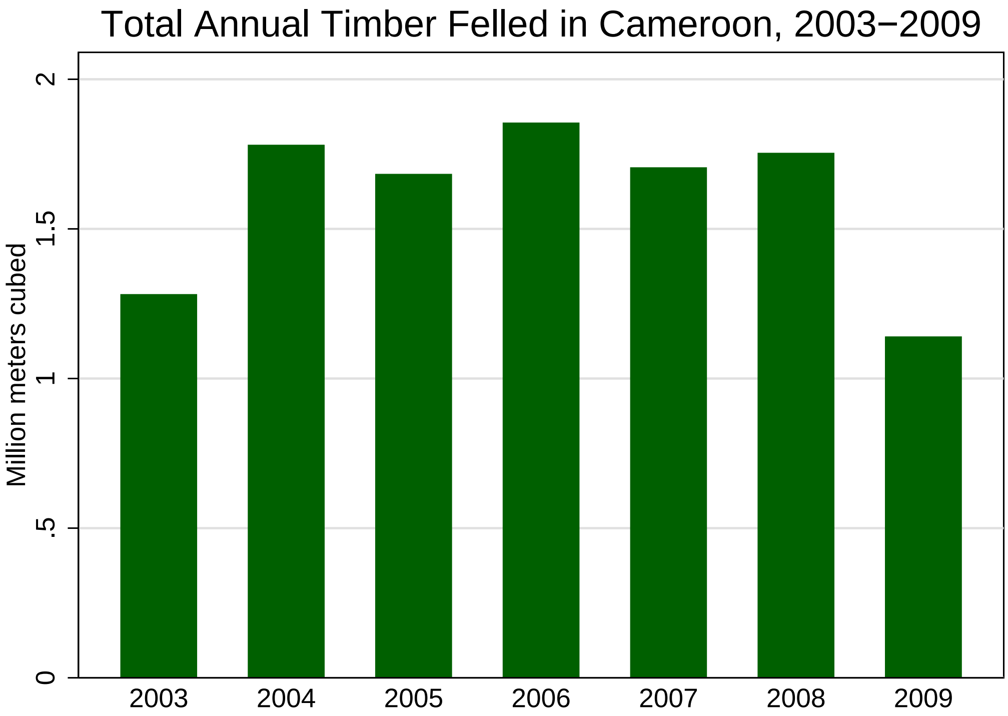

Figure 2: Trends Across Panel, Total Volume in Sector

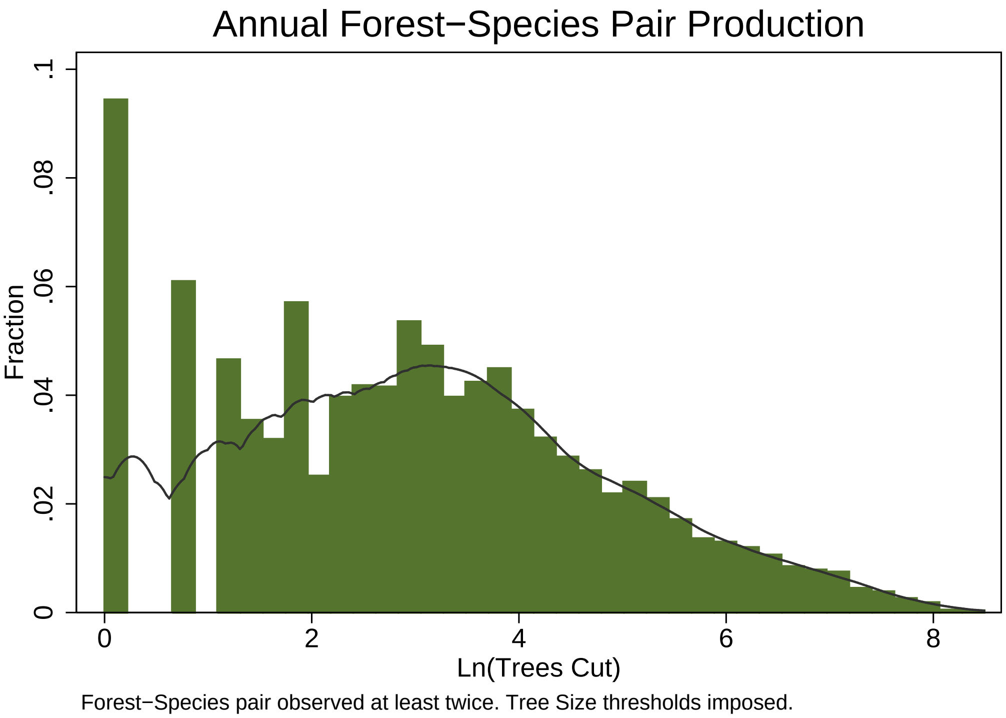

Figure 3: Distribution of Trees Felled by Forest-Species

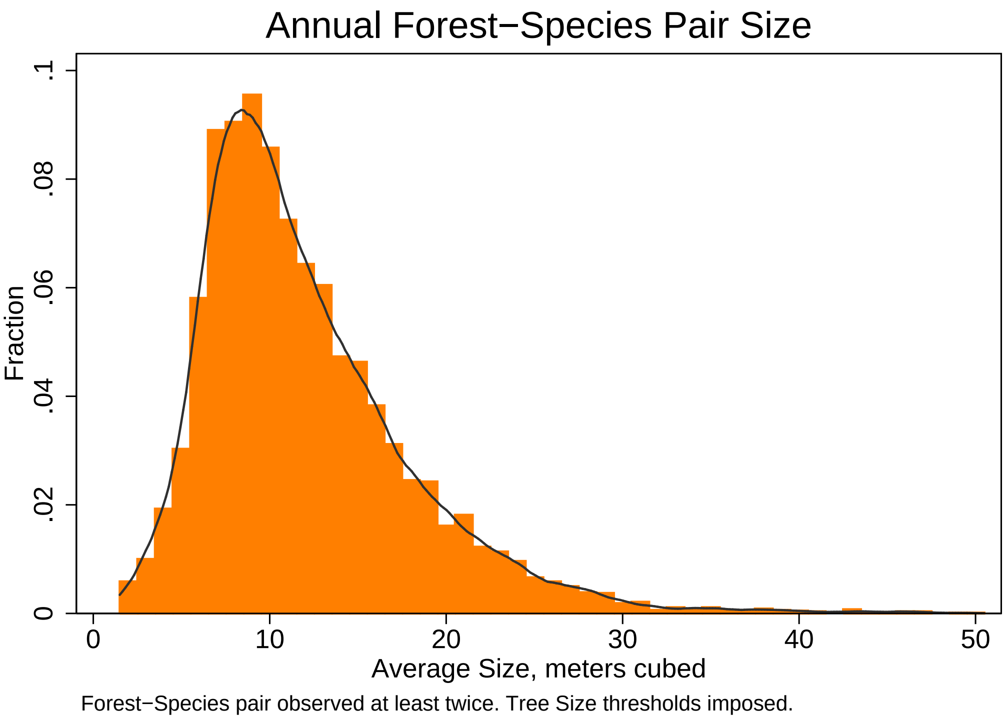

Figure 4: Distribution of Tree Size Observations

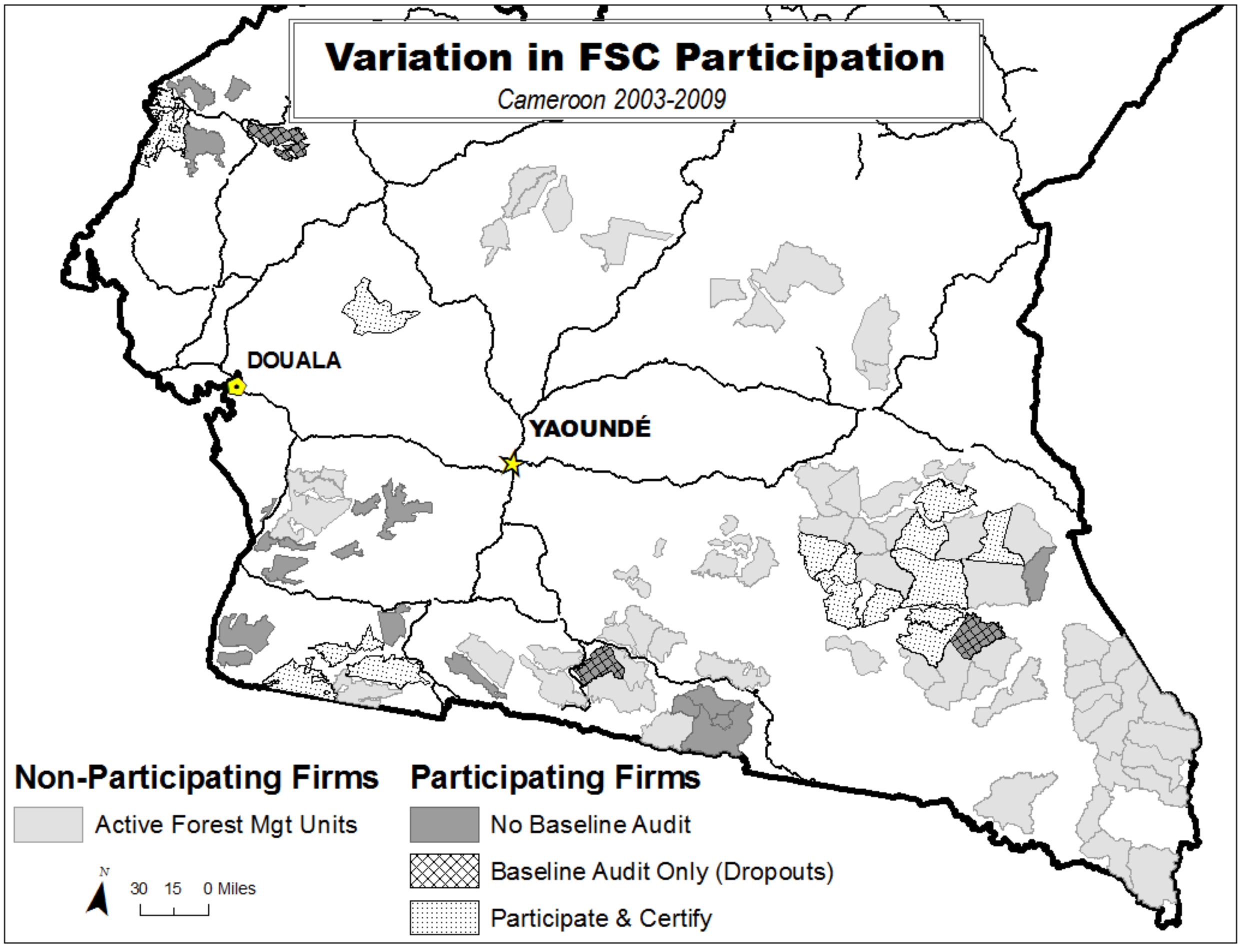

Figure 5: Geographical Variation in FSC Participation in Cameroon

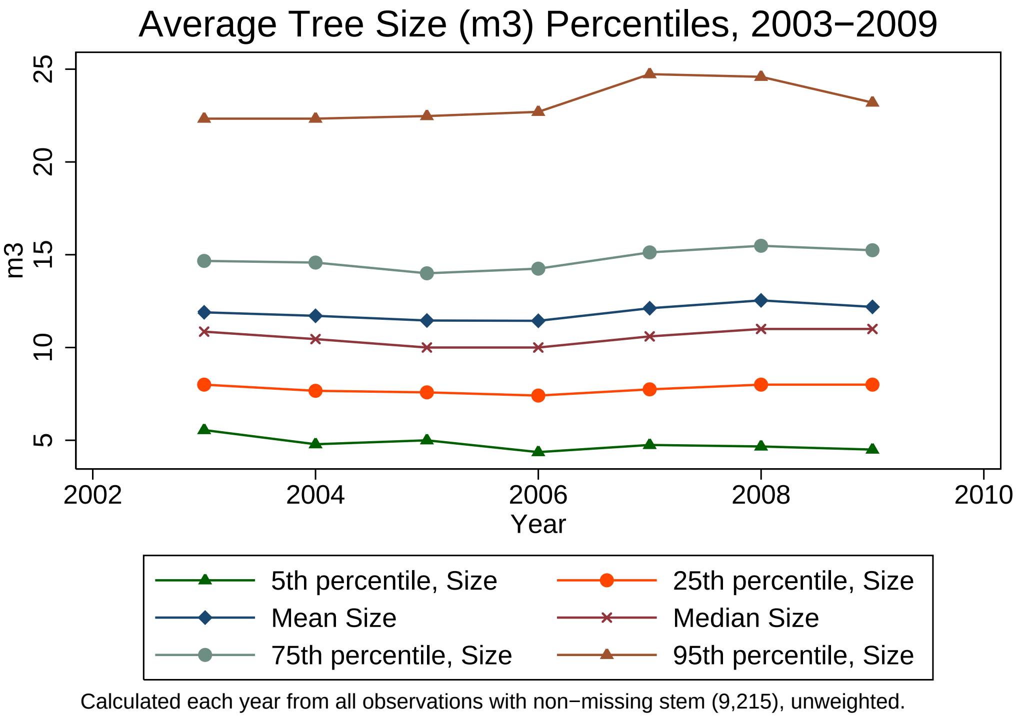

Figure 6: Trends Across Panel, Tree Size Percentiles

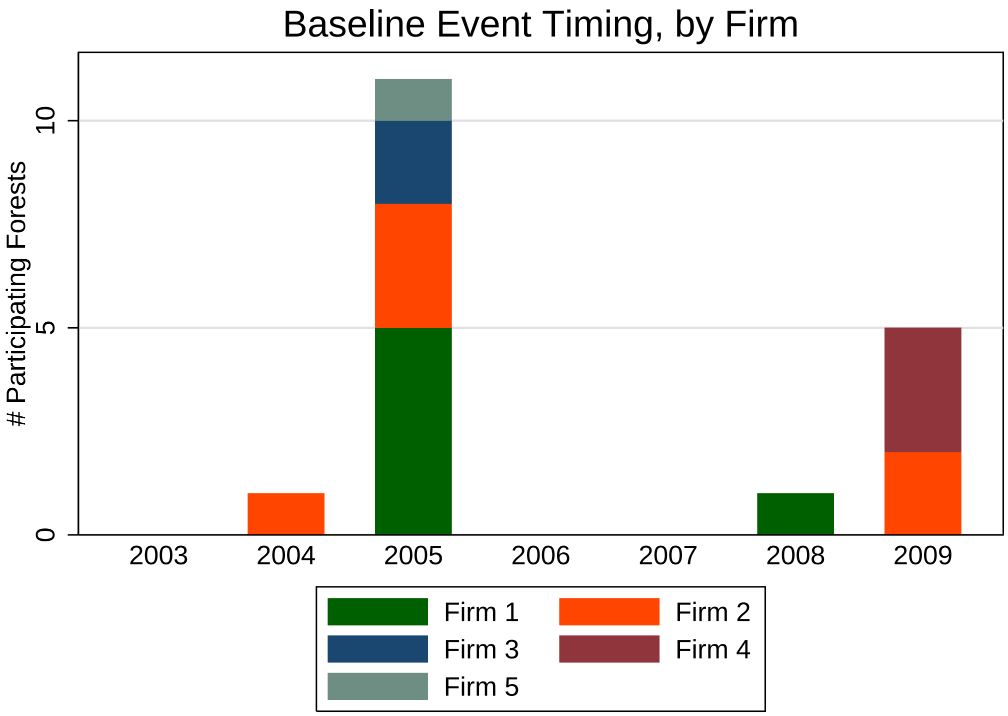

Figure 7: Variation in Baseline Event Timing

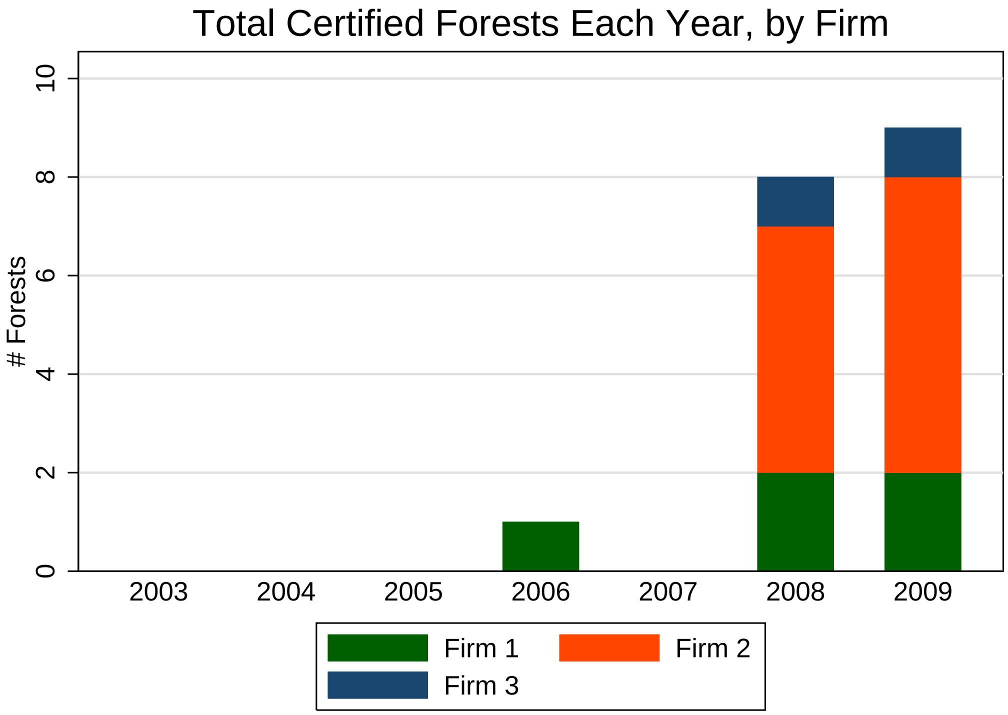

Figure 8: Variation in Certification Timing

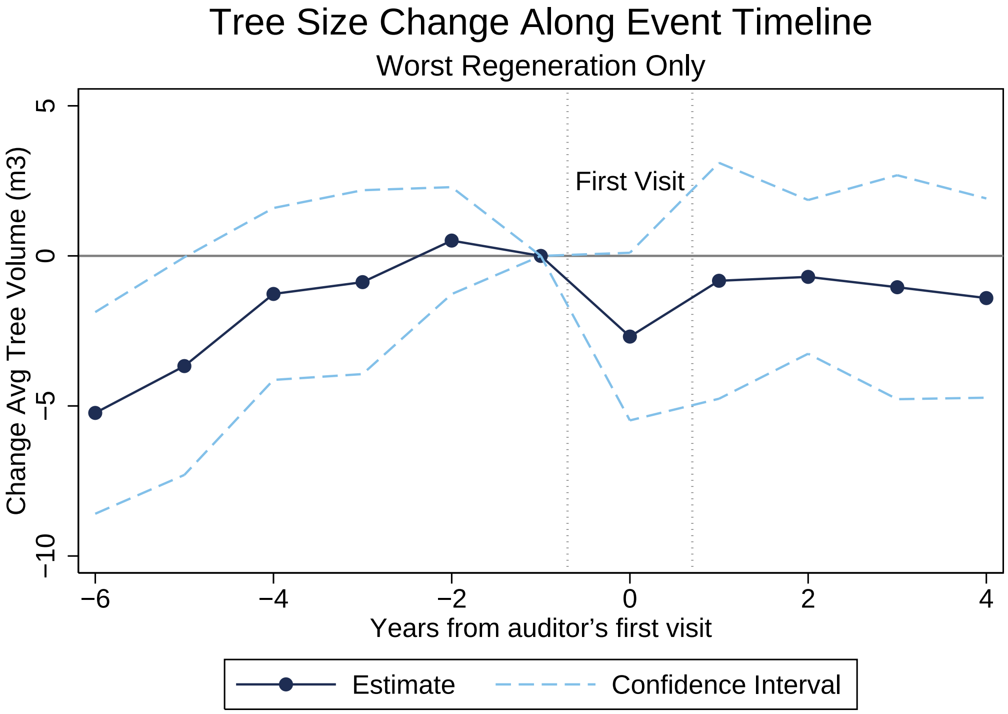

Figure 9: Abrupt, Temporary Fall in Tree Size at Baseline for At-Risk Species

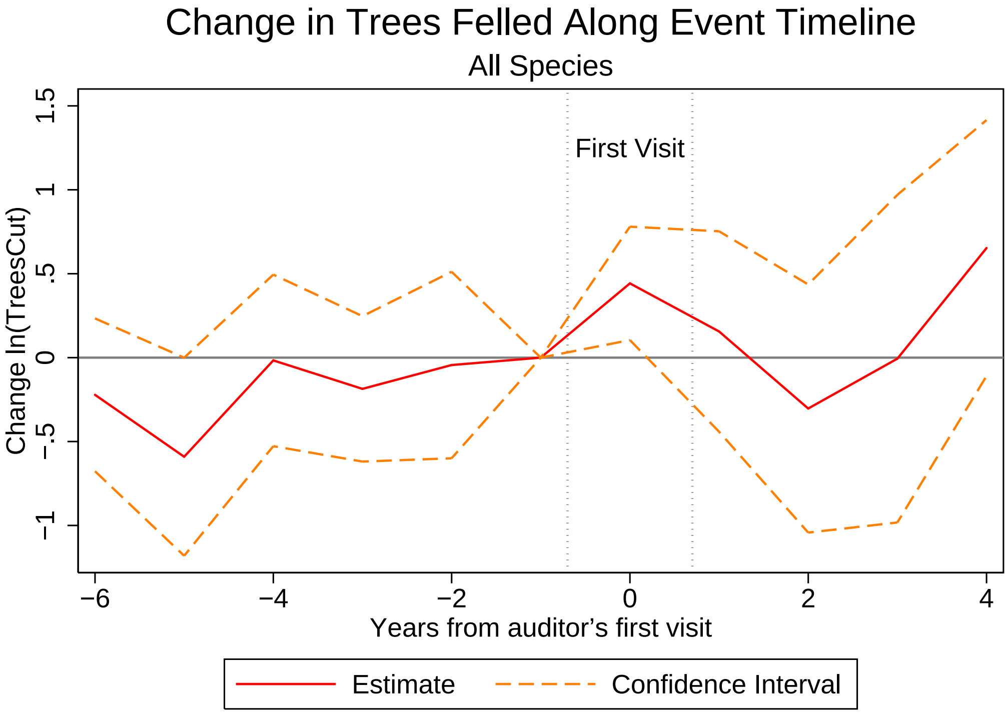

Figure 10: Temporary Production Increase at Baseline Event for All Species

CHAPTER 2

Unintended Impacts from Forest Certification: Evidence from Congolese Households

1 Abstract

Forest Stewardship Council's (FSC) certifies forests where timber management is "socially beneficial." To satisfy this criterion, a certified timber firm in Congo built a road connecting villages to a regional trade network and facilitated trade in agricultural goods. A model of a rural household predicts changes in consumption, production, and wealth from the new road connection depending on a household's comparative advantage in production. Primary data collected along the boundary of a certified and an uncertified forest management unit in the Republic of Congo shows that household nutrition changes with certification. Certified households decrease the frequency of animal protein consumption by one third, so that half of the time, certified households report eating no animal protein. Indigenous households, net buyers of farmed starch, shift consumption to starch foraged from the forest, a source inferior in calories. Non-indigenous, farming households increase the number of fields they cultivate and decrease the fallow period for existing fields, threatening long term soil productivity. These households then invest their increased wealth in their dwelling, investing in walls made of sawnwood.

2 Introduction

Independent certification of sustainable production of commodities such as timber has emerged as a new governance tool, promising to address development needs of forest-dependent communities. Voluntary labels claiming to certify sustainable production have proliferated without evidence as to their effectiveness. Benefits to local households depend on which activities the firm chooses to implement and how these activities interact with the local context. There is reason to hope that certified firms may be able to provide services in contexts where developing country states fail to do so. For example, certified timber firms have better local knowledge than the state and since they are consistently monitored by an independent auditor, they have incentives to provide these services.

Skeptics point out that this new governance tool creates a new incentive problem for development activities, this time seated with the firm. Firms have incentives to choose development activities that are the least costly to them. When selecting among activities, they may be more likely to choose activities that benefit local elites. Finally, external monitoring creates incentives for them to choose activities that are easily legible to the independent auditor.

For certified timber firms in tropical forests, the development challenges they might address are manifold. On average, people living in tropical forests are more likely to suffer from malnutrition and extreme poverty. Disease loads are higher. Average literacy is very low. Dependence on forest resources for food and shelter is very high. Yet interventions pose two risks. First, they may change the distribution of benefits. Benefits may accrue to those most prepared to respond to new development opportunities and vulnerable groups may find themselves worse off. Second, interventions may bring about negative externalities from poorly selected implementation activities.

This paper investigates how activities implemented to satisfy FSC requirements change outcomes for forest households in northern Republic of Congo. I pay special attention to the distribution of benefits between indigenous and non-indigenous people. Using primary data I collected in Congo, I compare outcomes for 190 households on either side of the boundary between an FSC-certified forest and an uncertified forest.

The firm's primary activity implemented to satisfy FSC requirements was to construct a road segment linking five previously isolated villages to a regional road network. Villages in the non-FSC forest management unit remain inaccessible by road. The FSC-certified firm then encouraged trade of agricultural products from certified villages by constructing a marketplace in one village and making periodic trips to the villages to purchase food products. Roads facilitate access to game by hunters, both locals and non-locals. Recognizing the risk of defaunatation from the road, the firm also implemented protocols to control hunting.

We can think of the change from certification as a shift from autarky to trade for certified villages and make predictions as to how households will change consumption and production. The road changes relative prices, increasing the price of foodstuffs demanded for export. Foodstuffs demanded for export include wild protein and farmed starch. We expect to see total production increase, but we also expect to find winners and losers within connected villages. Households with a comparative advantage in producing wild protein or farmed starch will fare better than those that previously traded for those goods. In the short run, we expect all households to shift production toward exported goods within the constraints of their production technology. For households with a comparative advantage in the production of export goods, we expect to see an increase in wealth.

Empirically, I find evidence that fits this story. Households with a comparative advantage in exported foodstuffs have little change in their food consumption, whereas households that previously traded their labor for food decrease their consumption of exported food. Comaprative advantage in protein production does not vary consistently across ethnic groups. The likelihood that the average household consumes any animal protein the previous day falls by a third for certified households. Put another way, the frequency of no protein days increases by an additional 1.5 days per week. Households that specialize in fish production are less affected.

In contrast, comparative advantage in starch production varies by ethnic group. Indigenous people specialize in foraged starch but depend on seasonal access to farmed starch during periods when foraged starch yields are low. Farmed starch is higher in calories per unit mass and, prior to certification, yielded greater volume per hour of labor. With certification, non-indigenous households export farmed starch and forager households turn toward foraged starch to meet their calorie needs. For indigenous households in certified villages, we see substitution toward forager starch, which is inferior in calories per unit mass and requires great labor intensity per calorie during this time of year.

All households respond to new trade opportunities by shifting their production toward exported agricultural goods. Non-indigenous, farmer households both intensify and extensify production. They intensify production by decreasing the number of cultivars planted, specializing in exported foodstuff. They extensify production by increasing the number of fields they cultivate. Households may increase the area under cultivation by either opening up new fields or by using fallow fields sooner. From the household's perspective, using a fallow field represents a tradeoff across time: it is less costly in the short run but will reduce yield productivity in the long run through loss of soil nutrients. From a social standpoint, faster fallow rotation mines the soil of nutrients whereas opening up new fields contributes to local deforestation. I find that households respond to new trade opportunities by reducing the fallow period by about a half. These households appear to invest their increased wealth in their dwelling walls, taking advantage of lower prices for sawnwood from the road connection.

This paper contributes to literature on eco-label effectiveness and the impact of road connections on rural households. It addresses gaps in voluntary environmental policy effectiveness by analyzing FSC, the most important label. It does so in a context understudied, the Congo Basin. It contributes to literatures on indigenous peoples outcomes and traditional development activities.

The paper is structured as follow. I begin by describing the institutional context of timber production, FSC-certified and uncertified, and characterize the rural economy of forest dependent households living in industrial forests in Congo in Section Two. I then use a simple theoretical model to make predictions as to how consumption, production, and wealth will change with a new road connection, comparing predictions across groups with different comparative advantages in Section Three. Section Four describes how the the dataset was generated and characterizes the study population. In Section Five, I defend the empirical framework and investigate threats to identification. Study results are presented in Section Six and Section Seven concludes.

3 Institutional Context

This section gives the institutional context needed to interpret the study results. I begin by describing a firm's obligations to forest dependent households in first certified, then uncertified, forests. A description of the rural economy of forest dependent households in Congolese industrial forests follows.

3.1 Timber Production

3.1.1 FSC-Certified Timber Production

Forest Stewardship Council's (FSC) Forest Management Certification is the most well-known and well-respected among forestry eco-labels. Participation is voluntary. Ten principles and criteria are used to assess the "responsibility" of timber production. The principles and criteria that are most relevant to this study are those concerning rural development, indigenous peoples' rights, and controlled hunting.

Principle four states that firms must contribute to the "rural development" of forest users. "Forest management operations shall maintain or enhance the long-term social and economic well-being of forest workers and local communities" (FSC 1996). The spirit of this principle is that firms are extracting resources from communities and they should compensate them in some way. FSC is not a prescriptive policy; the activities implemented in order to satisfy its principles vary from forest to forest. In the Congo Basin, one common way timber firms fulfill their rural development mandate is by either resurfacing and maintaining old, derelict public roads or building a new road that connects previously isolated villages to a broader road network.

Timber firms in the Congo Basin choose to satisfy FSC requirements in this way for a couple of reasons. First, roads are easily monitored by FSC auditors. Second, because timber production in the Congo Basin is selective, these firms are skilled at road-building. Building roads is a low cost way, in terms of capital, management costs, and materials, for firms to satisfy the FSC requirement. Firms also elect to satisfy FSC requirements by building roads because roads in the Congo Basin are in terrible shape. Development agencies, such as the

World Bank, the IMF, the US Agency for International Development, and the United Nations Development Program, promote resurfacing roads and building new road connections as a way to improve development outcomes in the Congo Basin. The reasoning behind this is familiar to economists: roads offer opportunities for gains from trade and increase total production.

Though roads in the Congo Basin need rehabilitation, they bring risks, too. The risks most relevant in the Congo Basin are local deforestation, malnutrition, and defaunation. Evidence regarding their impact on deforestation is mixed, as it depends on how local agricultural production responds to changes in relative prices. The response is characterized as a pressure-cooker or pressure-relief valve. If households extensify their agricultural production and convert more forest to fields in order to respond to higher prices for agricultural goods, local deforestation will increase. If food is cheaper to import than produce after the road is built or resurfaced, deforestation will decrease.

Though roads promise to increase the size of the pie, impacts will be heterogeneous across households in the economy. A change in prices begets winners and losers, which in the short run depend on the location of a household's original endowment and in the long run depend on how easily the household can shift production in response the price change. An equity concern specific to the Congo Basin is if indigenous groups suffer more from changes in road connections. Criteria 3.2 explicitly governs resource access for indigenous peoples, stating that "forest management shall not threaten or diminish, either directly or indirectly, the resources or tenure rights of indigenous peoples" (FSC, 1996). In the context of the Motaba River, this criterion is most relevant with regard to BaAka access to wild protein, wild starch, and farmed starch, given their seasonal starch provision strategy.

Roads have been shown to be devastating for local fauna, as they facilitate access by hunters to previously inaccessible tracts of forests and encourage trade of bushmeat. Recognizing this, the state requires all forests to implement controlled hunting protocols. However, this requirement remains poorly enforced in uncertified forest management units. FSC also requires controlled hunting protocols. Criteria 6.2 states that "inappropriate hunting, fishing, trapping and collecting shall be controlled" (FSC, 1996). Activities satisfying this criterion include control posts on roads to check for illegal trade in wildlife, seasonal and annual permits, and patrols of hunting zones. In certified forests, firms are consistently monitored and compliance is better. The certified firm under study is recognized as having one of the most sophisticated and far-reaching anti-poaching programs.

The timeline for production and road-building activities begins in 2002. Figure 12 shows a map of the study site, where the Motaba River acts as the boundary between the certified and uncertified forest management units. In 2002 the certified firm, Congolaise Industrielle du Bois (CIB), signed a contract with the Congolese government and that granted rights to timber production in Loundoungou FMU for a period of fifteen years. In 2003, Thanry Congo began production in the uncertified Ipendja FMU and CIB began production in the north of the Loundoungou FMU. [1] In 2007, CIB resurfaced the road connecting the Loundoungou sawmill town to Makao and built a bridge across the Motaba River. This is the road sweeping from the bottom left corner of Figure 12 to the towns of Makao and Ipendja. At about this same time, CIB built the smaller road that branches off of this main road south of the Motaba, connecting the five certified villages and ending in Bangui Motaba. The Loundoungou sawmill was constructed between 2008-2009.

3.1.2 Uncertified Timber Production

The Motaba River forms the boundary between the certified and uncertified forest concessions. De jure, all forest management units have a responsibility to provide services to communities living within their forests. These social obligations are negotiated between the Congolese State and the timber firm and described in the contract as the *cahiers des charges.* These obligations are typically haphazard, modest, and their implementation is not enforced by the State. In the case of the Motaba River, the social obligations specified in the Ipendja forest concession had not changed road access for the three study villages. Study participants frequently complained that they had not seen benefits from Thanry Congo. Thus, we can interpret this study as an evaluation of the causal impact of FSC activities as compared to de facto timber management in Congo, where timber is extracted and no social services are provided by the firm.

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[1] In 2005, Loundoungou and Toukoulaka FMU were combined into one FMU. The FMU in Figure 12 includes both FMUs.

3.2 The Rural Economy of the Motaba River

Even with FSC certification and the new road connection, households remain focused on autoconsumption and production of agricultural goods. Logging activities are concentrated in the town that accompanies the sawmill and in the timber camp, which moves around within the forest concession depending on which part of the forest is being logged. The sawmill site for Thanry is Ipendja, visible in Figure 12, and for CIB it is Loundougou, which is south of this map. Both are several hours drive from the villages along the Motaba. Some households do seasonal work for the timber company, such as helping with forest inventories but firms typically prefer to hire individuals with better literacy and greater experience in timber production.

3.2.1 The Motaba River

Before FSC certification, for villages on either side of the Motaba River the primary method of trade was either to travel to a town with a market or to trade with merchants traveling up or down the Motaba by boat (Kitanishi, 1995). As seen in Figure 12, directly north and south of the study site are two towns, Makao and Djubé. These towns are much larger, with over one thousand inhabitants each. They have weekly markets active since before the road connection. Merchants travel down the Motaba River by boat selling manufactured goods and buying agricultural goods from villagers. For villages connected by road, merchants come by truck or motorcycle. The price of imported goods falls when a village is connected by road, most notably for housing materials, such as sawnwood, and imported medicine, such as antibiotics.

The Motaba River begins north of the study site, flowing southward to eventually join the Ubangi River. The river runs roughly southeast. Figure 12 shows the study site, about a 20 mile stretch of the Upper Motaba. Within this segment, historical settlement patterns reflect colonial prerogatives during World War II. Villagers were forced to resettle along the river to facilitate monitoring by the French colonial government. During resettlement, clans chose sites with a suitable sandy bay for launching and receiving dugout canoes. For the study site's stretch of the Motaba, villages north of 17.31 longitude are on the east side of the river whereas villages south of this latitude are on the west side of the river. Ecology and demographics change along the Motaba River gradient. Semi-nomadic BaAka households form trade partnerships with permanent households in both the Upper and Lower Motaba. When compared to the Lower Motaba, the Upper Motaba has weaker fishing productivity and the Kaka ethnic group dominates, whereas Lower Motaba settlements are majority Bondongo households.

3.2.2 The Rural Economy

The main production activities for households along the Upper Motaba River include food and shelter production and artisanal work. With regard to food, household members may farm, forage in the forest, hunt, or fish for themselves or they may do so for another household in exchange for payment. Households use labor, in conjunction with human and physical capital such as machetes, guns, snares, harpoons, or fish traps, to produce starch and protein to eat and trade. Land rights are inherited and there was no evidence of a shortage of suitable sites for planting.

Households have a comparative advantage in protein activities, specializing in fishing or hunting. Fishing and hunting are mostly done by men and require specialized knowledge of tools, such as fish traps or rifles, and the most effective places to put these tools. Fisher and hunter expertise does not break down neatly along ethnic lines. For the indigenous group, the BaAka, men may specialize in one or the other, or both. Generally, Bondongo households have greater fishing expertise, as seen by a wider range of fishing techniques and greater participation in fishing. Kaka, on the other hand, have greater hunting expertise and are more likely to spend extended periods of time in the forest on hunting trips. To identify a household's comparative advantage in protein production, I rely on the presence of specialized tools rather than ethnic group affiliation.

In contrast to protein provision, starch provision expertise breaks down along ethnic lines. BaAka, the indigenous group, specialize in foraged starch whereas all other ethnic groups focus on farmed starch. During the dry season, from November to February, foraged starch is less abundant and all households rely on farmed starch as their main calorie source. Farmed starch includes manioc, plantains, or sweet potatoes. These foodstuffs are more calorie dense per unit mass and are less perishable than foraged starch, particularly manioc, which can be processed in a variety of ways to extend its shelf life. They are also in high demand for export. Logging company employees in logging towns hail from Cameroon, Central African Republic, or the Democratic Republic of the Congo and are familiar with these farmed starches.

On average, each ethnic group cultivates some manioc. Agricultural investments by indigenous households households are modest compared to Bantu households. When not trading labor for farmed starch, BaAka rely on manioc from their own fields or foraged starch from the forest. Because of this distinction in starch comparative advantage, I label BaAka households as "forager households" and Bantu households as "farmer households" in the empirical analysis. Among Bantu households, the majority are either Kaka and Bondongo, both of which cultivate fields of corn and manioc. Historically, the Bondongo have been recognized as more sophisticated farmers, growing a more diverse set of cultivars and planting larger fields, on average.

Semi-nomadic, BaAka households are experts at foraging starch, fruit, mushrooms, and other foodstuffs in the forest. The BaAka are indigenous to the Congo Basin forest and are genetically distinct from more recent arrivals (Quintana-Murci et al., 2008). Their starch provision strategy has evolved in step with seasonal changes in wild roots and tubers. During the dry season, when the survey was implemented, the main foraged starches are *ekoule* and *mela*. Forest starch, in general, is less abundant during the dry season. BaAka and Bantu farmers have developed a symbiotic relationship emerged where BaAka spend time in villages during the dry season trading their labor in Bantu fields for calorie rich farmed starch, among other things. Historically, access to farmed starch during the dry season has been critical for forager households for three reasons. One, they need to replenish glycogen stores after spending a long period of time in the forest. Two, foraged starch is less abundant during this time of year, thus the farmed starch serves as part of an annual starch strategy. And three, the labor of clearing fields and harvesting manioc for farmer households is physically taxing, requiring a more calorie dense starch.

4 Theoretical Model

The theoretical model simplifies the rural economy and describes how it changes with activities implemented to satisfy FSC certification. After describing the model, I make predictions for how consumption, production, and wealth will change for households with different comparative advantages.

4.1 Model Primitives

Imagine an autarkic, rural economy with many households. Households are producers and consumers of foodstuffs, which may be produced from agriculture, foraging, hunting, or fishing. Each household has a stock of potential labor, $\bar{L}$, that they divide between food production work l^s and other work or leisure l^d. Households use work to produce food y via the production technology:

$$y^s = f(l^s, K, A) \tag{1}$$

Where K is physical capital, and A is human capital. Human capital includes experience and expertise gained through cultural practices. The production technology, $f(.)$, is identical for all households and is continuously differentiable, increasing, and strictly concave in each factor. We can rewrite the production problem as the pareto possibilities frontier, $F(y^s, l^s)$.

Households derive utility from consuming foodstuffs y^d and other goods or leisure l^d, according to their utility function:

$$U(y^d, l^d) = g(y^d) + l^d \tag{2}$$

Where $U(y^d, l^d)$ is continuously differentiable, increasing, and strictly convex. I model the household's utility function as quasi-linear in other good consumption because we only observe food consumption along the extensive margin. With a quasi-linear utility function, the income expansion path for consumption of the non-linear good will remain fixed beyond some income level. Given that there are few food alternatives, this fits our context well.

Households maximize their utility subject to a budget constraint, their income I.

$$I = y^s p + l^s w \tag{3}$$

Income is a function of household production $\{y^s, l^s\}$, which is optimized separately, and the market price for food is p and the market wage for labor is w.

4.1.1 Competitive Equilibrium

In a competitive equilibrium, total supply and demand for food and leisure within the rural economy determines the relative price ratio $\frac{p^y}{w}$.

$$p^y \sum_{n=1}^{N} y^s + w \sum_{n=1}^{N} l^s = p^y \sum_{n=1}^{N} y^d + w \sum_{n=1}^{N} l^d \tag{4}$$

By definition, for each household $l^s = \bar{L} - l^d$. I assume that there are a sufficiently large number of households such that the supply and demand of any one household does not change the equilibrium price.

In competitive equilibrium, households maximize utility and profit from production separately. When maximizing utility, each household consumes $\{y^d, l^d\}$ such that their marginal rate of substitution between food and other goods is equal to their price ratio:

$$\frac{\frac{\partial U}{\partial y}}{\frac{\partial U}{\partial l}} = \frac{g'(y)}{1} = \frac{p}{w} \tag{5}$$

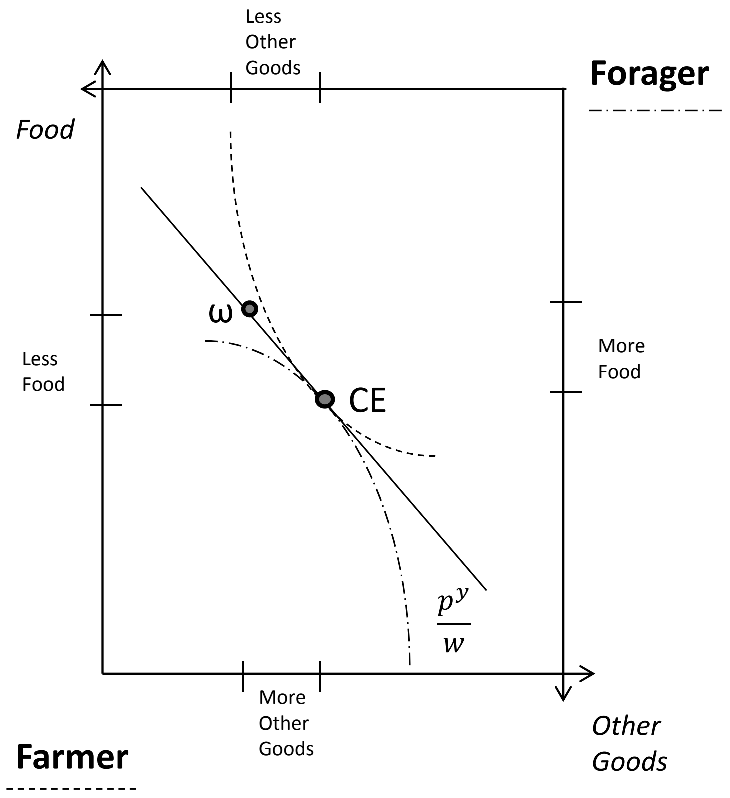
When optimizing production, the household chooses the production bundle $\{y^s, l^s\}$ that gives the largest income I. In this way, preferences are separable from production. The household chooses the production bundle such that the marginal rate of technical substitution is equal to the price ratio:

$$\frac{\frac{\partial F}{\partial y^s}}{\frac{\partial F}{\partial l}} = \frac{p}{w} \tag{6}$$

4.1.2 Comparative Advantage

Households differ in their comparative advantage in producing food y. The shape of the production technology, $f(\dot{})$, is identical across households. A household with high physical or human capital will have a comparative advantage in producing y as compared to a household with low physical or human capital. Preferences on food and other goods or leisure may vary across households.

If we simplify the economy to two households, one more skilled at food production than the other, we can depict the competitive equilibrium graphically. We can show the economy's competitive equilibrium using an edgeworth box. Each household's original endowment is ω, the sum of their labor and food endowments determine the dimensions of the box. Preferences are represented by the bowed curves emanating from each origin. Utility increases as you move away from the origin.



As compared to staying at their original endowment, households improve their utility by trading. The Farmer improves utility by trading food for other goods. The competitive equilibrium price $\frac{p^y}{w}$ is determined by the original endowment and each household's marginal rate of substitution.

4.2 Prediction Changes from FSC Certification

The FSC certified firm changes this competitive equilibrium by connecting village to a road network and facilitating trade with logging towns. This shifts the village form a competitive equilibrium determined locally, through local supply and demand for goods and leisure, to a competitive equilibrium where prices are changed exogenously through excess demand for food from newly connected logging towns. Normalizing the price of other goods and leisure, e.g. the wage, to 1, we have:

$$p^c > p \tag{7}$$

Each section below describes how households change their consumption, production, and investment in response to the higher price from the road connection.

4.2.1 Consumption

Villages connected by road face excess demand for foodstuffs y. Excess demand changes local relative prices as described above. In this section, I make predictions as to how a household's consumption of y changes with the new price. This will depend on whether the household was a net buyer or net seller of foodstuff y at the original price p, which in turn depends on the household's comparative advantage in production. For predictions with regard to consumption, I assume the original production bundle does not change. Short run changes in the production bundle, evaluated in the next section, are likely to be small relative to the gap between households with or without a comparative advantage in the production of foodstuff y.

Consumption of y by the net seller will remain unchanged after the price increase, due to the household's quasi-linear preferences. Since they are comparatively richer given their production bundle and the new higher price for y, these households enjoy other goods or greater leisure, which they may invest in other activities. For net buyers of y, the new price shrinks their budget set. They reduce their consumption of y as well as their consumption of other goods and leisure. They must work more for less food.

4.2.2 Production

The changes in relative prices from the new road connection for FSC-certified villages changes incentives for agricultural production. In the short run, households will adjust by shifting production along their pareto possibilities frontier away from other goods and leisure and toward production of y. They will continue to shift toward production of foodstuff y until the point at which the marginal rate of technical substitution is equal to the price ratio of food to other goods and leisure:

$$\frac{\frac{\partial F}{\partial y}}{\frac{\partial F}{\partial l}} = \frac{p}{w} \tag{8}$$

Households with a comparative advantage in the production of foodstuff y will increase their demand for agricultural labor. If Farmer households increase demand for external agricultural labor, the wage rate should increase. In this way, households with a comparative advantage in other work or leisure l^d may share in the benefits from the new road connection. Farmer households may instead draw from their stock of potential labor $\bar{L}$ depending on the shadow value of their time.

Households with a comparative advantage in the production of y will unambiguously have an increased budget set after certification increases the price of y. These households are now wealthier and, given a quasi-linear utility function, they will have a larger endowment of other goods and leisure. They may choose to spend these resources on other investments, such as improving their dwelling, something I investigate in the next section.

Changes in meat production deserve a special note because the firm's controlled hunting protocol changes the shape of a household's pareto possibility frontier. The price of meat increases like that of other exportable foodstuffs. However, unlike for agricultural production or fishing, FSC activities change the production technology in two competing ways. Roads enable access to game and may improve meat yield. Controlled hunting measures restrict access to munitions and increase the cost of hunting by requiring a license. Their impact together makes the prediction for meat production ambiguous.

4.3 Wealth and Investment

As we saw in the previous section, households with a comparative advantage in production of foodstuff y will be wealthier after the road connection and increased prices of p. Because preferences are quasi-linear, these households will not increase their consumption of y but instead enjoy greater leisure and consumption of other goods. One way they might spend revenues from the sale of y and invest these resources in better housing services by improving their dwelling.

Suppose a household can improve the quality of their dwelling H via labor,

$$H = H_0 + h(\bar{L} - l^s) \tag{9}$$

Suppose further that households may upgrade the materials of their dwelling - the walls and roof - from local materials to more durable materials that are now cheaper to import. In this case, we would predict that net seller households can use their increased income, additional leisure, and lower price of durable housing materials to invest in dwelling upgrades.

5 Data

For this study, I use primary data collected expressly to investigate how FSC changes outcomes for local forest-dependent households along the Motaba River in the Republic of Congo. Below, I first walk through the data generation process. I then discuss observable household characteristics and how they differ across the two sides of the Motaba River. Finally, I discuss evidence from the survey for a shift from autarky to trade with the new road connection.

5.1 Survey Methodology

The data come from a household survey of 190 participating households living in nine village along the Upper Motaba River from November 2012 to February 2013. The Motaba River demarcates the boundary between a certified and an uncertified forest concession. The nine study villages described in Table 14 begin south of the town of Makao and end north of the town of Djoubé. Six of the villages are on the certified side of the Motaba River. In order along the River, the certified villages are Ipenda-Pape, Beye, Seke, Moulapa, Anikou, and Bangui Motaba. The uncertified villages, in order, are Likombo, Zingo, and Bodzuanda. The number of participating households in each village ranges from six to seventy-nine. The time in each village corresponded roughly to the number of participants.

The study takes place within one season, the 2012 main dry season. The dry season begins in November and ends in February and is the time of year when semi-nomadic households are most likely to be spend time in the village (Kitanishi, 1995)(Riddell and Obongo, 2011). I randomized the visit order for the study villages prior to the start of the survey. The survey dates for each village are included in Table 14.

The survey sampling scheme was a simple census. All households in the village were recruited to participate. Participation was voluntary and either the enumerator or the household could refuse participation. Table 15 relates the census of all village households to survey participation. Nine households refused to participate when approached. The primary reason given for refusal by these households was that the occupants were too old or unwell to participate in a two hour long survey. 31 households were refused by the enumerator, all of these households were in one neighborhood of Bangui-Motaba, Bobate. The Bobate neighborhood was insisting on additional fees for participation and not adhering to the original agreement, so I terminated surveys in that village. Before we stopped surveying in Bobate, we interviewed 11 households. All regressions include these 11 households.

Participants or the enumerator could choose to stop the survey at any time. Seven households started but did not finish the survey. Finally, 51 households were absent during our stay in the village, about half of which were from certified villages. The survey was given in either French, Lingala, or BaAka and took no more than 2 hours per household. Survey questions were adapted from the ECAM survey in Cameroon and Michael Riddell's thesis. Questions were approved by the University of Michigan Internal Review Board. The survey was piloted and revised from in Makao prior to implementation.

5.2 Observable Household and Individual Characteristics and Outcomes

We can investigate whether households' observable characteristics are different in certified and uncertified villages using Table 17. The number of residents in a household is the same on either side of the river, about 4 people per household. Most households plant a field, about 84%. The age of the household head is about the same, mid-forties. A household head is "old" if they are at least 55 years old or older. Rates for old household heads are similar across the two sides. The *Educated* variable is a dummy equal to one if the household head has ever attended school. Education rates, defined this way, are about the same at 74%. With regard to observable characteristics, FSC and non-FSC villages appear similar.

In addition to generic household characteristics that may affect productivity, we would like to know how a household's comparative advantage varies across certified and uncertified villages. Table 16 reports comparative advantage frequencies across treatment status. Farmers and Foragers are fairly evenly split within villages of either type. Farmers include all Bantu households. Fishers are households that reported having fishhooks. We see that most households fish in this way and fraction of non-Fishers is about even across the two sides. Bantu households where the household head claims a Kaka affiliation are expected to be adept at rifle hunting. We find fewer Kaka households in uncertified villages, likely owing to the greater ratio of BaAka to Bantu in these villages.

5.3 Mechanisms: Hunting Restrictions and Road Connection

Evidence of the effectiveness of the certified firm's controlled hunting protocols can be found in respondents' hunting behavior Table 19 reports the difference in hunting behavior, reporting the difference between not FSC households and FSC households. Positive values indicate number or frequency of the outcome in uncertified households. We see that fewer certified households have a rifle, any shotgun shells, or many shotgun shells. They are less likely to hunt at night, a type of hunting forbidden in FSC forests. The total number of snares is similar across certified and uncertified households, but the types of snares differ. Nylon and wire snares are more effective at trapping game but are also snare more indiscriminately, threatening protected fauna. Certified households report fewer wire snares, prohibited in FSC forests, and more raffia snares, legal in FSC forests. Nylon snare usage is about the same across certification status, though nylon snares are also illegal in FSC forests.

The FSC-certified firm builds a road segment that connects certified villages to a broader road network. They also built a sheltered marketplace and helped organize a weekly market on Sundays. Finally, the certified firm periodically sent a truck to villages to buy agricultural goods to then sell to logging town employees. All of these changes increased the opportunity for households to sell agricultural goods they produce.

6 Empirical Strategy

The goal of the empirical analysis is to estimate how the average rural household's consumption, production, and investment change as a result of FSC interventions. Furthermore, I want to investigate whether these changes are driven by one intervention in particular: a new road connecting the village to a broader road network. To do this, I compare forest user outcomes for households living on either side of the border of an FSC-certified forest management unit. In order to attribute these changes to the road, I compare how consumption, production, and investment changes for households with a comparative advantage in exportable good production to households those with less of a comparative advantage.

I begin by describing the regression specification, emphasizing the coefficients of interest and their interpretation. Next, I make explicit the identifying assumption that must hold for causal inference of this specification. Finally, using institutional detail and empirical evidence, I investigate two potential threats to this identifying assumption.

6.1 Regression Specification

The goal of the empirical analysis is to estimate how household consumption, production, and investment outcomes change with certification. For most outcomes, we are also interested in investigating how changes differ across households with or without a comparative advantage in exportable foodstuffs. The most basic regression specification compares outcomes for households h in villages v, estimating the difference between households in certified villages and uncertified villages:

$$y_{h,v} = \alpha + \beta_c Cert_v + \gamma' X_h + \epsilon_{h,v} \tag{10}$$

In this specification, $Cert_v$ is a dummy variable equal to one if the village is on the east bank of the Motaba River, within the certified Forest Management Unit. For all regressions, the X_h term includes two dummy variables that characterize the household head: whether female and whether the household head arrived within the last five years. For production regressions, X_h also includes covariates that capture a household's physical or human capital.

Most regressions investigate how certification changes outcomes for a subgroup predicted to be important within the theoretical model. For consumption, we expect net buyers of exported good y to reduce consumption only. So $Subgroup_h$ is a dummy variable equal to one if the household has a comparative advantage in the production of y and is likely a net seller.

$$y_{h,v} = \alpha + \beta_c Cert_v + \beta_{c,SG}(Cert_v * Subgroup_h) + \beta_{SG} Subgroup_h + \gamma' X + \epsilon_{h,v} \tag{11}$$

For production, a household's response to new trade opportunities is limited by their existing production technology. In this case, $Subgroup_h$ will indicate the household's technology, e.g. whether a Fisher or non-Fisher, or whether Farmer or a Forager. Recall that Fisher and Hunter do not vary by ethnic subgroup but Farmer and Forager do, corresponding to Bantu and BaAka households, respectively.

Households live in agglomerations in space such as neighborhoods and villages. Households within the same village share unobserved shocks and likely covary. This makes each observation less informative than if they were from an independent distribution. To correct for this, I cluster the standard errors at the village-level v. Because there are only nine villages, this correction may make us more likely to reject the null hypothesis. This problem is particularly severe for estimates of regressors that change at the village-level only, e.g. the $Cert_v$ treatment variable. For regressions that interact certification with a household characteristic, the likelihood of over-rejecting is less severe. To help understand the degree of intra-class correlation within villages, I include results tables with robust standard errors that do not correct for clustering.

6.2 Identifying Assumption

The identifying assumption describes how household characteristics change across space. I assume there is no discontinuous change in unobserved household characteristics across the Motaba River. Recall that the boundary of the FSC-certified forest assigns villages on the west bank of the Motaba River to treatment; villages on the east bank are considered controls. The historical settlement pattern along this stretch of the Motaba River created a longitudinal pattern for treated and untreated villages. Villages north of 17.32 degrees longitude are on the west, certified side and villages below this are located on the east, uncertified bank. As discussed in the institutions section, village settlement pre-dates both forest concessions by several decades. However, in order to identify the average change from certification, I must assume that there is no unobserved effect that discontinuously changes at this boundary. When estimating differential impacts across subgroups, this settlement pattern does not pose problems because I am comparing outcomes across subgroups within certified villages.

Below, I use data from survey respondents to investigate two threats to this identifying assumption: selection and sorting.

6.2.1 Potential Threat to Identification: Study Site or Study Activities Selection into Treatment

The first potential threat to identification is if unobserved characteristics of local households drive selection into treatment. Selection into treatment has two levels. First, unobserved characteristics could drive a firm's participation in FSC certification. Second, these characteristics could determine the activities implemented by the firm in order to satisfy FSC requirements.

In either case, observed differences in household outcomes across the treatment boundary would reflect ex ante differences in local household characteristics, not changes caused by the new road connection.

Evaluating voluntary policy effectiveness is typically fraught because, unlike in an experiment, participation in the treatment is not randomly assigned. In this paper, the decision to participate in FSC occurs at a much larger scale, decoupling it from local forest user characteristics. The firm's decision to participate in FSC certification occurs at the forest management unit level. Two arguments make it highly unlikely that firms choose to participate in FSC based on the characteristics of the five villages included in this study. First, the scale of the participation decision and the scale of the study site are vastly different. Firms cannot certify only part of their forest concession. The area of the certified forest management unit is 571,000 hectares and about 5,700 people reside within its boundaries. Loundoungou-Toukoulaka is the last of three contiguous forest management units managed to be certified. The total certified area is over 1 million hectares.

The 190 households surveyed along the Upper Motaba include 547 individuals, about 10% of the total inhabitants of the forest management unit. The firm's decision to certify is not based on the characteristics of these households along a short stretch of river. Firms choose to participate in FSC if it is profit-maximizing to do so and the profitability of FSC certification is primarily a function of timber stock, firm timber harvesting productivity, and demand. Though household characteristics may affect the cost of complying with FSC's rural development mandate, the magnitude of these costs is likely dwarfed by costs from changes in timber production and new revenues from an FSC price premium.

A related but distinct concern is whether an unobserved characteristic unique to the FSC side of the River drove the firm's choice to build a road connection. In this case, estimates of the change from the road connection may in fact reflect ex ante unobservable differences between the two sides of the Motaba River that incited the firm to select a road as their way of fulfilling FSC requirements. Suppose the east side of the Motaba was more export-oriented prior to the road connection. In this scenario, households would have been selling their foodstuffs to river merchants or after traveling to a market town. If this were the case, we would expect to see different rates of skilled work - more farming on the FSC side, for example - something we do not observe.

6.2.2 Potential Threat to Identification: Sorting in Response to Treatment

If households sort in response to treatment, the regression specified above will reflect differences in the treated and control populations instead of changes from treatment. Concerns about sorting in response to treatment can be grouped into three types: households that sort within the study site, households that sort into the study site (immigration), and households that sort out of the study site (emigration). Sorting is likely to be limited because local institutions, e.g. kinship relations, govern property rights and access to dwellings, agricultural fields, firewood, palms, hunting zones and fishing zones. These institutions mediate potential immigration into treated and untreated villages. Below, I use survey responses to look for evidence of each type of sorting using observable characteristics. Table 7 presents results from a t-test comparing immigration status across certified and uncertified households. Positive values indicate a higher frequency among uncertified households.

Kaka and BaAka households may more easily sort within the study area in response to treatment because their kinship relations enable access to different villages. We see evidence of more recent and less recent arrivals in certified villages. Recent arrivals came within the last five years - after the road connection. Arrived last decade includes households that arrived between five and ten years ago. In uncertified villages, we see greater arrival rates for both periods, within five years and between five to ten years. The pattern is consistent before and after the FSC treatment, however there are more recent arrivals.

Immigration into the study area by non-natives is only observed to occur when the non-native is the spouse or dependent of a person with kinship ties to the village. The immigration patterns mimics that of the arrival pattern for natives. More immigrants move to uncertified villages than certified villages, recently and between five and ten years before the survey.

Evaluating emigration out of the study area is difficult because emigrants are not present to answer survey questions. The fraction of households absent is similar across certified and uncertified villages, as reported in Table 15. Another indicator of emigration could be different rates of female-headed households. These households may reflect emigration out of the study area by men seeking wage-earning work opportunities elsewhere. In Table 7 we see a higher preponderance of female-headed households in uncertified villages. I include a dummy for female-headed households will be included in all regressions.

7 Results

The new road connection changes relative prices, increasing the price of goods demanded by logging towns. This provokes changes in consumption, production, and wealth for households in newly connected villages.

7.1 Consumption

The road connects excess demand for meat and starch from logging towns to remote villages with excess agriculture and few imported goods. In Table 21, I evaluate how protein and starch consumption changes with the road connection.

7.1.1 Protein Consumption

The relative price of wild protein, either meat or fish, increases in certified villages due to the new road connecting urban consumers to villages. Some households are skilled fishers, others hunters. Households that are net sellers in either product will see an income increase while net buyers will see their budget constraint shrink. Column one of Table 21 shows changes in the likelihood of reporting fish consumption from certification for fisher and non-fisher households. Fisher households are identified as having fish hooks. For certified, non-fisher households, consumption decreases by a large magnitude, 24 percentage points, a 50% decrease. For these households, the increased price of fish has essentially eliminated fish consumption. Another way to interpret this change is that non-fisher, certified households go from eating fish about every other day to every four days. Fisher households do not decrease their likelihood of consuming fish the previous day.

Like fish, the price of bushmeat increases with the road connection. Meat consumption during the dry season is low due to seasonality in the availability of game and additional hunting restrictions. The unconditional likelihood a household reports eating meat the previous day is 19%. Unlike in the case of fish, certification brings two additional changes to the likelihood of accessing bushmeat: additional hunting technology restrictions and increased access to fauna. How bushmeat yield changes with certification will depend on the household's hunting technology and access to hunting technology also changes with certification. Gun hunters are expected to enjoy increased yields from improved access to fauna whereas snare hunters are expected to experience decreased yields from a forced shift from nylon and wire snares to less effective raffia snares. Since hunting technology changes with treatment, I evaluate the average change in meat consumption. Column two of Table 21 estimates that the average certified household reduces the likelihood of meat consumption by ten percentage points, about a 50% decrease.

Finally, we can look at how consumption of any animal protein changes with certification. Since we expect the price of animal protein to increase, we expect consumption to fall. Column three of Table 21 estimates the change in animal protein consumption from certification. I find that certified households are 20 percentage points less likely to report consuming any animal protein the previous day, a decrease of about one third. Put another way, certified households go from eating animal protein two out of three days to eating it less than every other day. Also of note, independent of certification, female-headed households have trouble procuring meat, likely because hunting is now exclusively done by men.

7.1.2 Starch Consumption

Starch is the main calorie source for all households during the dry season and farmed starch is more calorie dense than foraged starch. The unconditional likelihood that the average household consumes farmed starch the previous day is high, about 84%. Certification brings a new road, which increases the price of farmed starch. Indigenous households, net buyers of farmed starch, reduce their consumption in response to the higher price. Table 21 reports regression results for three types of starch consumption. The outcome variable for column one is a dummy variable equal to one if the household reported consuming any farmed starch the previous day. Farmed starch includes any kind of manioc, plantains, or sweet potatoes. Column two is a dummy variable equal to one if the household reported eating starch foraged from the forest, which includes *ekoulé*, a tuber, and *méla*, a root, both of which are found in the forest. Finally, column three is a dummy variable equal to one if the household reported eating any kind of starch, farmed or foraged.

Certified, indigenous households are 12% less likely to report consuming farmed starch the previous day as compared to uncertified indigenous households. Another way to interpret the coefficient estimate is to convert it to the number of days per week without farmed starch. A 14% reduction in the likelihood of eating farmed starch is equivalent to about an additional day per week without farmed starch. Farmed starch offers more calories per ounce and is more reliably available than foraged starch. Certified Farmer households increase their likelihood of consuming farmed starch by about the same magnitude, 12 percentage points.

To cope, indigenous households turn to the forest for foraged starch. Column two of Table 21 shows that certified BaAka households are 14 percentage points more likely to report eating foraged starch than uncertified indigenous households. The magnitude of this change is massive; the unconditional average for foraged starch is a frequency of 7%, making this a 200% increase in the likelihood of eating foraged starch. The magnitude of the increase is almost identical in size to the reduction in farmed starch consumption for certified, indigenous households. In response to higher prices for farmed starch, certified indigenous households appear to fall back on the forest as a safety net for starch consumption.

Farmer households report no change in consumption of foraged starch. Comparing the coefficient for recent immigrants across foraged and farmed starch, we see that immigrants are less likely to report eating foraged starch as compared to farmed. This makes sense since foraged starch requires local knowledge, which immigrants lack.

Column six reports any starch consumption, farmed or foraged. I find no net change in any starch consumption from certification. This masks BaAka households' substitution to foraged starch, which is inferior in terms of calories and may be more labor intensive, due to a higher search cost during the dry season.

7.2 Production

The road connection and increased demand for farmed starch provokes households to shift production along their production possibilities frontier in the short run. A household's increase in agricultural investment will depend on its comparative advantage. We expect Farmer households to increase production and of exported cultivars. For foraging households, we expect investments that reflect their production possibilities frontier, which reflects their need to spend time outside of the village and away from fields.

Table 22 shows how agricultural investment outcomes change across certified and uncertified households, for farmer and forager households. The first three columns include only the 87 farmer households as the regression population. The last two columns include all 190 households and an interaction term between treatment and household type.[2] All regressions include the same set of covariates, including whether the household head is female, a recent arrival to the town, older, or ever educated. Below, I characterize farmers' and foragers' change in agricultural investment.

7.2.1 Agricultural Investment by Farmer Households

The first three regressions are restricted to the 87 non-indigenous, Farmer households. I investigate three agricultural investment outcomes: the number of cultivars currently under cultivation, the number of fields a Farmer household cultivates, and the number of fallow fields a Farmer household claims.

Our prediction is that Farmer households will invest more heavily in the production of exported foodstuffs in response to the new road connection. Increased production can occur through intensification of production, extensification of production, or both. If Farmers intensify, they apply inputs, additional labor, or plant improved seeds on existing fields. If Farmers extensify, they plant additional fields.

One way to intensify production is to concentrate planting in the cultivars demanded for export. Column one reports the number of cultivars planted, and we see that certified Farmer

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[2] 189 households because one BaAka household is missing education information. Will check codebook for whether reported education there.

households plant 1.6 fewer cultivars when compared to uncertified Farmer households. The average Farmer household plants 5.9 cultivars, so certified Farmers plant about one quarter fewer cultivars, which is consistent with intensification of production toward foodstuffs that travel well and are in high demand by logging towns.

Column two of Table 22 indicates that Farmers respond to the new road by extensifying production and increasing the number of fields under cultivation by one almost one field. Farmer households in certified villages report an additional 0.87 fields, on average, when compared to uncertified villages. The average number of fields under cultivation, for Farmer households, is 2.3 fields, making this an increase about a third in the number of fields per household.

In the short run, Farmers may extensify production by either clearing a new field or replanting a fallow field after a shorter fallow period. Column three reports the number of fallow fields per Farmer household to see if Farmers extensify by shortening their fallow rotation. We see that the certified Farmer households have, on average, 1.7 fewer fallows than uncertified households. The average household has 3.5 fallows, which, when taken with the average number of active fields, 2.3, this corresponds roughly to a pattern of two years on, and four years off. One way to interpret the change from certification is that the fallow period has been reduced by about half, from four years to two. This suggests that, on the plus side, households are not increasing local deforestation. However, on the negative side, shorter fallows threaten long-term soil productivity.

Farmers' extensification of agricultural production requires additional labor. Additional labor could come from the Farmer's own stock of household labor or could be supplied via trade with Indigenous households. The source of the additional labor supplied depends on Farmers' shadow value of time. If labor is supplied by Indigenous workers, those workers should receive a higher wage and benefit from the road connection. Given the fall in farmed starch consumption by Indigenous households, it appears that Farmers use their own labor to increase agricultural production.

7.2.2 Agricultural Investment by Forager Households

Forager households have less physical and human farming capital but they too can shift production in response to the road connection. Regressions four and five of Table 22 investigate chicken husbandry and manioc processing for all households. Both outcome variables are dummy variables equal to one if the household raised any chickens or processed any manioc within the last year. Chickens are mobile and can be brought to forest camps if needed, making them a strategic investment for Forager households. Manioc processing is familiar to BaAka households, but typically was done for a Bantu household in exchange for other goods. Certification brings a shift where BaAka process manioc either to consume or to trade.

We are interested in how Forager households change their agricultural investment, so the coefficient on Certified Village is the main estimate of interest. We see a large, positive increase in the likelihood of chicken husbandry or manioc processing. For chicken husbandry, the likelihood a BaAka household raises chickens increases by 45 percentage points. On average, 50% of BaAka households raise chickens, making this nearly a doubling in the likelihood of chicken husbandry. A look at the interaction term shows that though Farmers increase their chicken husbandry, the change is smaller, about 14 percentage points.

This pattern is repeated for processing manioc into fufu, a powder that people sell by the scoop. The likelihood a Forager household processes manioc for themselves increases by 29 percentage points, a 150% increase. Farmer households also increase the likelihood of fufu production, but the change is smaller: 13 percentage points.

7.3 Housing Investments

The new price ratio makes households with a comparative advantage in exported goods wealthier. This is most pronounced for Farmer households, who now have more leisure, more money to spend on other goods, and can take advantage of lower prices for imported goods. One of the imported goods with a lower price is sawnwood; the certified company has a policy for distributing sawnwood that fails export quality standards. Thus, we might expect Farmer households to invest their new revenues and leisure time in improving their dwelling, improving the quality of their walls from mud to wood.[3]

The first regression in Table 23 investigates how wall type differs across certified and uncertified households for Farmer households only.[4] We see that Farmer households in Certified Villages are 34 percentage points less likely to have mud walls than those in uncertified villages. Since the average likelihood of mud walls is .81, this is a decrease of about 41%.

Forager households dwellings are different. Forager dwellings are more often constructed with walls made of leaves or palm fronds, a less durable material but one that also requires less investment. Mud walls suggest a more permanent village presence. In column two, we see that Forager households are 25 percentage points less likely to have mud walls in Certified Villages. Given the average incidence of mud walls is about 35%, this is a 72% decrease. This may reflect either lost leisure time, increased time spent in the forest, or both for Forager households in Certified Villages.

8 Conclusion

This paper investigated how forest dependent households' consumption, production, and wealth outcomes changes as a result of implementation activities satisfying Forest Stewardship Council's forest management standard. I compare outcomes for 190 household living on either side of the boundary of the Motaba River in the Republic of Congo, the border of a certified and an uncertified forest management unit. I use primary data I collected for this purpose.

A theoretical model describes how the road changes villages from autarky to trade with a broader network. We expect net buyers of exported goods will reduce their consumption and net sellers will enjoy greater wealth. We also expect all households to shift production toward exported goods in the short run, conditional on their production technology.

Exported goods include wild protein and farmed agricultural goods. Empirically, I find that certified households consume protein less frequently, decreasing consumption by about a third. In response to higher prices, indigenous households shift starch consumption to sources

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[3] Households also improve the quality of their roof, from palm panels to metal. Metal sheets are cheaper to import with the road. Metal roofs are only observed in certified villages.

[4] Wall type was assessed during the initial census. Seven households did not have an entry for the initial census and thus lack wall type data.

foraged from the forest. These sources are inferior in calories and more labor intensive due to their relative scarcity during the dry season.

Certified farmer households intensify production by reducing the number of cultivars, focusing on agricultural goods demanded for export. They extensify production by increasing the number of fields they cultivate by about one field. Instead of opening a new field, Farmer households appear to reduce the length of their fallow period. Indigenous households also increase production of exported goods, given their production technology constraints. Certified indigenous households are more likely to raise chickens and process manioc.

Farmer households enjoy greater wealth from selling their agricultural goods. They also enjoy cheaper prices for materials to improve their dwelling, such as concrete, wood, and tin roofing. We see more non-mud homes among certified Farmer households, consistent with their investment in improvements in their accommodations.

We learn from this work that implementation activities for sustainable forestry can have unintended impacts on forest dependent households. Firms choose implementation activities that are low cost and easy to monitor. They may choose activities that benefit village elites. This paper reveals tradeoffs in voluntary environmental standards like FSC forest management certification as a governance tool to address sustainable development.

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Table 14: Documenting Village Visitation

village	FSC	Latitude	Longitude	Num HH	Survey Start	Survey End
Anikou	1	2.51938	17.28497	9	76	79
Bangui Motaba	1	2.50582	17.31132	79	5	36
Beye	1	2.52981	17.27217	6	58	63
Bodzuanda	0	2.44231	17.44804	20	64	69
Likombo	0	2.47728	17.37473	32	45	57
Moulapa	1	2.52244	17.28228	6	70	79
Pape	1	2.56042	17.21312	9	1	3
Seke	1	2.53211	17.26872	13	59	63
Zingo	0	2.46708	17.38973	23	38	44

Table 15: Participant Counts

	Uncertified	Certified	Total
Terminated Survey	0	31	31
Refusal	4	5	9
Absent	22	29	51
Started Survey	6	1	7
Finished Survey	76	114	190
Total	108	180	288

Table 16: Characterizing Comparative Advantage

	Uncertified No.	Certified No.	Total No.
Starch Strategy			
Forager	34	69	103
Farmer	35	52	87
Total	69	121	190
Protein Strategy			
Not Fisher	10	23	33
Fisher	59	97	156
Total	69	120	189

Table 17: Comparing Persistent Observable Characteristics, FSC & non-FSC

	Mean (not FSC) - Mean (FSC)	SE	Mean (not FSC)
Residents in Household	0.114	0.291	4.130
Planted field	-0.0272	0.0541	0.841
Age in years	-0.476	2.504	43.23
Old Head of Household	-0.0656	0.0660	0.232
Educated	-0.0275	0.0659	0.739
Observations	190		

Table 18: Outcome Variables

Table 1: Summary statistics

Variable	**Mean**	**(Std. Dev.)**	**Min.**	**Max.**	**N**
Fish	0.479	(0.501)	0	1	190
Meat	0.189	(0.393)	0	1	190
Any Animal Protein	0.663	(0.474)	0	1	190
Farmed Starch	0.837	(0.37)	0	1	190
Foraged Starch	0.068	(0.253)	0	1	190
Any Starch	0.916	(0.278)	0	1	190
\ # Cultivars	5.908	(3.378)	0	12	87
\ # Fields	2.333	(2.631)	0	22	87
\ # Fallows	3.517	(3.365)	0	10	87
Any Chickens	0.626	(0.485)	0	1	190
Ever Fufu	0.426	(0.496)	0	1	190
Mud Walls, Farmer	0.813	(0.393)	0	1	80
Mud Walls, Forager	0.347	(0.478)	0	1	101

Table 19: Changes in Hunting Activity

	Mean (not FSC) - Mean (FSC)	SE	Mean (not FSC)
Any Rifle	0.0837	0.0651	0.275
Any Shotgun Shell	0.140	0.0640	0.290
Many Shotgun Shells	0.134	0.0466	0.159
Hunt at Night	0.227	0.107	0.677
No. of Snares	-0.150	0.494	2.362
No. of Wire Snares	1.262	0.783	2.203
No. of Nylon Snares	-0.0254	0.406	1.058
No. of Raffia Snares	-0.951	0.585	0.735
Observations	190		

Table 20: Identification Threat: Sorting

	Mean (not FSC) - Mean (FSC)	SE	Mean (not FSC)
Recent Arrival	0.108	0.0594	0.232
Arrived last decade	0.0458	0.0507	0.145
Recent Immigrant	0.0892	0.0547	0.188
Immigrated last decade	0.0519	0.0416	0.101
Female	0.141	0.0575	0.232
Observations	190		

Table 21: Changes in Food Consumption

	(1) Fish	(2) Meat	(3) Any Protein	(4) Farm Starch	(5) Forest Starch	(6) Any Starch
Certified Village	-0.243*	-0.0970*	-0.204**	-0.123	0.138*	0.00196
	(0.0942)	(0.0368)	(0.0467)	(0.0750)	(0.0559)	(0.0712)
Fisher & Certified	0.170*					
	(0.0597)					
Fisher	0.119**					
	(0.0209)					
Farmer & Certified				0.119^{+}	-0.149*	-0.00856
				(0.0524)	(0.0573)	(0.0605)
Farmer			0.202	0.117*	-0.0162	0.133**
			(0.111)	(0.0469)	(0.0176)	(0.0349)
Female	-0.000317	-0.163*	-0.216*	-0.0916	-0.0339	-0.106
	(0.0511)	(0.0495)	(0.0683)	(0.106)	(0.0185)	(0.0783)
1(Kaka ethnicity)	-0.175*	0.283**	-0.0431			
	(0.0560)	(0.0814)	(0.138)			
Recent Arrival	0.0806	-0.0225	0.00903	0.0554	-0.0422*	-0.0132
	(0.0882)	(0.0677)	(0.0880)	(0.0480)	(0.0175)	(0.0441)
Constant	0.507**	0.167**	0.747**	0.833**	0.0403^{+}	0.873**
	(0.0394)	(0.0290)	(0.0338)	(0.0625)	(0.0216)	(0.0427)
Observations	189	190	190	190	190	190
R^2	0.077	0.133	0.084	0.091	0.107	0.058

Standard errors in parentheses. SE clustered at village level. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 22: Changes in Agricultural Production

	(1) # cultivars	(2) # Fields	(3) # Fallows	(4) Any Chickens	(5) Ever Fufu
Certified Village	-1.598*	0.873*	-1.670*	0.457**	0.290***
	(0.618)	(0.317)	(0.651)	(0.110)	(0.0556)
Farmer & Certified				-0.395*	-0.162*
				(0.145)	(0.0681)
Farmer				0.601**	0.641***
				(0.129)	(0.0442)
Female	0.223	0.512*	0.155	0.108	0.0837
	(1.100)	(0.174)	(0.902)	(0.0738)	(0.142)
Recent Arrival	0.615	-0.543^{+}	-1.259*	-0.0919	-0.0351
	(0.629)	(0.259)	(0.477)	(0.0786)	(0.0766)
Residents in Household	0.621***	0.234***	0.549**	0.0565**	0.0482**
	(0.121)	(0.0450)	(0.152)	(0.0121)	(0.0131)
Old Head of Household	0.545	0.373	2.899*	0.0334	0.135^{+}
	(0.697)	(0.404)	(0.997)	(0.0535)	(0.0650)
Educated	0.727	0.513	1.421^{+}	-0.0514	0.184**
	(1.003)	(0.361)	(0.719)	(0.102)	(0.0429)
Constant	3.599*	0.443	0.709	-0.0336	-0.384**
	(1.123)	(0.408)	(0.669)	(0.152)	(0.0796)
Observations	87	87	87	189	189
R^2	0.177	0.084	0.320	0.249	0.396

Standard errors in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 23: Changes in Housing Investment

	(1) Mud Walls	(2) Mud Walls
Certified Village	-0.337**	-0.253**
	(0.0391)	(0.0541)
Female	0.0763	-0.165
	(0.0913)	(0.174)
Recent Arrival	-0.247	0.0417
	(0.136)	(0.165)
Residents in Household	-0.0321*	-0.00756
	(0.0131)	(0.0151)
Old Head of Household	-0.193^{+}	-0.0431
	(0.0837)	(0.0750)
Educated	-0.0126	0.150
	(0.0855)	(0.0854)
Constant	1.243**	0.466**
	(0.106)	(0.111)
Observations	80	100
R^2	0.254	0.092

Standard errors in parentheses

SE clustered at village level.

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 24: Food Consumption, Unclustered Standard Errors

	(1) Fish	(2) Meat	(3) Any Protein	(4) Farm Starch	(5) Forest Starch	(6) Any Starch
Certified Village	-0.243	-0.0970	-0.204**	-0.123	0.138*	0.00196
	(0.186)	(0.0610)	(0.0679)	(0.0833)	(0.0544)	(0.0696)
Fisher & Certified	0.170					
	(0.203)					
Fisher	0.119					
	(0.180)					
Farmer & Certified				0.119	-0.149**	-0.00856
				(0.0977)	(0.0554)	(0.0780)
Farmer			0.202^{+}	0.117	-0.0162	0.133*
			(0.120)	(0.0729)	(0.0278)	(0.0642)
Female	-0.000317	-0.163*	-0.216*	-0.0916	-0.0339*	-0.106
	(0.111)	(0.0792)	(0.108)	(0.0787)	(0.0163)	(0.0677)
1(Kaka ethnicity)	-0.175*	0.283**	-0.0431			
	(0.0771)	(0.0640)	(0.120)			
Recent Arrival	0.0806	-0.0225	0.00903	0.0554	-0.0422*	-0.0132
	(0.0934)	(0.0780)	(0.0886)	(0.0511)	(0.0170)	(0.0479)
Constant	0.507**	0.167**	0.747**	0.833**	0.0403	0.873**
	(0.177)	(0.0565)	(0.0639)	(0.0629)	(0.0315)	(0.0563)
Observations	189	190	190	190	190	190
R^2	0.077	0.133	0.084	0.091	0.107	0.058

Standard errors in parentheses. Robust Standard Errors. $^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 25: Agricultural Production, Unclustered Standard Errors

	(1) # Cultivars	(2) # Fields	(3) # Fallows	(4) Any Chickens	(5) Ever Fufu
Certified Village	-1.598*	0.873^{+}	-1.670*	0.457***	0.290***
	(0.764)	(0.445)	(0.733)	(0.0960)	(0.0553)
Farmer & Certified				-0.395**	-0.162
				(0.126)	(0.117)
Farmer				0.601***	0.641***
				(0.0993)	(0.0921)
Female	0.223	0.512	0.155	0.108	0.0837
	(1.015)	(0.321)	(0.906)	(0.0802)	(0.0801)
Recent Arrival	0.615	-0.543	-1.259^{+}	-0.0919	-0.0351
	(0.881)	(0.573)	(0.756)	(0.0980)	(0.0847)
Residents in Household	0.621**	0.234*	0.549**	0.0565**	0.0482**
	(0.196)	(0.0938)	(0.204)	(0.0171)	(0.0165)
Old Head of Household	0.545	0.373	2.899***	0.0334	0.135^{+}
	(0.815)	(0.547)	(0.822)	(0.0742)	(0.0749)
Educated	0.727	0.513	1.421	-0.0514	0.184**
	(0.995)	(0.493)	(0.903)	(0.0704)	(0.0665)
Constant	3.599**	0.443	0.709	-0.0336	-0.384***
	(1.284)	(0.536)	(1.143)	(0.120)	(0.0911)
Observations	87	87	87	189	189
R^2	0.177	0.084	0.320	0.249	0.396

Standard errors in parentheses

Robust SE.

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 26: Housing Investment, Unclustered Standard Errors

	(1) Mud Walls	(2) Mud Walls
Certified Village	-0.337**	-0.287**
	(0.0751)	(0.106)
Female	0.0763	-0.206
	(0.106)	(0.161)
Recent Arrival	-0.247*	0.0248
	(0.108)	(0.170)
Residents in Household	-0.0321^{+}	-0.0101
	(0.0180)	(0.0263)
Old Head of Household	-0.193^{+}	-0.0538
	(0.100)	(0.116)
Educated	-0.0126	0.113
	(0.0945)	(0.103)
Constant	1.243**	0.544**
	(0.127)	(0.182)
Observations	80	100
R^2	0.254	0.100

Standard errors in parentheses

Robust Standard Errors.

$^{+}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

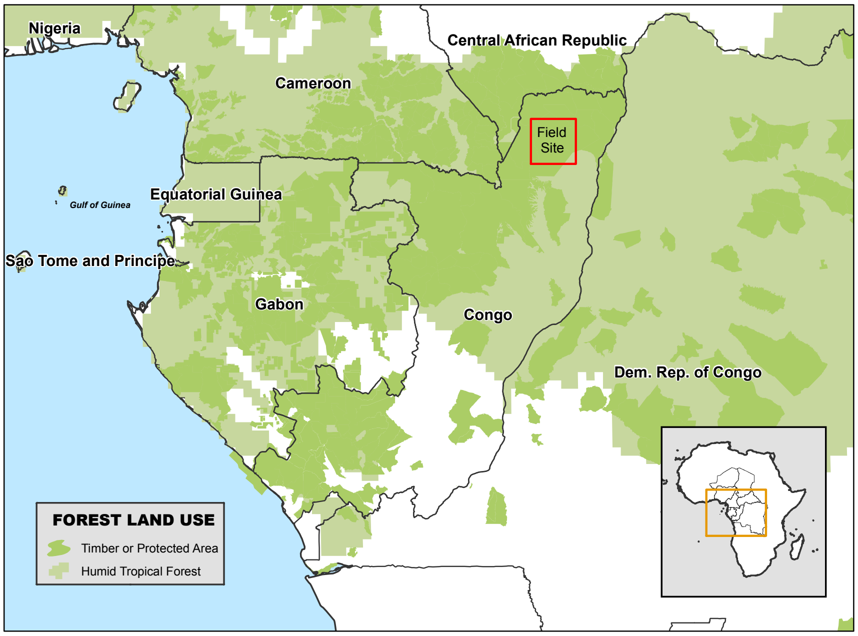

Figure 11: Site within Congo Basin

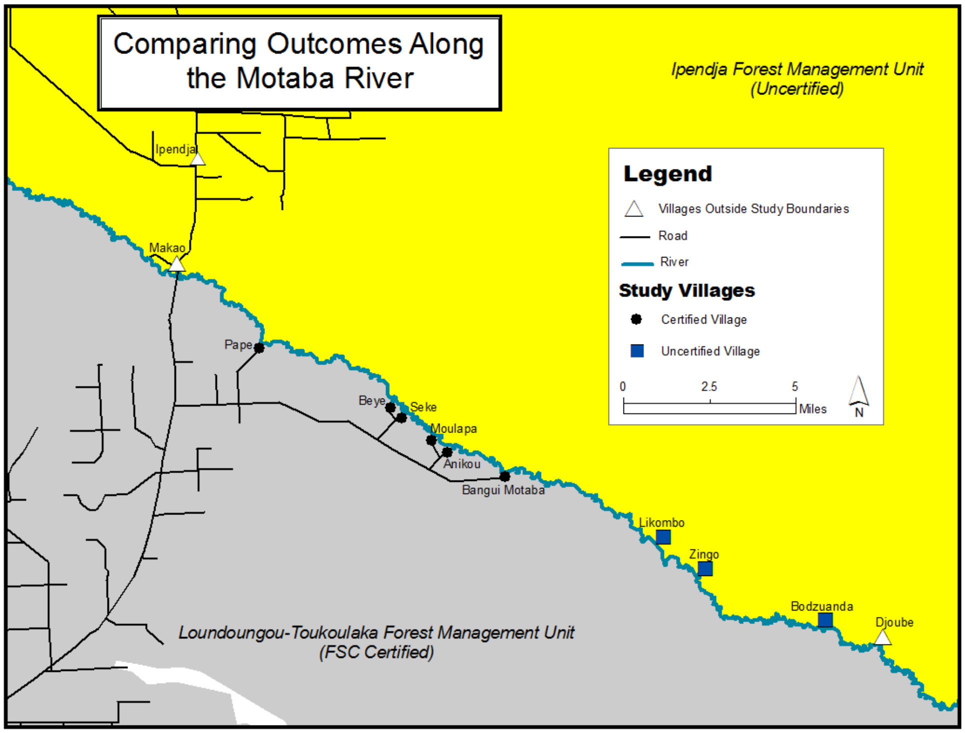

Figure 12: Treatment Boundary

CHAPTER 3

Drivers of Participation in Voluntary Forest Regulation and their Implications for Conservation

1 Abstract

Timber firms participate in legality or forest management certification if doing so increases their profits. Participation in voluntary forest regulation begets new costs, such as compliance costs from greater forest management effort or opportunity costs from enforcement of the legal harvesting maximum. A theoretical model predicts that forests with lower compliance or opportunity costs from participation are more likely to certify. For legality certification, I find that firms with higher ex ante production costs, which imply lower compliance and opportunity costs, are more likely to participate. For Forest Stewardship Council (FSC) forest management certification, compliance costs depend on forest characteristics. FSC compliance costs are higher for forests with high amenity value, such as suitable gorilla habitat, or sensitive areas that require additional management effort. Though these forest types are more likely to participate in legality certification, they do not predict participation in FSC forest management certification, suggesting that the highest ex ante production cost forests and highest amenity value forests opt not to continue beyond legality to FSC certification.

2 Introduction

Timber firms earn profits by extracting timber to sell to global consumers in the export market. Some consumers are concerned about the origin of the timber they purchase and whether or not the timber was harvested legally. Other consumers are concerned with the manner in which the timber was harvested and impacts on biodiversity and future timber stock. Both types of consumers cannot monitor the source or production process of timber directly and instead rely on third-party auditors. Timber firms may choose, voluntarily, to have timber origin or their production process monitored by these auditors. If they do so, they incur additional costs when compared to unmonitored timber production.

Firms that choose to participate in legality and forest management certification incur opportunity and compliance costs. Are firms that have lower compliance or opportunity costs more likely to participate in legality and FSC forest management certification? If so, how does this selection into legality and FSC forest management certification limit each policy's effectiveness at addressing overexploitation and biodiversity? Using data on biophysical forest characteristics from 194 forest management units in Cameroon, Congo, and Gabon, I estimate the determinants of participation in legality and FSC forest management certification.

I model how participation in legality and FSC forest management certification changes a firm's costs and revenues. Both standards bring fixed costs from audit visits. Both standards enforce the legal harvest maximum for timber. Firms that harvest more than this maximum when uncertified will incur an opportunity cost from participating. FSC forest management certification brings additional management requirements that reflect biophysical characteristics of the forest and the forest's amenity value. For example, forests with higher biodiversity will need to implement additional conservation activities and forests with more challenging forest terrain will need to implement additional management effort to protect sensitive areas.

I test these predictions using proxies for a forest's ex ante production costs and amenity value. I geoprocess publicly available, time-invariant biophysical forest characteristics for 194 forest management units in Gabon, Cameroon, and the Republic of Congo in order to proxy for production costs and amenity value. Proxies include include the slope of forest terrain, annual precipitation, distance to the seaport, forest size, and habitat suitability for gorillas.

For legality certification, we expect forests with lower ex ante quantity and higher ex ante management effort to be more likely to participate. In both cases, these forests will have higher ex ante production costs, resulting in lower opportunity costs and compliance costs, respectively. I test whether cost proxies for unobserved production costs predict participation in legality certification. I find that forests with higher annual precipitation or greater average slope are more likely to participate. Increasing either characteristic by one standard deviation increases the likelihood of participation in legality certification by 5-9%. The forest's distance to seaport, a proxy for transportation costs, also predicts participation in legality certification though the magnitude is much smaller, 1.5 %. Though legality certification does not confer biodiversity protection, I find that gorilla habitat suitability strongly predicts participation in legality certification. I suggest that this relationship may be due to correlation between gorillas and low human population density, which increases production costs, or from firms responding to pressure from conservation non-governmental organizations.

FSC forest management certification requirements are tailored to forest characteristics. In return, firms earn a higher price premium. Management reflects forest characteristics and effort may exceed the legal requirement. Firms must also address forest amenity value. Forests with higher amenity value, such as those suitable for gorillas, will have higher compliance costs. The higher price premium reduces opportunity costs for forests with lower production costs. Thus we expect reduced participation by forests with the highest production costs and forests with high amenity value. I find that two of the three proxies for high production costs fail to strongly predict participation in FSC forest management certification. Unlike in the legality case, sloped terrain does not predict participation in FSC certification. The effect of being far from the seaport is one quarter that of legality certification. Gorilla habitat suitability fails to predict participation as well. Taken together, these patterns suggest that high production cost and high amenity value forests choose not to pursue FSC certification. FSC fails to target high conservation value forests and forests needing additional management, but I do not find evidence of adverse selection.

This paper contributes to the literature on drivers of participation in voluntary environmental policies. Like Morgenstern and Pizer (2007) and Vidovic and Khanna (2007), I find that firms with low compliance costs are more likely to participate, making the overall change from the policies small. This paper joins the few studies that look at voluntayr regulation participation in developing country contexts (Blackman et al., 2010). Legality certification has not yet been studied and voluntary regulation's effectiveness in the context of renewable resources in general and forestry in particular is poorly understood (Blackman and Rivera, 2011). This paper's empirical analysis addresses several of these gaps. The theoretical model highlights a participation driver unique to producers of renewable resources: in addition to compliance costs, firms consider opportunity costs when choosing to participate in voluntary environmental regulation.

I begin by characterizing timber production and amenity value in the Congo Basin, legality and FSC forest management in Section Two. In Section ThreeI use a simple model to give intuition as to how eco-label standards may change firm costs follows. I describe the geographic and administrative data I use in Section Four as well as in a Data Appendix. I introduce my preferred regression specification in Section Five. Finally, I present my results and robustness checks in Section Six. Section Seven concludes.

3 Institutional Context

Spanning over 180 million hectares, the Congo Basin is the second largest tropical rainforest in the world, after the Amazon. In addition to tropical hardwood logs and sawnwood, the Congo Basin provides globally important environmental services. In this section, I describe uncertified timber production, the additional requirements necessary for legality and FSC forest management certification, and Congo Basin forests' amenity value .

3.1 Forest Governance in the Congo Basin

In my analysis, I focus on three countries in the Congo Basin[1] Cameroon, Gabon, and the Republic of Congo. These three countries are the most important for timber production and as of 2009 they were the only countries in the Congo Basin with FSC certified forest management units. Together, these three countries have 68 million hectares of forest. In 2008, they produced 9.8 million cubic meters of timber representing almost two-thirds of the volume produced in the Basin and valued at approximately $1.7 billion in 2008 dollars (FAO, 2011).

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[1] Characterizations of the Congo Basin include Central African Republic, the Democratic Republic of the Congo, Equatorial Guinea, the island nation of Sao Tomé and Principe, Rwanda and Burundi in addition to Cameroon, Republic of Congo, and Gabon.

Across Central Africa, governments claim rights to all forested areas. The vast majority of tropical forests exhibit similar ownership structures and 86% of global forests are publicly owned (Agrawal et al., 2008). Governments delimit protected areas, which prohibit extractive activities, to keep intact some zones representative of key ecosystems and as well as to act as source forests for foraging and migrating fauna. Governments also auction rights to extract tropical timber from forest management units to private, profit-maximizing firms via a "concession" system, which grants a 15 to 30 year lease to timber rights. Figure 13 depicts the forest estate of the three-country region of the Congo Basin and its management structure. Protected areas have hatch marks and and forest management units are color-coded by participation status.

Within the context of important ecosystem services and weak forest governance,[2] private, profit-maximizing firms manage over 32.2 million hectares of forest across the three countries. This is almost half of the total forest estate. Concern over irregularities in tropical timber production and increased recognition of the importance of environmental services provided by tropical forests, such as carbon sequestration, has led to a spate of legislation in the United States and Europe. In 2008 the United States amended the Lacey Act, a piece of legislation from the turn of the century intended to prohibit the trade in endangered birds and other animals, to include timber. The European Union's Forest Law Enforcement and Governance and Trade (FLEGT) Act of 2003 prohibits illegally harvested timber's access to European markets. Beyond trade restrictions for illegal timber, consumers and government procurement programs are also sensitive to negative externalities associated with tropical timber production, such as the opening of roads and destruction of forest canopy.

3.2 Uncertified Timber Production in the Congo Basin

Timber firms select trees to harvest and deploy management effort to protect residual trees and soil or to improve harvesting efficiency. Congo Basin forests are highly diverse; a forest may include over 400 unique tree species. The bulk of timber harvesting focuses on about

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[2] According to Transparency International's Corruption Perceptions Index in 2006, and Gabon, Cameroon and the Republic of Congo ranked 90, 138, and 142 respectively among 163 countries (TI, 2006).

twenty tree species. Because the proportion of commercial trees is small relative to the forest, firms deploy a system of identifying trees for harvest and build an extensive road network to access these trees.

Weather, topography, and a forest's distance to the seaport affect production costs. Heavy rainfall reduces the harvest period. Frequent rainfall during the harvest period slows down production, increases equipment maintenance costs, and increases secondary road maintenance and improvement costs. Forests with varying topography, such as steep slopes, make maneuvering tractors and logging trucks more dangerous and time-consuming. Firms must make skid trails longer and felling trees on very steep slopes risks soil erosion. In contrast, flat areas facilitate road building and maintenance. Typically, forest management units feature low population densities with few large agglomerations of settlements. Most industrial timber is exported, so logs and sawnwood must travel from the forest management unit to a seaport for export. Timber is heavy and bulky and roads in the Congo Basin are in notoriously poor shape, making transport costs a non-trivial component of a firm's marginal cost. Seaports are often the closest city to the forest management unit

Firms may spend resources on forest management when uncertified. Basic forest management involves creating an inventory of trees in the forest and planning roads in order to access commercial trees, improving timber harvesting efficiency. In uncertified timber production, high management effort could include a census of the cutting area before harvesting during which the firm notes the location, species, size, and quality of commercial trees and geo-references their position within the forest management unit. The firm would then use this census to plan roads to access commercial trees at lowest cost. In contrast, uncertified timber production with little management effort would plan roads without knowing tree distribution across space and harvest trees opportunistically. Investments in management effort can improve harvesting efficiency in forests where harvesting is more complex. For example, a forest with a shorter dry season can use the wet season, when harvesting is impossible, to create a precise census and then use this census to more nimbly access trees during the dry season.

3.3 Certified Legal Timber Production

Legality certification verifies timber origin, timber quantity, and minimum management effort. As of 2009, forests in Gabon, Cameroon, and Congo were legality certified by one of four different standards: Société Générale de Surveillance (SGS), Bureau Véritas, Forest Stewardship Council (FSC), and Rainforest Alliance. Legality standard rigor varies across these four labels. I focus on legal compliance with the original timber harvest contract.

An independent auditor verifies timber origin by inspecting documentation such as the harvesting contract and receipts for taxes paid. Timber origin must be documented from stump to port. For example, criteria 6.4 of SGS's Timber Legality, Traceability, and Verification (TLTV) standard for Gabon requires that firms mark and register stumps, logs, and trees and then implement a system of tree identification when prospecting, extracting and transporting timber (SGS, 2008). This system must include a geo-referenced inventory prior to exploitation and a harvest map. Implementing this system requires management effort; firms purchase geospatial and timber tracking software, such as Helveta Ltd's CI World ™, and train or hire personnel to manage the timber tracking process. After verifying timber origin, auditors verify that firms do not exceed the legal harvesting maximum. Continuing with the example of SGS in Gabon, to satisfy criteria 6.5 firms must prove they have not harvested more timber than authorized (SGS, 2008).

Firms must satisfy the minimum management effort required by law. Management effort includes inventories and harvest maps, as described above, as well as legal protections for forest amenity value. Biodiversity protection from legality certification is limited to the existence of an approved forest management plan that respects the Convention on International Trade in Endangered Species (CITES). SGS, Rainforest Alliance recognize that these requirements are insufficient to protect forest amenity value and instead frame legality certification as a step within a broader process that ends with forest management certification.[3]

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[3] For example, Rainforest Alliance's Smartwood certification is part of SmartStep, "a phased approach to FSC Certification," and "require[s] that verified organizations undertake activities to attain full certification" (Alliance, 2011). SGS cite three categories of timber certification: "legal," "legal progressing to sustainable," and "sustainable."

3.4 FSC Certified Managed Timber Production

Forest Management certification embeds the requirements of a legality standard within a broader sustainable forest management standard. As of 2009, the only accepted forest management standard in use in the Congo Basin is that of the Forest Stewardship Council (FSC). FSC's mission, stated on their website, is that "The Forest Stewardship Council A.C. (FSC) shall promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests," where environmentally appropriate forest management is further defined as "the harvest of timber and non-timber products [that] maintains the forest's biodiversity, productivity, and ecological processes" (FSC, 1996). Through a consultative process involving governments, industry, academia, non-governmental organizations, and the public, FSC develops and revises global, national and regional forest management standards. Before 2009, FSC forest management standards were unique to each of the three countries. Since then, FSC has initiated a consultative process to define sub-regional standards for the Congo Basin.

Forest management standards are forest-specific. Management effort reflects forest characteristics, not the legal minimum. For example, Indicator 5.3.7 of the Congo Basin Sub-Regional FSC standard requires that "Large scale maps shall be developed for all compartments prior to harvesting, identifying compartment boundaries, protected areas, extraction routes and depots within the compartment, and storage sites for consumer and production wastes" (FSC, 2009). Areas important to the protection of threatened or endangered species are set-aside and logging is "forbidden" (Indicator 6.2.3). Indicator 6.2.4 requires the firm to control hunting and trade in illegal bushmeat, typically achieved through a system of armed sentries, checkpoints, and barriers. Indicator 6.5.1 has implications for road-building: "forest management and its infrastructure shall avoid sensitive areas (valleys, river banks, steep slopes)" and "the setting up of infrastructure needed for forest management shall be planned in relation to site topography and resources location." Similarly, Indicator 6.5.9 affects road-building, specifying that "the transport network within the FMU shall be properly constructed and maintained so as to avoid erosion and disturbance to natural drainage patterns." FSC certification has a social component as well, targeting employee safety and the health and well-being of people living within the FMU. For example, timber employees must be equipped with personal, identifiable uniforms and equipment.

As these indicators suggest, implementing FSC's forest management standards is costly and takes time. Rainforest Alliance's SmartStep program anticipates that it takes about five years to move from no legality certification to FSC forest management certification. Forest Stewardship Council's management certification changes firm management of timber extraction processes in costly ways. Estimates from the FSC certified Kabo concession in Northern Republic of Congo estimates that certifying a forest management unit incurs an initial cost of 1,500 to 2000 FCFA/ha (about \$3/ha), and a recurring annual cost ranging from 355 to 1,000 FCFA/ha (Bank, 2007).

3.5 Congo Basin Forest Amenities: Conservation

Habitat protection for endemic and threatened species like the mountain gorilla, carbon sequestration, rich plant, amphibian, bird, insect, and mammal biodiversity, and climate regulation services are just some examples of Congo Basin Forest environmental services. To proxy for a forest management unit's amenity potential, I use gorilla habitat and proximity to a protected area.

The Congo Basin is home to all four gorilla species, all of which are listed by the World Conservation Union's Red List as "endangered" or "critically endangered." I focus on gorilla habitat as a marker of amenity value because gorillas are an endangered species and considered a high conservation priority among policymakers, non-governmental organizations, scholars, and the general public. Figure 14 depicts the area of occupancy for the Western Gorilla, *Gorilla gorilla*, across Cameroon, Republic of Congo, and Gabon. A species' area of occupancy describes a species' range. Areas not colored are unsuitable for gorilla habitat. As seen in the map, gorilla habitat is patchy across space and includes a range of elevations. Gorillas prefer secondary stands and clearings and avoid areas with human pressure. Recently, primatologists identified swamp forests and mixed forests as key habitat for gorillas (Poulsen and Clark, 2004)(Melletti et al., 2009)(Rainey et al., 2010).

In addition to gorilla habitat suitability, I use a forest's distance to the nearest protected area as a proxy for amenity value. Protected areas may harbor endemic flora and fauna, have high species richness, or both. Protected areas in Gabon, Cameroon, and Congo are indicated with hatch marks in Figure 13. Forests closer to protected areas may have higher biodiversity potential than forests further away. Managing forests that surround protected areas improves the resilience of protected area ecosystem services (Clark et al., 2009)(Poulsen and Clark, eds, 2010).

4 Theoretical Model

In this section, I model timber production under three regimes, uncertified, certified legal, and certified managed. I use this model to make predictions as to the type of forest most likely to certify as legal or managed. The model is most similar to Amacher et al. (2012), who model incentives for firms to illegally log a forest concession.

I start with a model of uncertified timber production and then build in additional compliance costs from legality and forest management certification. Firms choose a quantity of timber, a management effort level, and voluntary policy participation status. Legality certification enforces a legal maximum harvesting quantity and minimum effort level. Firms incur an opportunity cost if the legal quantity maximum is smaller than the profit-maximizing quantity. They may also incur a compliance cost from greater management effort. FSC forest management certification enforces these legal requirements and adds additional costs to protect a forest's biodiversity.

4.1 Uncertified Timber Production

I simplify the forest to be a stand of two species of trees, only one of which is sold for timber. I assume the size of each tree, the proportion of commercial trees, and the number of trees per hectare are identical for all forest management units. Forests vary only in biophysical characteristics that affect the cost of timber harvest and in their amenity value. The biophysical characteristics that affect production costs include a forest's size, distance to a seaport, weather pattern, and topography. These characteristics are summarized by the forest parameter β. The forest with the highest production costs has parameter $\bar{\beta}$. A forest's amenity value is summarized by the forest parameter θ. Costs and amenity value may covary. A forest's costs and amenity value are known to the firm and auditor.[4]

In uncertified timber production, firms choose a quantity of timber q and management effort level l that maximizes their profit given production costs $C(q, l)$ and an exogenous timber price p. Timber harvesting costs are increasing and strictly convex in quantity for all types, $C_q(.) > 0, C_{qq}(.) > 0$. Some management effort decreases harvesting costs $C_l(q, 0) < 0$, but increasing management effort increases costs $C_{ll}(q, l) > 0$. All forest types will choose some positive amount of management effort, however high costs forests benefit more from management, $C_{l\beta}(.) < 0$. For example, consider a forest with few dry days for timber harvesting. Firms can spend management effort on rainy days to create a precise inventory and targeted road network that improves their efficiency at accessing and felling commercial trees on dry days. The firm extracts more trees per dry day which reduces the marginal harvesting cost per tree. On the other hand, for a dry forest, management effort spent producing a precise inventory takes resources away from harvesting activities, which are unconstrained by weather.[5] I summarize the relationship between costs and forest type as $C(q, l|\beta)$. Uncertified timber profit-maximization is:

$$\pi(q, l|\beta) = pq - C(q, l|\beta) \tag{1}$$

Timber contracts specify a legal maximum allowable harvest limit, $\bar{q}$ and a minimum effort level $\bar{l}$. I assume these requirements are unenforced for uncertified forests. Firms choose a quantity q^* and management effort level l^* that maximize profit. Firms managing a low cost forest will choose a management effort level less than the minimum legal requirement, $l^* < \bar{l}$. High cost forests will choose an effort level of $l^* \geq \bar{l}$.

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[4] This eliminates strategic behavior between the firm and auditor. In this model, I am interested in understanding the threshold firm type that chooses to participate in certification.

[5] In Amacher et al. (2012), management effort includes environmentally sensitive management techniques. These include longer routes, better road layout, and protection for residual trees, from longer time skidding methods. In their model, these activities always increase harvesting costs, e.g. the cross partial derivative is greater than zero for all forests, $C_{ql}(.) > 0$, and firms never choose a positive amount of management unless it is required. I broaden management effort to include the most primitive types of management, making inventories, so that effort can improve firm targeting of commercial trees.

4.2 Certified Legal Timber Production

Compliance with legality certification changes uncertified timber production costs in two ways. First, external auditors enforce the maximum harvesting quantity and minimum management effort level. Second, the firm must pay a fixed cost for auditors to monitor their compliance. In return, the firm earns a small price premium γ_L. The profit expression becomes:

$$\pi_{Legal}(q, l|\beta) = \gamma_L pq - C(q, l|\beta) - A \tag{2}$$

Participation in legality certification is voluntary. Let $\{q^*, l^*\}$ be the profit-maximizing quantity and effort level when uncertified. Firms participate if it is rational to do so:

$$\gamma_L pq - C(q, l|\beta) - A > pq^* - C(q^*, l^*|\beta) \tag{3}$$

If we rearrange this expression, we can compare how participation changes revenues to how it changes costs:

$$p(\gamma_L q - q^*) > C(q, l|\beta) - C(q^*, l^*|\beta) + A \tag{4}$$

Equation (4) shows two types of participation costs: opportunity costs and compliance costs. Opportunity costs are on the left; if the profit-maximizing quantity for basic timber production exceeds the legal maximum, $q^* > \bar{q}$, the firm may incur an opportunity cost from participating. Compliance costs, on the right, depend on how quantity and management effort level change with participation. All forests, regardless of type, incur fixed costs A. Compliance costs unambiguously increase if the uncertified management effort was less than the legal requirement. In the case where uncertified management effort exceeds the legal requirement, compliance costs will increase if the uncertified quantity was less than the legal requirement. This increase will be offset by new revenues on the righthand side.

Like in the case of uncertified timber production, amenity value θ does not directly factor into the costs of production for certified legal timber production. It is only to the extent to which the forest cost parameter β covaries with amenity value that we will see a relationship between amenity value and participation in legality certification.

4.3 Certified Responsibly Managed Timber Production (FSC)

Responsible forest management brings two additional requirements beyond legal timber certification. First, mandatory management effort depends on forest characteristics and exceeds the legal minimum, $l_F(\beta) > \bar{l}$. Second, firms must implement activities that address the amenity value of their forest, incurring costs $F(\theta)$. In return, they earn a larger price premium γ_F. The profit-maximization expression becomes:

$$\pi_{FSC}(q, l_F(\beta)|\beta) = \gamma_F pq - C(q, l_F(\beta)|\beta) - A - F(\theta) \tag{5}$$

Like in the case of legality certification, the harvested quantity must not exceed the legal maximum $q_F \leq \bar{q}$. Now, management effort must satisfy $l \geq l_{FSC}$, where $\bar{l} < l_{FSC}$. The Individual Rationality condition comparing uncertified timber production to FSC-certified production is:

$$\gamma_F pq - C(q, l|\beta) - A - F(\theta) > pq^* - C(q^*, l^*|\beta) \tag{6}$$

Where $q \leq \bar{q}$ and $l \geq l_{FSC}$. Costs $F(\theta)$ reflect the fact that as amenity value increases, the cost of implementing activities to safeguard this value also increases. If we rearrange terms, we can better see a firm's incentives to participate:

$$p(\gamma_F q - q^*) > C(q, l|\beta) - C(q^*, l^*|\beta) + A + F(\theta) \tag{7}$$

Using this expression, we predict that forests with very high costs or very high amenity value are less likely to participate in forest management certification. Forests with a high cost parameter β will have a higher mandatory effort level, $l_F(\beta)$. For example, in addition to a precise inventory and road plan, a forest with steep slopes may require special felling techniques and additional infrastructure to prevent soil erosion.[6] We would predict that forests with the highest costs $\bar{\beta}$ will be less likely to participate than forests with costs $\beta < \bar{\beta}$. Forests with

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[6] This management effort level is more similar to the management effort level described in Amacher et al. (2012).

high amenity value will have higher compliance costs $F(\theta)$. For example, a forest with a high gorilla population will need to take additional measures to protect gorilla habitat and prevent poaching. A forest with a low gorilla population will not incur these costs.

5 Data

I characterize production costs and amenity value for forest management units in three countries in the Congo Basin, Cameroon, Gabon, and the Republic of Congo, using publicly available management and biophysical data. I processed geospatial data in order to create proxies for forest production costs and forest amenity potential. I describe the details of the data geoprocessing and each data source in the Data Appendix.

5.1 Forest Management Data

Management information spans from 1989 to 2009 and comes from the World Resources Institute (WRI) Forest Atlases for Gabon, Cameroon, and the Republic of Congo. I dropped forest management units that were never attributed to a firm throughout the period, leaving 194 forest management units that span 24.8 million hectares of forest. Table 24 breaks down the population of forest management units by country and certification type. About half of all forest management units are in Cameroon; Gabon and Congo each have about a quarter of the total.

Figure 15 presents a histogram of active forest management units by year awarded. The average year awarded is 2002; less than half of all FMUs were awarded before 2002 and about one third of all FMUs were awarded after 2005. Forest management unit size varies greatly among FMUs. The average size across FMUs is 141,000 ha with a standard deviation of 166,000 ha. The largest FMU, Danzer's IFO concession in the Republic of Congo, is over 100 times the size of the smallest FMU, Rougier's Lorema concession.

I used multiple sources to code legality and FSC forest management certification for the period up until 2009. For legality certification, I focused on the four standards used in the region: FSC's Chain of Custody, Bureau Veritas' OLB standard, SGS's TLTV standard, and

Rainforest Alliance's VLO and VLC standards. I updated the WRI Forest Atlas legality certification status if I found evidence from one of these standards that the forest had been legality certified during the period of inquiry. All FSC certified forests are legality certified. In Table 24 we see that about one quarter of all FMUs have legality certification. Legality certification appears less common in Congo, though this may reflect a bias in missing certification data.[7] I also augmented WRI Forest Atlas data with certificate information from Forest Stewardship Council's Certificate Database.[8]. Returning to Table 24, we see that the pattern of FSC Forest Management Certification reflects the general breakdown of FMUs by country. More than half of all FSC certified FMUs are in Cameroon, with the remainder split between Congo and Gabon.

5.2 Production Cost Proxies

In the theoretical model, I describe variation in forests as a function of biophysical features that make harvesting more or less costly. I summarized these features in the forest parameter β. I do not observe a forest's harvesting costs. Instead, I proxy for harvesting costs related to weather, terrain, and location using observable biophysical characteristics.

To proxy for costs related to weather, such as harvest season length or depreciation of roads or machines, I use a forest's average annual rainfall. Most of the Congo Basin is humid tropical forest and very rainy. We see in Table 25 that the average annual precipitation is 1,740 cm and the standard deviation is about 295 cm. I calculated a forest's average annual rainfall by summing monthly rainfall for each pixel across twelve months, then taking the average across all pixels within the FMU. To capture variation in a forest's terrain, I calculated the average slope, in degrees, within a forest management unit. The average slope is 1.2 degrees with a standard deviation of 0.77 degrees. To proxy for a forest's transportation costs, I use the Euclidean distance to the nearest seaport. The furthest forest is over 460 km from the closest seaport, while the average distance is 177 km, with a standard deviation of 98 km.

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[7] Legality certification coding suffers from three weakness. First, not all labels publish forest management unit identities. Second, it is not clear how consistently each standard body updates their information. Finally, the WRI Version 1 Forest Atlas for the Republic of Congo did not publish legality certification status.

[8] http://info.fsc.org/ Accessed February 2011

5.3 Forest Amenity Value Proxies

Ecologists do not agree on the best way to quantify the manifold of ecosystem services provided by Congo Basin forests. Lacking a measurement for general amenity potential, I focus on two types of proxies for measuring an FMU's amenity potential: gorilla habitat suitability and distance to a protected area.

I calculate two measures of gorilla habitat suitability using data from IEA. First, I calculated the percentage of the FMU's total area that is at least somewhat suitable for gorilla habitat. A pixel's dimensions are one meter by one meter. We see in Table 25 that on average 16% of forest area is highly suitable for gorillas, with a standard deviation of 21%. One forest is almost entirely highly suitable for gorillas: 92%. Next, I create a dummy variable equal to one if there is at least one pixel of "highly suitable" gorilla habitat within the forest management unit. About three-quarters of all FMUs have at least one meter squared of highly suitable gorilla habitat.

For distance to the nearest protected area, I calculated the forest's Euclidean distance to the border of the nearest protected area using polygons of protected areas in Cameroon, Congo, and Gabon. The average is about 11 km, as reported in Table 25, and the standard deviation 13 km. The maximum distance is 62 km away and the minimum is adjacent to a protected area.

6 Empirical Strategy

The goal of the empirical analysis is to predict the drivers of participation in legality and FSC forest management certification. This section begins by introducing and justifying my preferred specification, a probit regression with robust standard errors. From the theoretical model, I predict that participation in legality and forest management certification depends on forest type and amenity value, which I do not observe. Instead, I use proxies for forest type to investigate whether this prediction holds empirically.

Forest type is summarized by the vector β, which includes a forest's weather, terrain, size and location, among other factors that may affect production costs. Empirically, I proxy for β

using average rainfall $Rain_i$, average slope $Slope_i$, and distance to seaport $DistPort_i$. Fixed costs, such as auditing expenses, are proxied by forest $Size_i$. I also control for unobserved characteristics common across a country using $Country_i$ the length of time since the forest was awarded via Age_i. Finally, I proxy for amenity value using two measures of gorilla habitat $GorHabitat_i$ and the forest's distance to a protected area.

6.1 Regression Specification: Latent Variable Approach

I model the decision to participate in legality or forest management certification using a latent variable approach. I assume the unobserved error component is normally distributed and test hypotheses regarding participation drivers using a probit regression.

A firm managing a forest has a binary choice, whether or not to certify their FMU. The participation decision reflects a threshold for an unobserved latent random variable w, where firms choose to certify if $w > 0$. The latent random variable w reflects the individual rationality constraint, reported in Equation (4) for legality and Equation (7) for FSC forest management certification. Focusing on forest management certification, the critical value for the latent random variable is:

$$w = f(\beta) + \epsilon \tag{8}$$

$$w = f(Slope_i, DistPort_i, Rain_i, Size_i, GorHabitat_i, Country_i, Age_i) + \epsilon \tag{9}$$

If I assume that these terms enter linearly and the unobserved error term is normally distributed, $\epsilon\ N(0, \sigma^2)$, I can estimate this using a probit regression. The likelihood that a forest participates in legality certification is then:

$$\begin{aligned} Pr(\chi = 1) &= Pr(w > 0) \\ &= \Phi(Slope_i + DistPort_i + Rain_i + Size_i + GorHabitat_i + Country_i + Age_i) \end{aligned}$$

In practice, I allow for general heteroskedasticity of the error term by using a probit regression with robust (sandwich) standard errors.

The cost proxies for forest type β are derived as summary statistics using a forest's polygon. We find great variation across forest management units in size; thus the population for each summary statistic varies across forests, introducing heteroskedasticity in the error term. I address variation in forest size by including estimates that use the natural log of each cost proxy.

7 Results

I investigate drivers of participation in legality and FSC forest management certification for 194 Forest Management Units (FMUs) from three countries, Cameroon, Congo, and Gabon, over the period of 1987 to 2009. I test the theoretical model's prediction that forests with lower compliance costs or lower opportunity costs are more likely to participate in either legality or FSC forest management certification. I then investigate whether forests with higher amenity potential are less likely to become legality or FSC forest management certified. To test these hypotheses, I use a probit regression with robust standard errors. Results tables 26, 27, and 28 report the sample mean of the estimated derivative.

7.1 Predicting Participation in Legality Certification

From the theoretical model, we predict that forests with low participation costs are more likely to participate in legality certification. Forests with high ex ante production costs are more likely to have low compliance and opportunity costs. Amenity value should not deter or encourage participation in legality certification directly. This section characterizes how proxies for high production costs and amenity value predict participation in legality certification in Table 26. For each regression specification, the outcome variable is a dummy variable equal to one if the forest management unit was ever legality certified before 2009.

I use a forest's observable biophysical features as proxies for high ex ante production costs. These biophysical features include average annual precipitation, average slope of forest terrain, distance to seaport, and forest size. For rainy or steeply sloped forests, management effort spent on improved inventories and road-planning reduces harvesting costs. For these forests, compliance with legality certification requires minimal additional management effort and is less costly. In Table 26 we see that average annual rainfall across the FMU, measured in 100 centimeters, predicts participation in legality certification. Forest management units with higher precipitation are more likely to participate. An additional 100 centimeters of rain per year increases the likelihood of participating in legality certification by between 2-3 percentage points. Increasing annual precipitation by one standard deviation increases the likelihood of legality certification by 6-9%. Steeper average slope also predicts legality participation. The magnitude of the increase is similar to that of precipitation: an increase of one standard deviation, 0.7 degrees, increases the likelihood of participating by 5%.

FMUs with a low opportunity cost from the enforced legal maximum are more likely to participate in legality certification. Recall that opportunity costs are the difference between uncertified and certified revenues, $pq^* - \gamma_L p q_L$, where certified volume must not exceed the legal maximum $q_L \leq \bar{q}$. Firms with ex ante lower quantity q^* will have lower opportunity costs from participating in legality certification, where the harvesting maximum is enforced. High transport costs make it more likley that a forest has lower profit-maximizing uncertified quantity. I use the forest management unit's distance to a seaport as a proxy for transportation costs. We see in Table 26 that moving an additional 10 km away increases the likelihood of participating by about 1.5%.

Legality certification costs do not vary with a forest's amenity value. I proxy amenity value using gorilla habitat suitability or a forest's distance to a protected area. If amenity value predicts participation, it must be through correlation with unobserved forest characteristics that make legality certification profitable. I find that forests with habitat suitable for gorillas are more likely to participate, however proximity to a protected area does not predict participation. The greater the proportion of the forest highly suitable for gorilla habitat, the more likely the firm participates in legality certification. Increasing the proportion of forest highly suitable for gorilla habitat by one standard deviation increases the likelihood of legality certification by 8%. Moving from no highly suitable gorilla habitat to at least one meter squared increases the likelihood of legality certification by 16 percentage points. In contrast, the distance to the nearest protected area has no effect.

Legality certification does not address gorilla conservation directly. Why then are forests with highly suitable gorilla habitat more likely to participate? Two different explanations could explain the relationship. Perhaps gorilla habitat suitability is correlated with an unobserved forest characteristic that also affects compliance or opportunity costs of participation. For example, gorillas are highly sensitive to human pressure and prefer areas with low human settlement density. Lower human population density implies fewer skilled workers, less infrastructure such as major roads, electricity, or cell phone coverage, and higher input costs such as gasoline and agricultural goods to feed workers, all of which imply higher ex ante production costs. Or perhaps forests with highly suitable gorilla habitat experience pressure from conservation non-governmental organizations (NGOs) who object to timber production in high amenity value forests. If NGOs use campaigns to shift timber demand away from these forests, firms may opt to certify that their timber is legal to recapture timber demand from environmentally sensitive customers.

7.2 Predicting Participation in FSC Forest Management Certification

Like in the case of legality certification, we expect forests with lower participation costs to be more likely to participate in FSC forest management certification. The FSC forest management includes the same requirements as legality certification, but requires additional management effort and protection of forest amenity value. In return, firms earn a higher price premium from FSC certification. These differences from the legality case change our predictions in three ways. First, larger fixed costs from FSC participation implies that larger forests will be more likely to participate. Second, a large price premium and management effort tied to forest type make lower cost forests more likely to participate than in the case of legality certification. Third, we expect forests with higher amenity value to have higher compliance costs and be less likely to become FSC certified.

Table 27 reports the likelihood of participating in FSC forest management certification. For each specification, the outcome variable is a dummy variable equal to one if the forest management unit was ever FSC forest management certified before 2009. Covariates are identical to the previous table for legality certification. FSC forest management standard's higher fixed costs imply that larger forests are more likely to participate. Size does appear to be a strong predictor of FSC forest management certification, however the magnitude is smaller than in the case of legality certification. For FSC, increasing forest size by one standard deviation increases the likelihood of certification by 4.5%.

Two features of FSC forest management certification make it more likely that forests with ex ante low production costs forests may be more likely to participate than in the case of legality certification. First, we expect compliance costs related to management effort to increase for forests with high production cost characteristics. For example, a forest with steep slopes will have a higher management effort requirement than a flat forest. Because of this, we expect forests with the highest production cost characteristics to be less likely to participate in FSC. Second, a higher price premium for FSC-certified timber provides a greater offset for lost revenues from enforcing the harvest maximum. For both standards, production quantity may not exceed the legal maximum $q_L, q_F \leq \bar{q}$. A firm's opportunity costs, $pq^* - \gamma_F p q_F$, are always higher for forests with higher uncertified quantity, q^*. However, a higher price premium will enable greater participation by forests with low production costs as compared to legality certification.

We can compare estimates for FSC participation drivers in Table 27 to legality participation drivers to see if these predictions hold for production cost proxies. Precipitation is a reliable driver of participation in either policy; the magnitude of the estimate is about the same for both legality and FSC certification. This makes sense because precipitation begets few additional management activities. For FSC participation, slope of forest terrain no longer predicts participation and the magnitude of the estimate is zero, compared to 6 percentage points in the case of legality certification. This may reflect very sloped forests choosing not to pursue FSC certification due to additional compliance costs from increased management effort. Like in the case of legality certification, forests further from the seaport are more likely to participate in FSC. However, the relationship is weaker and the magnitude is only a quarter of that for legality certification. This fits with our intuition that a higher price premium will enable forests with lower transportation costs to participate.

For FSC forest management certification, having high amenity value poses a liability for the forest. Higher amenity value brings greater compliance costs, as firms must biodiversity needs. In Table 26, we found a correlation between gorilla habitat suitability and likelihood to participate in legality certification. We speculated that either gorilla habitat is correlated with an unobserved driver of participation in legality certification or that pressure from conservation non-governmental organizations pushes firms to participate.

In the case of FSC forest management certification, the presence of gorillas brings additional costs through monitoring and protection measures. Having gorilla populations within an FMU increases the cost of FSC compliance and may discourage participation. Across all specifications of Table 27, I do not find direct evidence that forests with suitable gorilla habitat are less likely to participate in FSC. The coefficients for percentage of FMU highly suitable for gorillas and a dummy for any suitable gorilla habitat are both near zero but positive, a pattern repeated for the distance to a protected area measure. However, given that gorilla habitat suitability was correlated with profitable legality certification, the elimination of this correlation may indicate that forests with suitable gorilla habitat are opting out of FSC certification.

7.3 Alternative Specification

In this section, I continue to use a probit regression specification with robust standard errors. I focus on one amenity value measure, the percentage FMU with highly suitable gorilla habitat measure for amenity value. Because forests vary greatly in size, I present results using the natural log of the suite of production cost proxies in Table 28. I start by discussing changes in the direction of predictions then compare their magnitudes and significance.

For legality certification, the direction of participation drivers, cost proxies and amenity value, remains the same as in the main specification. For FSC certification, two estimates change sign: forest slope and the percentage of the forest highly suitable for gorillas. The gorilla estimate remains nearly zero, however the slope estimate magnitude is fairly large. Neither estimate is significant.

8 Conclusion

In this paper, I investigated the drivers of participation in two voluntary forest policies, legality certification and Forest Stewardship Council (FSC) forest management certification. Because both policies are voluntary, firms only participate if it is profitable to do so. I use this relationship and a model of how each policy changes costs and revenues to investigate drivers of participation in legality and FSC forest management certification for 194 forest management units in Gabon, Cameroon, and the Republic of Congo. Voluntary policy participation costs vary with a forest's ex ante production costs and amenity value. I use biophysical forest characteristics as a proxy for ex ante production costs and test whether forests with lower participation costs are more likely to participate in either voluntary policy.

For legality certification, firms must respect the legal harvest maximum and management level minimum. In return, they earn a small price premium. Two predictions emerge from the theoretical model. First, we expect forests with lower opportunity costs to be more likely to participate in legality certification. Opportunity costs refer to foregone revenues from respecting the legal harvesting maximum. Forests with higher ex ante production costs are less likely to incur opportunity costs. Second, we expect firms with lower compliance costs to be more likely to participate. Compliance costs come from increasing management effort to the legal minimum. Forests with higher ex ante production costs may also have higher ex ante management effort, thus lower compliance costs.

Based on these two predictions, we expect forests with cost proxies that indicate higher production costs to be more likely to participate in legality certification. Consistent with the model, I find that higher annual precipitation, greater average slope of forest terrain, and greater distance to seaport predict participation in legality certification. I also find that gorilla habitat suitability strongly predicts participation in legality certification, despite the fact that legality certification does not address biodiversity protection directly. I suggest that this relationship may be due to correlation between gorillas and low human population density, which increases production costs, or from firms responding to pressure from conservation non-governmental organizations.

FSC forest management certification, brings two additional requirements beyond legality certification. Management effort is no longer capped at the legal requirement and instead reflects forest characteristics. Forests with higher production costs will have higher management effort requirements and thus higher compliance costs. Similarly, firms must protect forest amenity value. Forests with higher amenity value, such as those suitable for gorillas, will have higher compliance costs. These requirements make participation less likely for forests with high production costs or high amenity value. Unlike in the legality case, forests with very sloped terrain or far from the seaport are not more likely to participate in FSC certification. Likewise, forests suitable for gorillas are not more likely to participate in FSC. These patterns could reflect additional compliance costs associated with forest management and gorilla conservation, which is not the case for legality certification.

These participation drivers have implications for each standard's overall effectiveness. I find that firms with high ex ante production costs are more likely to participate in legality certification. The goal of legality certification is to reduce illegal logging. These forests may be less likely to overexploit as compared to forests with low production costs, limiting the reduction in illegal logging caused by the policy. For FSC forest management certification, I find that forests with high amenity value are not less likely to participate than the average forest. FSC forest management certification may fail to target conservation of forests with the highest biodiversity value but I do not find evidence of adverse selection.

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Table 27: Certification Frequency by Country

Participation Status	Country Cameroon No.	 Gabon No.	 Congo No.	 Total No.
Basic	68	35	46	149
Certified Legal	17	8	0	25
Certified FSC	12	5	3	20
Total	97	48	49	194

Table 28: Summary Statistics

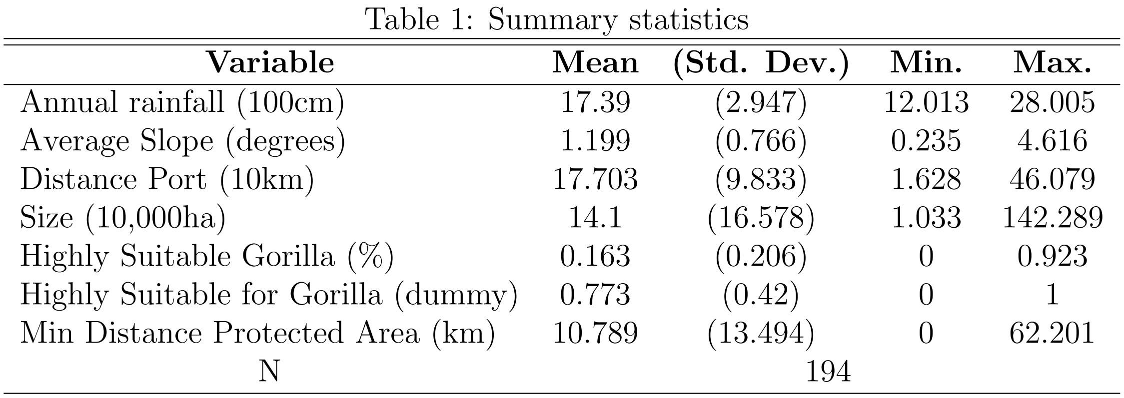

Table 1: Summary statistics

Variable	**Mean**	**(Std. Dev.)**	**Min.**	**Max.**
Annual rainfall (100cm)	17.39	(2.947)	12.013	28.005
Average Slope (degrees)	1.199	(0.766)	0.235	4.616
Distance Port (10km)	17.703	(9.833)	1.628	46.079
Size (10,000ha)	14.1	(16.578)	1.033	142.289
Highly Suitable Gorilla (%)	0.163	(0.206)	0	0.923
Highly Suitable for Gorilla (dummy)	0.773	(0.42)	0	1
Min Distance Protected Area (km)	10.789	(13.494)	0	62.201
N		194		

Table 29: Participation Drivers for Legality Certification

	(1) Legality	(2) Legality	(3) Legality
Annual rainfall (100cm)	0.0238* (0.0104)	0.0320** (0.0114)	0.0326** (0.0122)
Slope of Terrain (degree)	0.0634 (0.0340)	0.0688* (0.0344)	0.0613 (0.0360)
Distance Port (10km)	0.0148*** (0.00310)	0.0149*** (0.00310)	0.0171*** (0.00350)
FMU Size (10,000ha)	0.00366* (0.00174)	0.00268 (0.00176)	0.00343 (0.00191)
% FMU Highly Suitable Gorilla	0.431** (0.144)		
Highly Suitable for Gorillas		0.162** (0.0524)	
Distance Protected Area (km)			0.000929 (0.00204)
Observations	194	194	194

Probit regression with robust standard errors. Marginal effects reported.

Regression includes country and concession age dummies (not reported).

Standard errors in parentheses. * p<0.05, ** p<.01, *** p<.001

Table 30: Participation Drivers for Forest Management Certification

	(1) FSC	(2) FSC	(3) FSC
Annual rainfall (100cm)	0.0235**	0.0249**	0.0256**
	(0.00842)	(0.00887)	(0.00884)
Slope of Terrain (degree)	0.000408	0.00512	-0.0000304
	(0.0266)	(0.0261)	(0.0266)
Distance Port (10km)	0.00341	0.00340	0.00367*
	(0.00183)	(0.00180)	(0.00184)
FMU Size (10,000ha)	0.00277**	0.00271**	0.00285**
	(0.000997)	(0.001000)	(0.00101)
% FMU Highly Suitable Gorilla	0.0103		
	(0.0911)		
Highly Suitable for Gorillas		0.0467	
		(0.0414)	
Distance Protected Area (km)			0.00112
			(0.00143)
Observations	194	194	194

Probit regression with robust standard errors. Marginal effects reported.

Regression includes country and concession age dummies (not reported).

Standard errors in parentheses. * p<0.05, ** p<.01, *** p<.001

Table 31: Alternative Specification (Logs)

	(1) Legality	(2) FSC
Log Annual rainfall (100cm)	0.758**	0.777**
	(0.249)	(0.254)
Log Slope of Terrain (degree)	0.0702	-0.0424
	(0.0541)	(0.0431)
Log Distance Port (10km)	0.276***	0.124*
	(0.0576)	(0.0525)
Log FMU Size (10,000ha)	0.0690	0.0619*
	(0.0444)	(0.0293)
% FMU Highly Suitable Gorilla	0.370**	-0.0225
	(0.131)	(0.108)
Observations	194	194

Probit regression with robust standard errors. Marginal effects reported.

Regression includes country and concession age dummies (not reported).

Standard errors in parentheses. * p<0.05, ** p<.01, *** p<.001

Table 32: Data Sources

Data Type	Source	Scale
Country boundaries	World Resources Institute's ROC Forest Atlas, Version 1	
Rivers & Lakes	Digital Chart of the world	1:1,000,000 map
Towns	Columbia University's Socioeconomic Data and Applications Center, Gridded Rural-Urban Mapping Project, version alpha	~ 90 m resolution
Soils	ESRI digitized FAO-UNESCO's Soil Map of the World	1:5,000,000 map
Precipitation	WorldClim database, Version 4 (release 3). See Hijmans et al. (2005) for details.	~ 90 m resolution
Elevation	NASA Shuttle Radar Topographic Mission's (SRTM) Digital Elevation Model, Version 4	~ 90 m resolution
Ports	EGY Shipping's World Port Codes	
Gorilla Area of Occupancy	Institute of Applied Ecology's (IEA) African Mammals Databank	~ 90 m resolution
Priority Landscape Boundaries	Central Africa Regional Program on the Environment, USAID	
FMU and Protected Area boundaries, Cameroon	World Resources Institute's Cameroon Forest Atlas, Version 2	
FMU and Protected Area boundaries, Republic of Congo	World Resources Institute's ROC Forest Atlas, Version 1	
FMU and Protected Area boundaries, Gabon	World Resources Institute's Gabon Forest Atlas, Version 1	

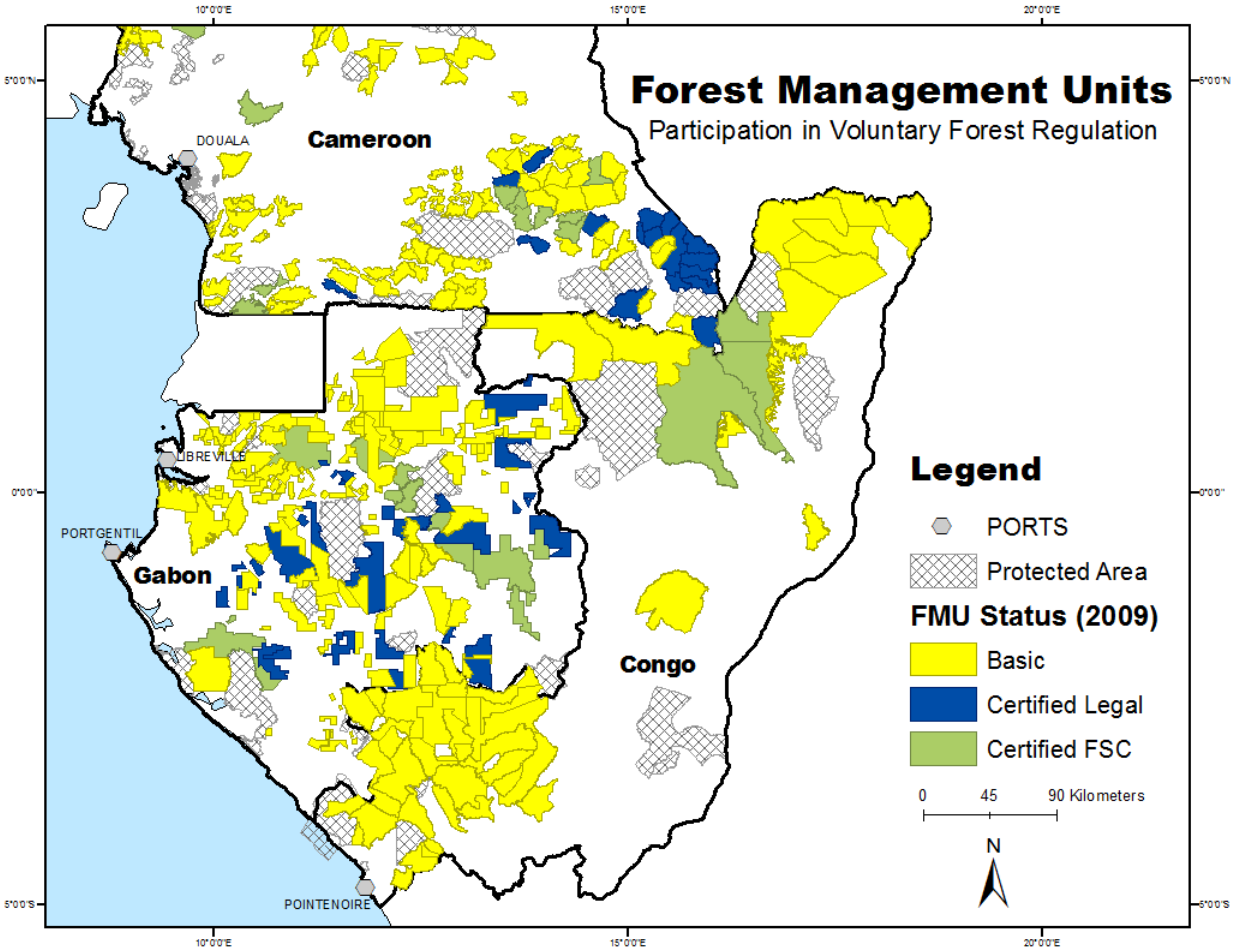

Figure 13: Forest Management Units in Cameroon, Gabon and Congo

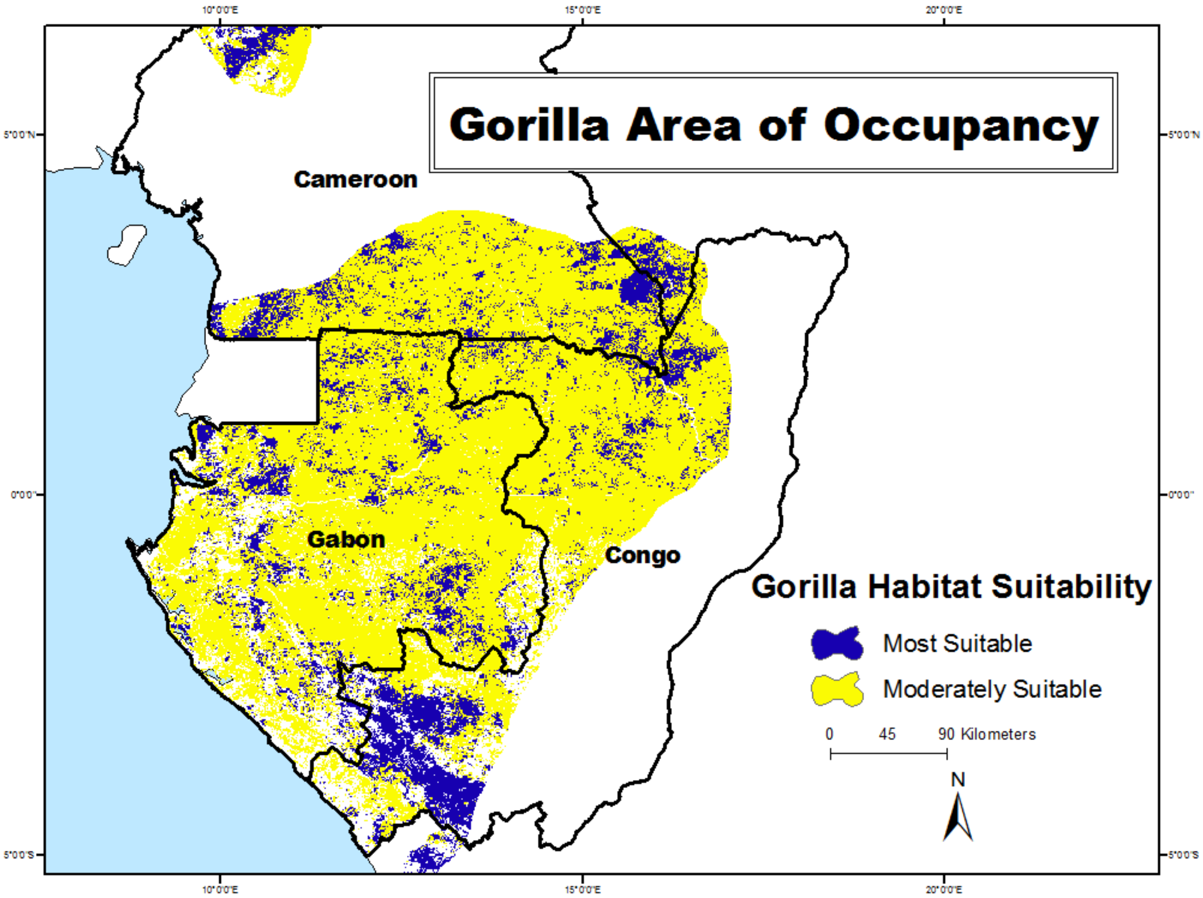

Figure 14: Western Gorilla *Gorilla gorilla* habitat in study area

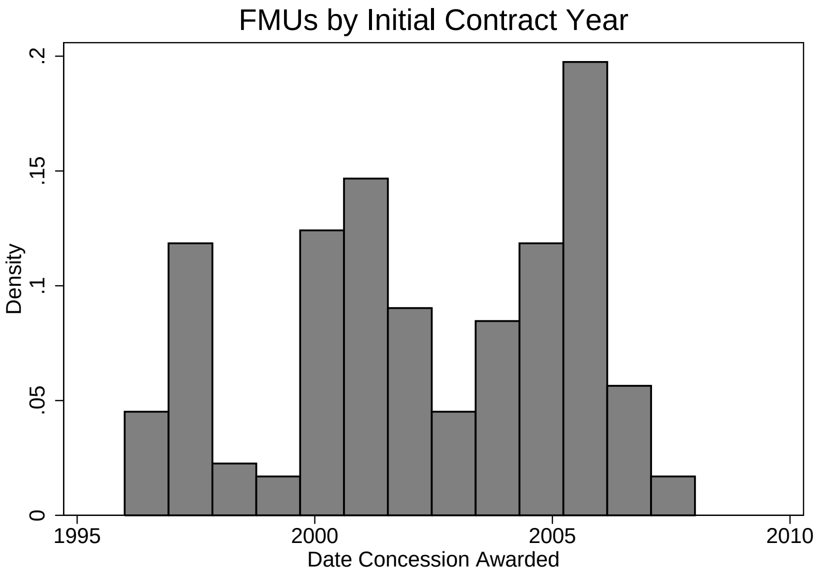

Figure 15: Histogram of Forest Management Unit Initial Allocation Year

Data Appendix

Table 29 describes the geospatial data, source, and scale used in the empirical analysis. All geospatial data were processed using ArcGIS version 9.3's scripting module, arcgisscripting, and Python version 2.5. For the digital elevation model data, the panels covering the five country region were downloaded from the Consultative Group on International Agricultural Research's website (CGIAR) and knitted together before processing. The following describes how data were prepared for the econometric analysis:

- Data were transformed into WGS-84 datum and projected using the Mercator projection
- Boundaries clipped to the boundaries of the five Congo Basin countries (Cameroon, Central African Republic, Republic of Congo, Democratic Republic of Congo, and Gabon)
- Vector data was rasterized to cell size of 1 km and raster data was resampled to cell size 1 km
- FMU and Protected Area boundaries were used as inputs for the zonal statistics tool from the Spatial Analyst toolbox to calculate mean, min, max, range, and variety of pixel values for each zone

Additional processing was necessary for some datasets. To calculate the slope of each 1 km cell across the three countries, I used the slope tool in ArcGIS's Spatial Analyst toolbox's Surface kit to process elevation data derived from 90m NASA's SRTM. For each 1 km square, the slope tool measures in degrees, ζ, where $\tan(\zeta)$ = rise/run, by taking the maximum rise/run from the eight neighboring cells.[9] Note that the slope does not include information on aspect (the direction the slope is pointing).

Aspect is captured in the wetness index, which is derived using a two step process. First, I calculated a grid that predicted water flow direction. Flow direction is calculated by comparing the slope of adjacent cells and determining which has the steepest descent.[10] Using flow

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[9] More precisely, using map algebra the tool finds slope as $\zeta = \arctan((dz/dx)2 + (dz/dy)2) * 57.29578$, where the coefficient converts from radians to degrees

[10] "Flow Direction" finds the change in the z-value/distance, where distance between two orthogonal cells is 1 km and between two diagonal cells is 1.414

direction, I then calculated another raster for water flow accumulation, what I call the wetness index. For each 1 km square, flow accumulation recursively counts the number of upslope cells and each upslope cell counts as 1.[11] Higher values indicate a greater propensity to be wet. I summarized this data for all cells in an FMU zone using measures meaningful for timber costs, such as the average. For regressions, then normalized the mean wetness variable (205 observations, one for each FMU) to create an easier to interpret wetness index with mean 0 and standard deviation of 1.

Population data comes from two sources, both produced by the Center for International Earth Science Information Network (CIESIN) of the Earth Institute at Columbia University. CIESIN produces the Gridded Population of the World, version 3 (GPWv3), and the georeferenced Global Rural-Urban Mapping Project (GRUMP) dataset of point settlements and their estimated population. I used the gridded population for the measure of max population in one square kilometer within an FMU. However, for selecting towns of greater than 100,000 people, I used the settlement dataset's population estimate for the year 2000. This dataset is an amalgamation of diverse population data sources, each with varying reliability. I also used the settlement dataset to define seaports. Because I was unable to locate a publicly available dataset that included georeferenced seaports, I coded settlements from CIESIN's data using SGY shipping's port locator reference to include a dummy for whether or not the town was a seaport.

To calculate the distance of an FMU to the seaport, I would have preferred to calculate the distance by road. However, I lack a complete road network and thus was forced to use Euclidean distance. Euclidean distance is measured by creating a right triangle on an x-y plane, where the centroid of the source and origin cells act as the acute angle vertices. The distance of the hypotenuse of this triangle is recorded as the Euclidean distance between the two points.[12] I used the same process to find FMU distance to the nearest protected area and to large towns.

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[11] Upslope is defined as having a Flow Direction value greater than that cells own value

[12] Elevation data is not included in the analysis, so the actual Euclidean distances may be longer.