Market segmentation by certification: Quantity effects on tropical timber production

Matthew T. Cole[*], Jacqueline M. Doremus[†], and Stephen F. Hamilton[‡]

June 19, 2019

Abstract

Eco-certification standards are increasingly used by industrial countries to impose import restrictions on goods produced by foreign suppliers. Import restrictions on eco-certified goods that prevent the trade of goods derived from unsustainable practices serve to segment global markets served by foreign producers into a conventional market and a certified market, altering market structure and equilibrium prices in a manner that potentially works against sustainability goals. In this paper, we examine the effect of forest certification on tropical timber production in Central Africa. Using panel data of timber production in Cameroon from 2003 to 2009, we show that conventional timber producers substantially increase harvest rates in response to eco-certification standards, and that this effect is strongest in less competitive timber markets. Moreover, we find eco-certification shifts production to forests with higher extraction costs and potentially higher marginal damages from timber extraction, exacerbating economic inefficiency.

Keywords: forestry, trade, product differentiation, eco-label
JEL Classification: Q23, O13, L31

[*]Department of Economics, California Polytechnic State University, CA 93407, USA. Email: mtcole@calpoly.edu.

[†]Corresponding author: Department of Economics, California Polytechnic State University, CA 93407, USA. Email: jdoremus@calpoly.edu.

[‡]Department of Economics, California Polytechnic State University, CA 93407, USA. Email: shamilto@calpoly.edu

1 Introduction

Policymakers in industrial countries have increasingly turned toward import restrictions to prevent the trade of goods derived from unsustainable practices. Import restrictions are currently used to prevent consumers from purchasing foreign goods derived from endangered species, unsustainable fishing and forestry practices (Asner et al. 2009; Crane and Lidgard 1989), and genetically-modified crops, and are being discussed as a way to limit the carbon-content of trade (Pauwelyn 2013). Given their proliferation and scope, import restrictions represent an important class of environmental policies to consider. They are naturally attractive to policymakers as an alternative to quotas and tariffs, because mandating eco-labels on imported goods does not violate free trade agreements and requires little in the way of direct intervention. The use of eco-certification standards as the basis for import restrictions provides simple means for a country to control access to its consumer market, while at the same time supporting environmental standards that ostensibly help resolve global externalities.

Nevertheless, using import restrictions to solve global externality problems suffers from the problem of imperfect targeting. Policymakers in industrial country cannot compel producers in foreign countries to harvest natural resources in a sustainable manner, as foreign producers facing import restrictions on certified goods in industrial countries can continue to sell uncertified goods in unrestricted markets. Moreover, because import restrictions on the sale of products derived from unsustainable practices segment global demand into certified and conventional markets, eco-certification standards on imported goods limits the ability of global consumers to substitute between products, reducing the degree of competition among producers in resource-extractive industries. In industries where producers have heterogeneous extraction costs, restricting imports through the use of eco-certification standards can alter production incentives for foreign producers in ways that potentially work against global sustainability goals.

In this paper, we examine the effect of import restrictions in industrial countries that seek to limit tropical forest degradation through eco-certification standards on forest outcomes in Central Africa. Import restrictions address unsustainable timber harvesting by requiring verification of the origin and legality of timber production. Firms can satisfy verification requirements through independent certification, either via Forest Stewardship Council (FSC), which certifies responsible timber management, or through industry eco-labels that verify timber origin and legality. It is currently illegal to purchase timber harvested from tropical forests not certified as sustainable under the Lacey Act Amendments (2008) in the US, under the Green Purchasing Law (2006) in Japan, under the Illegal Logging Prohibition Act (2012) in Australia, and under the the Forest Law Enforcement, Governance, and Trade Action Plan (2003) and the Timber Regulation Act (2013) in the EU.

We consider the effect of sustainable forest certification on timber managers in tropical forest areas. Timber producers facing import restrictions on non-certified goods can choose to sell eco-certified wood products to consumers in the restricted market or to sell conventional wood products to consumers in the unrestricted market, as the import restriction segments the market for producers in the resource-extractive industry. We examine the effect of segmented markets in altering equilibrium prices and production incentives for timber products in both the certified and non-certified markets.

Our analysis is framed by a model of Cournot competition among firms with heterogeneous costs and asymmetric information. Individual forest producers choose to sell timber products either in a conventional market or an eco-certified market subject to an import restriction. We demonstrate that segmenting a regional timber market into conventional and certified marketing channels results in three economic incentives that alter forest management outcomes. First, eco-labeling differentiates timber products, relaxing price competition and increasing industry profits along the lines of Shaked and Sutton (1982). This *competition effect* raises global prices and provides individual forest owners with an incentive to increase timber output. Second, introduction of an eco-label segments demand, resulting in equilibrium changes in relative timber prices that create incentives for reduced timber production in a *demand effect*. Finally, introducing an eco-label truncates the distribution of firm costs in each market, allowing high-cost producers to profitably harvest timber that would otherwise not harvest at all. This *selection effect* increases harvest incentives for forests switching into the certified sustainable market while decreasing harvest incentives for forests with the lowest extraction costs. Depending on which of these three effects dominates on the supply-side of the market, our model demonstrates that conventional and certified timber production can increase or decrease in response to an import restriction.

We test our hypotheses using highly granular data on forest production in Cameroon. Making use of panel data at the species level, we document how certification changes harvest rates for certified forests, conventional forests, and forests on the certification margin. Our model predicts certified and marginal conventional producers will increase harvest rates in response to an import restriction, with more pronounced effects arising in less competitive markets served by fewer firms. We test our model predictions by exploiting ecological variation in the geographic ranges of the various timber species that generates variation in potential competition across species. Perhaps surprisingly, we find firms switching from conventional to certified forest management substantially *increase* production after certification. Indeed, the magnitude of this adjustment effect is quite significant, as we show certified production more than doubles after certification for some specifications of our model, and that this effect is driven primarily by harvest of tree species in less competitive markets.

Our evidence reveals that eco-certification standards segmented the Cameroonian timber market in a manner that resulted in a net increase in production for some forests not certified as sustainable. This finding indicates the potential for import restrictions to achieve adverse environmental consequences, at least in the case harvest rates in primary tropical forests. The loss of primary forests in tropical countries is a significant obstacle to global biodiversity conservation (Gibson et al. 2011).[1]

[1]Increased harvest intensity in remote forests results in a greater road network, increasing forest frag-

A rich literature has emerged to model how eco-certification changes environmental benefits (e.g. Fischer and Lyon 2014, Li and van't Veld 2015, Chen 2001, Heyes and Martin 2016, Amacher et al. 2004).[2] We contribute to this literature with a model explicitly designed to address quantity effects among suppliers serving globally-segmented markets for certified and uncertified products.

Early work along these lines recognized that feedback in the supply chain between conventional and certified markets could increase total production.[3] In Mattoo and Singh (1994), quantity increased after certification because consumers of green products have higher willingness-to-pay, so serving the certified market increases aggregate demand. Sedjo and Swallow (2002) describe the demand and competition effects in a competitive partial equilibrium model, and note that conventional firms could benefit from a higher price after certified firms exit the conventional market. Our point of departure is to consider how import restrictions mediated by eco-labels change production incentives among producers with market power and heterogeneous costs.[4] We formalize three channels that drive quantity effects from differentiation by certification – a competition effect, a demand effect, and a new selection effect – and find them to be empirically relevant in determining tropical forest outcomes in Cameroon.

The remainder of the paper is structured as follows. In the next section, we provide background detail on the use of import restrictions to prohibit the consumption of products harvested through unsustainable practices in the timber market. In Section 3, we present a

mentation and leading to greater deforestation rates along roads, skid trails, and gaps from when trees fall (Laporte et al. 2007). Roads from selective logging empty forests of protein (Wilkie et al. 2000), increase the risk of primate extinction (Edwards et al. 2014) and facilitate greater carbon emissions from primary forest conversion to alternative uses (Estrada et al. 2017).

[2] See Bonroy and Constantatos (2014) for a summary

[3] Similar feedback exists when considering alternative land uses in response to a conservation program (Wu 2000) which result in so-called "leakage" or "slippage" effects. Selective conservation practices on forest cover in one area raise the opportunity cost of retaining forest cover in other areas, and there is evidence this has contributed to deforestation in Vietnam (Meyfroidt and Lambin 2009) and in protected areas of Costa Rica (Robalino et al. 2017). We focus on a different margin, changes in production *given* land use.

[4] Eco-labels' potential to decrease consumer surplus (Zago and Pick 2004) or change the intensity of competition in a duopoly (Amacher et al. 2004) has been recognized in eco-label models of vertical product differentiation; however, quantity effects are limited in these models, because consumers are restricted to purchasing one unit of either good and the focus is on how relative prices separate consumers with heterogeneous demand for the certified attribute.

theoretical model to explain how production incentives change in resource-extractive industries in response to import restrictions that segment the global consumer market into certified and non-certified markets. In Section 4, we present our empirical analysis on the effect of eco-certified timber requirements in industrial countries on forest outcomes in Cameroon, and in Section 5 we discuss the policy implications of our findings.

2 Forest Certification in Cameroon

Protecting global tropical forests is an important policy goal. Tropical forests have more plant species (Crane and Lidgard 1989) and contain more locally-rare species (Clark et al. 1999) than temperate or boreal forests. Markets exist for a small share of the total number of species within tropical forests, leading to a practice of selective logging that is often destructive to the remaining forest (Putz et al. 2000).[5]

In tropical forests, species vary in their distribution across space. Neutral theories of the assembly of tropical trees model tree species dispersion as a random process (Hubbell 2001). Though recent evidence suggests that some species variation is linked to variation in soil type (John et al. 2007), in Cameroon species variation was best characterized as randomly dispersed (Manel et al. 2014). The pattern of tree species assembly in tropical forests creates exogenous variation in the likelihood a species is found in multiple forests, which we exploit in our empirical approach as a source of exogenous variation in the degree of potential competition across forest products.

Eco-labels emerged in the 1990s as a market-based solution that can be used to restrict imports while respecting trade agreements and the sovereignty of producer nations. The use of eco-certification standards as a trade requirement confines legal trade with consumers in the restricting country to consist only of products that meet the eco-certification standard. In

[5]Distinct properties like density, workability, finishing, strength and durability make each species uniquely valuable to specific markets, creating incentives for selective cutting (Wassink 1982).

the case of forests, eco-labels like Forest Stewardship Council certify that firms leave resources behind for regeneration and future sustainable harvesting. While firm participation in eco-certification programs is voluntary, firms typically earn a higher price in the eco-certified market relative to the conventional market. The higher price may come from consumers in the eco-certified market having a higher willingness to pay or it could emerge in equilibrium through feedback between the conventional and certified market.[6]

In recent years, green procurement programs in Europe have grown in importance, foreclosing markets for conventional timber and stimulating European demand for certified timber products (Brusselaers et al. 2017). More formally, in 2003, the European Union (EU) established the Forest Law Enforcement, Governance, and Trade (FLEGT) Action Plan to reduce illegal logging. FLEGT requires imported timber to have a FLEGT license from the exporting country. In Cameroon, most timber is exported either as sawn planks or logs and graded into different levels of quality. Formal FLEGT negotiations between Cameroon and the EU began in 2007 and were finalized in 2011. Before 2011, Cameroon had not signed a Voluntary Partnership Agreement and was unable to issue FLEGT licenses. In order to access EU markets, Cameroonian timber needed independent certification of timber legality.

The Cameroon timber market is characterized by heterogeneous harvesting costs across forests. Extraction cost varies across forests in Cameroon for several reasons. First, some forests are further from export terminals, which increases transportation costs. Second, some forests receive greater rainfall than others, compressing the timber extraction season, increasing material costs from equipment break downs, and raising road maintenance costs. Moreover, some forests are bisected by rivers and waterways, which require additional road planning, construction, and maintenance to bypass or bridge.

Accounting for heterogeneous harvesting costs across forests is important for understanding the performance of eco-certification standards. Doremus (2018) presents evidence that the cost

[6] Though there may be some variation in willingness-to-pay across countries, the fact that some consumers have a higher willingness to pay for environmentally friendly commodities is well established; see, for example, Upton and Bass (1996), Mattoo and Singh (1994), and Stevens et al. (1998).

of complying with sustainable harvesting standards is inversely related to extraction costs in the Cameroon timber market, as higher extraction costs imply lower opportunity costs from leaving trees behind.[7]

This paper assesses changes in certified and conventional production in response to Forest Stewardship Council (FSC) Certification in Cameroon. FSC certification is the dominant eco-label used to restrict imports to products from sustainably-managed forests, as well as two weaker labels managed by FSC auditors SGS and Bureau Veritas. FSC certification relies on ten principles and criteria used to evaluate responsible forestry (Forest Stewardship Council 2004), including respect for indigenous use rights, reduced-impact logging practices, and set-aside areas for conservation. Our focus is on the FSC certification requirement for sustainable practices, which requires forest managers to leave behind a sufficient number of trees to allow the forest to regenerate and remain productive in the future.[8] For firms that operate on high-quality land that allows a large number of trees to be extracted, this constraint increases the opportunity cost of participating in the program relative to areas where the terrain favors selective harvesting.

3 Theoretical Model

We consider timber producer incentives to adopt forest management practices in response to import restrictions in industrial countries that segment global demand for timber products into two, distinct markets: (i) a "green market" for certified wood that prohibits the sale of unsustainable forest products to consumers in the regulated country; and (ii) a "conventional market" for uncertified wood comprised of buyers outside the regulated country that continue

[7]Doremus (2018) assigns each forest a score that relates their harvesting costs to the overall distribution of harvesting costs among forests in Cameroon and Gabon.

[8]We focus on quantity effects in certified and conventional forests in this paper. Negative spillovers to conventional forests are less likely for other dimensions of the FSC standard, e.g. reduced-impact logging. Improved harvesting practices may be a source of significant environmental benefits for tropical forests given that the returns to reduced-impact logging are low in the tropics (Putz et al. 2000).

to accept wood from forests using unsustainable practices. Given that the import restriction makes trade of uncertified timber products illegal in the regulating country, the effect of the policy is to create regionally distinct markets for certified and conventional products.[9]

The supply-side of the model is comprised of a large number of firms that compete in a Cournot oligopoly market. Timber harvesting firms have heterogeneous costs of timber extraction due to topographical differences such as contour and slope that vary across land parcels. Each firm i has constant marginal cost of production represented by the parameter c_i, which is unknown to rivals' but drawn from a known cost distribution, $G(c)$ on the support $[c_0, c_M]$. The number of timber-producing firms is fixed at N, and we confine attention to cases in which entry is not possible, for instance when timber resources are harvested on finite plots of land that vary cross-sectionally in terms of land quality.

We compare forest resource allocations in two different oligopoly regimes: (i) a pooling equilibrium in which certification is not possible; and (ii) a separating equilibrium in which individual firms select whether or not to certify and a positive number of firms produces for each market segment. As we discuss below, meeting the certification standard provides firms access to the restricted green market, where consumers potentially have higher willingness to pay for certified wood products, but require firms to incur eco-certification costs.

In general, eco-certification segments heterogeneous distributions of both consumers and firms across the two markets. Here, because the effect of the import restriction is to eliminate sales of uncertified timber in the restricted consumer market, we suppress variation in consumers' valuations for the certified attribute and consider a representative consumer model to describe demand in the globally segmented market.[10] The eco-certification requirement by

[9] We suppress the possibility of fraudulent sales of non-certified wood in the foreign market as in Hamilton and Zilberman (2006) and limit attention to cases in which the price of certified wood remains higher than the price of uncertified wood. While illegal logging often coexists with formal industrial logging in tropical forests, the magnitude of illegal production is smaller when allowable forest practices are stipulated in forest concessions (Cerutti and Tacconi 2008).

[10] Symmetric utility for green and conventional consumers ensures that our results on the market segmentation effect of global eco-certification standards are not driven by demand differences between domestic and foreign consumers.

an importing country segments the consumer market into two distinct markets in which an exogenous fraction of "green" consumers in the restricted market consume only certified timber, while the remaining consumers in the unrestricted market are free to consume uncertified timber.

Firms select between the markets based on relative prices and compliance costs. Models of eco-label competition have demonstrated that firms with lower compliance costs to participate in certification programs while firms with higher compliance costs do not (Fischer and Lyon 2014; Li and van't Veld 2015). For the case of timber harvesting in Cameroon, (Doremus 2018) provides empirical support for selection into forest certification programs based on relative harvesting costs.

Consider a frictionless global economy with a mass of L consumers that inelastically supply one unit of labor. Labor is the only factor of production, which is used to produce a numeraire good with constant returns to scale technology. We normalize marginal cost to 1 and interpret our results in terms of a unit wage.

The utility function for the representative consumers is

$$U = q_0 + \alpha q - \frac{1}{2}\beta q^2 \tag{1}$$

where q_0 and q represent the individual consumption levels of the numeraire good and of timber, respectively, and α and β are positive constants. Utility function (1) differs from the typical utility function in the eco-certification literature in which consumers are distributed vertically on a unit line according to the strength of their preferences over the certified attribute and only consume one unit of the good.[11] Here, because our focus is on how import restrictions alter harvest incentives among forest managers by segmenting global demand, we focus the model on segmentation effects by modeling a representative consumer in the global timber market.

[11] See for example, Chen (2001), Zago and Pick (2004), and Walter and Chang (2017).

3.1 Pooling Equilibrium

Consider first the case in which firms cannot certify. Absent certification, all consumers purchase timber from a common, global market, which yields the inverse demand function $P = \alpha - \frac{\beta}{L}Q$, where Q is aggregate quantity.

Following Lepore (2008), the equilibrium best response function for firm i is

$$q_i = L\left[\frac{\alpha - c_i}{2\beta}\right] - \frac{1}{2}\mathbb{E}\left[Q_{-i}\right], \tag{2}$$

where $\mathbb{E}\left[Q_{-i}\right]$ is firm i's expectation of his rivals' output levels. Since each firm's cost is independently drawn, by symmetry we have

$$\mathbb{E}\left[Q_{-i}\right] = L\left(\frac{N-1}{N+1}\right)\left(\frac{\alpha - \mathbb{E}[c]}{\beta}\right). \tag{3}$$

Substituting equation (3) into (2), the equilibrium quantity of firm i, the expected market quantity, and the expected market price are

$$q_i = \frac{L}{\beta}\left[\frac{\alpha - \bar{c}}{(N+1)} + \frac{\bar{c} - c_i}{2}\right] \tag{4}$$

$$\mathbb{E}[Q] = L\left(\frac{N}{N+1}\right)\left(\frac{\alpha - \bar{c}}{\beta}\right) \tag{5}$$

$$\mathbb{E}[P] = \left(\frac{\alpha + N\bar{c}}{N+1}\right). \tag{6}$$

respectively. To ensure each firm produces in equilibrium, we restrict the marginal cost of the least efficient firm, c_N, to be less than the market price, $\mathbb{E}[P] > c_N$. It follows that $\alpha > N(c_N - \bar{c}) + c_N$.

3.2 Separating Equilibrium

Now consider an import restriction that creates two markets for timber, one that accepts only certified products (C) and one that remains uncertified (U). Let ψ denote the proportion of consumers residing in the green region, so that ψL consumers are required to purchase certified timber, while the remaining population, $(1-\psi)L$ purchase conventional timber. Substitution between markets is not permissible, because ψ is exogenously determined by the share of consumers residing in the restricted region, and resale of non-certified timber in the certified market is not allowed.[12]

Firms in the separating equilibrium face market demand functions for certified and uncertified timber:

$$\text{Certified} \qquad P_C = \alpha - \frac{\beta}{\psi L} Q_C \tag{7}$$

$$\text{Uncertified} \qquad P_U = \alpha - \frac{\beta}{(1-\psi)L} Q_U. \tag{8}$$

Firms producing for the certified market must meet the certification criteria. Specifically, f a firm chooses to certify, it must agree to produce $q_i^C \leq q^{max}$, where q^{max} is the allowable harvest level under sustainable forest management. We assume that this constraint is binding for at least some low-cost timber producers, which provides, for these firms, a strictly positive opportunity cost to certification. For high-cost timber producers, in contrast, this constraint is slack, resulting in no opportunity cost to certification. To close the model, we assume the quantity constraint on the sustainable harvest level does not bind ex post for firms that choose to certify.[13]

We consider a two-stage certification game. In stage 1, each firm receives a draw of cost and decides whether to certify or not. In stage 2, each firm selects output conditional on the

[12] Note that if we allowed consumers to substitute between conventional and certified products, substitution effects would place additional pressure on the industry to lower equilibrium prices.

[13] Allowing for the possibility of the quantity constraint to bind complicates the analysis by introducing a potential range in which a firm's best response function is nondifferentiable.

certification decision of each firm in stage 1. We solve the model by backward induction and confine attention to pure strategy, subgame perfect equilibrium.

3.2.1 Stage 2

In stage 2, each producer knows the number of certified and uncertified producers that was revealed in stage 1. Each firm does not know rival firm's costs, although all firms know the conditional cost distribution. Following the same solution procedure as above, the equilibrium outcomes are:

$$q_i^U = \frac{(1-\psi)L}{\beta}\left[\frac{\alpha-\bar{c}_U}{(N_U+1)}+\frac{\bar{c}_U-c_i}{2}\right] \tag{9}$$
$$\mathbb{E}[Q_U] = (1-\psi)L\left(\frac{N_U}{N_U+1}\right)\left(\frac{\alpha-\bar{c}_U}{\beta}\right) \tag{10}$$
$$\mathbb{E}[P_U] = \left(\frac{\alpha+N_U\bar{c}_U}{N_U+1}\right) \tag{11}$$

for the uncertified market and

$$q_i^C = \frac{\psi L}{\beta}\left[\frac{\alpha-\bar{c}_C}{(N_C+1)}+\frac{\bar{c}_C-c_i}{2}\right] \tag{12}$$
$$\mathbb{E}[Q_C] = \psi L\left(\frac{N_C}{N_C+1}\right)\left(\frac{\alpha-\bar{c}_C}{\beta}\right) \tag{13}$$
$$\mathbb{E}[P_C] = \left(\frac{\alpha+N_C\bar{c}_C}{N_C+1}\right) \tag{14}$$

for the certified market.

We compare outcomes under an import restriction that segments the certified and uncertified markets and results in a higher equilibrium price of eco-certified wood products relative to the equilibrium price of uncertified wood products.[14]

[14]Implicitly, we assume a sufficiently large share of firms remain uncertified. Alternatively, we could ensure that the price of certified wood products remains higher than the price of uncertified products by selectively raising consumers' valuations for wood products in the restricted market.

3.2.2 Stage 1

Our goal in stage 1 is to characterize the conditional average costs, $\bar{c}_U$ and $\bar{c}_C$. To do so, define the cost level c^* to be the cost of a firm who would, in expectation, be indifferent between certifying and not, so that

$$\mathbb{E}[(P_U - c^*)q_U^*] = \mathbb{E}[(P_C - c^*)q_C^*]. \tag{15}$$

These expected profits are sum of the probability weighted profit for each possible realization of N_U and N_C.

For a firm with cost c^* that chooses to not certify, the expected profit conditional on being uncertified is

$$\begin{aligned}\mathbb{E}[\pi_U^*] = \left(\frac{(1-\psi)L}{\beta}\right)\Bigg[&(1-G(c^*))^{N-1}\left(\frac{\alpha-c^*}{2}\right)^2 \\ &+\sum_{n=1}^{N-1}\Pr((N_U-1)=n)\left(\left(\frac{\alpha+(n+1)\bar{c}_U}{(n+1)+1}\right)-c^*\right)\left[\frac{\alpha-\bar{c}_U}{(n+1)+1}+\frac{\bar{c}_U-c^*}{2}\right]\Bigg]\end{aligned}$$

where

$$\Pr((N_U-1)=n) = \frac{(N-1)!}{n!(N-1-n)!}\left(G(c^*)^n(1-G(c^*))^{N-1-n}\right).$$

Similarly, the expected profit conditional on being certified is

$$\begin{aligned}\mathbb{E}[\pi_C^*] = \left(\frac{\psi L}{\beta}\right)\Bigg[&G(c^*)^{N-1}\left(\frac{\alpha-c^*}{2}\right)^2 \\ &+\sum_{n=1}^{N-1}\Pr((N_C-1)=n)\left(\left(\frac{\alpha+(n+1)\bar{c}_C}{(n+1)+1}\right)-c^*\right)\left[\frac{\alpha-\bar{c}_C}{(n+1)+1}+\frac{\bar{c}_C-c^*}{2}\right]\Bigg]\end{aligned}$$

where

$$\Pr((N_C-1)=n) = \frac{(N-1)!}{n!(N-1-n)!}\left(G(c^*)^{N-1-n}(1-G(c^*))^n\right).$$

To characterize c^*, we assume that $q^{max} \geq \frac{(\alpha-c^*)}{2}$ and that ψ and $G(c^*)$ are such that

$\mathbb{E}[\pi_U(c_0)] > \mathbb{E}[P_C]q^{max}$.[15] We can now state the equilibrium conditional average costs as

$$\bar{c}_U = \frac{1}{G(c^*)} \int_{c_0}^{c^*} c dG(c) \tag{16}$$

$$\bar{c}_C = \frac{1}{1 - G(c^*)} \int_{c^*}^{c_M} c dG(c). \tag{17}$$

3.3 Comparing the Two Equilibrium

We confine our comparison to cases in which $N_C,\ N_U \geq 1$. To see how an import restriction that mandates certified wood products affects firm output decisions, consider the equilibrium quantity of an arbitrary firm in each market,

$$q_i^U = \frac{(1-\psi)L}{2\beta}\left[\frac{\alpha + (N_U - 1)\bar{c}_U}{(N_U + 1)} - c_i\right]$$

$$q_i^C = \frac{\psi L}{2\beta}\left[\frac{2\alpha + (N_C - 1)\bar{c}_C}{(N_C + 1)} - c_i\right].$$

Comparing output levels with the no-certification equilibrium output level (4), there are three effects driving the output decision with segmented global markets for certified and uncertified products:

(1) *Demand* effect: Market size decreases from L to $(1-\psi)L$ or ψL, so that $q_i^U \downarrow$ and $q_i^C \downarrow$.

(2) *Competition* effect: The number of firms serving the market decreases from N to N_U or N_C, which means $q_i^U \uparrow$ and $q_i^C \uparrow$.

(3) *Selection* effect: High cost firms certify, such that $\bar{c}_U < \bar{c} < \bar{c}_C$, and this implies $q_i^U \downarrow$; and $q_i^C \uparrow$.

In Figure I, we illustrate the quantity choice of firms with given parameterizations of cost in the market equilibrium with no certification and certification. Notice that market

[15] This rules out the possibility of mixed strategy equilbria and maintains well-defined best response functions in the continuation game.

segmentation shifts production across firms in each segment from the no-certification line, with high cost firms increasing production relative to their pre-certification level and low cost firms decreasing production relative to their pre-certification level in each market segment. This creates discontinuity in the output choices of firms under certification. Total timber production goes up in response to mandatory eco-certification in one region when the area under the dotted line is greater than the area under the no-certification line.

We next classify weak conditions under which an import restrictions to purchase only certified products in one region increases the rate of resource extraction in the producing industry. We consider the effect of market size in the restricting region and then consider the effect of competitive density in the producing region. In each case, we focus our attention on outcomes that satisfy $\mathbb{E}[P_U] \leq \mathbb{E}[P_C]$, so that producers do not have an incentive to sell certified wood products to consumers in the uncertified market.[16]

3.3.1 Market Size

Proposition 1. *There exists a $\psi > 0$ such that the quantity of uncertified firms increases.*

Proof. Suppose firm i has a cost $c_i \leq c^*$, then the change in its quantity is

$$\Delta q_i^U = q_i^U - q_i = \frac{(1-\psi)L}{\beta}\left[\frac{\alpha - \bar{c}_U}{(N_U+1)} + \frac{\bar{c}_U - c_i}{2}\right] - \frac{L}{\beta}\left[\frac{\alpha - \bar{c}}{(N+1)} + \frac{\bar{c} - c_i}{2}\right] \tag{18}$$

Equation (18) is positive if and only if

$$\psi < \frac{2N_C\alpha + (N+1)(N_U-1)\bar{c}_U - (N-1)(N_U+1)\bar{c}}{(2\alpha + (N_U-1)\bar{c}_U - (N_U+1)c_i)(N+1)} = \hat{\psi}_U \tag{19}$$

Note that the denominator is always positive (given that each firm produces a positive amount) and the numerator is always positive if $N_C \geq 1$. Furthermore, when $N_C = 1$, $N_U = N - 1$

[16] It is straightforward to show that this condition holds in our model whenever $N_C \leq$N$_U$.

and we evaluate at the lower bound of α:

$$\hat{\psi}_U = \frac{2c^* + (N+1)\left[2(c_M - \bar{c}_U) - N(\bar{c} - \bar{c}_U)\right]}{(2\alpha + (N-2)\bar{c}_U - Nc_i)(N+1)}$$

where c_M is the upper bound of the cost distribution. As $\psi \to 0$, it follows that $\hat{\psi}_U > 0$. Thus, by continuity there exists a $0 < \psi < \hat{\psi}_U$. □

Proposition 1 reveals that there is a ψ such that the competition effect outweighs the demand and selection effects of eco-certification, resulting in greater harvest rates for firms serving the uncertified market. In the certified market:

Proposition 2. *There exists a ψ large enough such that certified firms increase quantity.*

Proof. Note that

$$\Delta q_i^C = q_i^C - q_i = \frac{\psi L}{\beta}\left[\frac{\alpha - \bar{c}_C}{(N_C+1)} + \frac{\bar{c}_C - c_i}{2}\right] - \frac{L}{\beta}\left[\frac{\alpha - \bar{c}}{(N+1)} + \frac{\bar{c} - c_i}{2}\right] \tag{20}$$

Thus, $\Delta q_i^C > 0$ if and only if

$$\psi > \left(\frac{N_C+1}{N+1}\right)\left(\frac{2\alpha + (N-1)\bar{c} - (N+1)c_i}{2\alpha + (N_C-1)\bar{c}_C - (N_C+1)c_i}\right) = \hat{\psi}_C. \tag{21}$$

Note further that, because $\bar{c} < \bar{c}_C$,[17]

$$\frac{d\hat{\psi}_C}{dN_C} = \left(\frac{2(\alpha - \bar{c}_C)\left[2\alpha + (N-1)\bar{c} - (N+1)c_i\right]}{(N+1)\left[2\alpha + (N_C-1)\bar{c}_C - (N_C+1)c_i\right]^2}\right) > 0, \text{ and} \tag{22}$$

$$\hat{\psi}_C\Big|_{N_C=N} = \left(\frac{2\alpha + (N-1)\bar{c} - (N+1)c_i}{2\alpha + (N-1)\bar{c}_C - (N+1)c_i}\right) < 1. \tag{23}$$

□

[17] Strictly speaking, N_C is a discrete variable, so equation (22) along with additional comparative statics effects that follow regarding the number of firms should be interpreted as totally differentiating a function that interpolates our equation for the change in firm quantity. This does not pose a significant concern given the monotonicity of the functions.

Proposition 2 reveals that for any realization of N_C, it is possible for the selection and competition effects to outweigh the demand effect. Propositions 1 and 2 hold for any arbitrary cost distribution.

3.3.2 Competitive Density

Our data contain considerable variation in the number of firms harvesting each timber species. In this Section we consider the effect of variation in the number of producing firms, N. To do so, consider how N affects the identity of the marginal firm c^*, which we express in the following Lemma 1:

Lemma 1. *If* $G(c^*) > \frac{1}{2}$, *then* $\frac{\Delta c^*}{\Delta N} < 0$.

Proof. When $G(c^*) > \frac{1}{2}$, the probability of realizing a state of the world with low price competition and relatively high profit increases when the marginal firm chooses to certify. To see this, compare the relative probability of each respective state of the world:

$$\begin{aligned}\frac{\Pr((N_U - 1) = n)}{\Pr((N_C - 1) = n)} &= \frac{\frac{(N-1)!}{n!(N-1-n)!}\left(G(c^*)^n(1 - G(c^*))^{N-1-n}\right)}{\frac{(N-1)!}{n!(N-1-n)!}\left(G(c^*)^{N-1-n}(1 - G(c^*))^n\right)} \\ &= \left(\frac{(1 - G(c^*))}{G(c^*)}\right)^{N-1-2n}.\end{aligned}$$

Thus, for the original firm with cost c^*, $\mathbb{E}[\pi_U^*] < \mathbb{E}[\pi_C^*]$ when N increases to $N + 1$, causing the firm to certify. Therefore, $\frac{\Delta c^*}{\Delta N} < 0$. □

The condition $G(c^*) > \frac{1}{2}$ ensures that a sufficiently large number of firms choose not to certify in equilibrium.[18] Lemma 1 allows us to isolate and investigate the effect of N on the selection and competition effects. Provided N is differentiable, this results in the following proposition:

[18]While it is clear that $G(c^*)$ is endogenous, an interpretation of this condition is that ψ can not be *too* large.

Proposition 3. *If $G(c^*) > \frac{1}{2}$, a decrease in the number of firms serving a market causes certified firms to increase quantity, while uncertified can increase or decrease quantity.*

Proof. The impact of a change in the number of firms serving the market on firm output levels can be decomposed into the selection effect and competition effect of an import restriction. First, consider the selection effect in isolation, holding N_U and N_C fixed. Noting that $\frac{d\bar{c}_U}{dc^*} > 0$ and $\frac{d\bar{c}_C}{dc^*} > 0$ by definition, the selection effect is

$$\frac{dq_i^U}{dN} = \frac{(1-\psi)L}{\beta}\left[\frac{(N_U-1)}{2(N_U+1)}\frac{d\bar{c}_U}{dc^*}\frac{dc^*}{dN}\right] < 0 \tag{24}$$

$$\frac{dq_i^C}{dN} = \frac{\psi L}{\beta}\left[\frac{(N_C-1)}{2(N_C+1)}\frac{d\bar{c}_C}{dc^*}\frac{dc^*}{dN}\right] < 0. \tag{25}$$

where the signs hold by Lemma 1.

Next consider the competition effect. Expressing the expected number of firms in each market as $\mathbb{E}[N_U] = NG(c^*)$ and $\mathbb{E}[N_C] = N(1-G(c^*))$, we have

$$\frac{d\mathbb{E}[N_U]}{dN} = G(c^*) + Ng(c^*)\frac{dc^*}{dN} \gtreqless 0$$

$$\frac{d\mathbb{E}[N_C]}{dN} = (1-G(c^*)) - Ng(c^*)\frac{dc^*}{dN} > 0,$$

where the signs hold by Lemma 1. Holding $\bar{c}_U$ and $\bar{c}_C$ fixed, it follows that changes in the number of firms serving the market affect the competition effect of an import restriction as

$$\left.\frac{dq_i^U}{dN}\right|_{\bar{c}_U \text{ fixed}} = -\frac{(1-\psi)L}{\beta}\left[\frac{(\alpha-\bar{c}_U)}{(\mathbb{E}[N_U]+1)^2}\frac{d\mathbb{E}[N_U]}{dN}\right] \lesseqgtr 0 \tag{26}$$

$$\left.\frac{dq_i^C}{dN}\right|_{\bar{c}_C \text{ fixed}} = -\frac{\psi L}{\beta}\left[\frac{(\alpha-\bar{c}_C)}{(\mathbb{E}[N_C]+1)^2}\frac{d\mathbb{E}[N_C]}{dN}\right] < 0. \tag{27}$$

Combining effects completes the proof. □

Proposition 3 shows the effect of the degree of competition on the output effect of eco-certification. For forest species that are served by a sufficiently large number of firms, N, forests that certify reduce their harvest levels after certification, while forest certification causes firms to increase their harvest levels for forest species in less competitive markets served by a smaller number of firms.

4 Empirical Analysis

Under various parameterizations of the model, both certified and conventional firms increase production in response to an import restriction mandating eco-certification. In this Section, we conduct empirical analysis to explore output effects among timber producers in Cameroon following forest certification standards imposed by importers in the EU. Specifically, we test predictions from our theoretical model by examining quantity changes for certified forests and marginal conventional forests, which are forests that continue to harvest using conventional techniques but are adjacent in compliance costs to the switching margin for eco-certification. Our empirical approach exploits variation in species range that affects competition density, N, which allows us to examine how production changes for marginal conventional forests and certified forests across forest species that vary in the degree of competition.

4.1 Data

We rely on three sources of data to empirically test the predictions of the model: (i) production data, (ii) certification data, and (iii) predicted forest cost type. We provide detail below on the nature of each type of data.

4.1.1 Production Data

We collect data on forest ownership from the World Resources Institute's Global Forest Watch Atlas for Cameroon, Version 2, which we combine with primary production data from Cameroon's Ministry of Forestry in their Système Informatique de Gestion de l'Information

Forestière (SIGIF). Within these data, a total of 74 tree species satisfy the sample criteria detailed below and are included in the analysis.

Each tree species varies in its habitat and distribution across space. As discussed earlier, some species have a patchier or wider distribution than others, creating exogenous variation in the number of forest producers harvesting the species that leads to differing levels of competition by species type. For each tree species, we calculate the number of forests producing the species in 2004, prior to eco-certification. Figure III plots the frequency distribution of the degree of competition, measured in the number of rivals serving the market for each tree species prior to eco-certification. We define a species as having a high degree of competition if it has more than 40 forests producing in 2004.[19] Approximately 25% of all species satisfy this criterion for a highly-competitive market.

4.1.2 Forest Certification Data

Certification occurs at the forest level. Each forest's certification timeline comes from World Resources Institute's Forest Atlas for Cameroon, Version 2. The first forest in Cameroon certifies in 2005, after which certification rolls out among forests.[20] Because species' ranges and distribution patterns differ, not all forests produce all species. This feature of our data creates exogenous variation at the species-level in the timing of market segmentation at the point in which firms exit the conventional market and enter the certified market for a given tree species.

4.1.3 Predicted Forest Type

Theoretical models of certification predict that firms sort into certification based on their cost of compliance, which is inversely-related to marginal extraction costs (Fischer and Lyon 2014; Li and van't Veld 2015). Empirically, Doremus (2018) tested whether this outcome holds for

[19]In practice, the number of firms that sell the species does not vary substantially across the panel, as we would expect if ecological distribution limits market access. Results are robust to using cutoffs of 30 and 50.

[20]see Doremus (2018) for more details on roll out timing.

timber firms in Cameroon and found evidence that firms sort into strong and weak certification programs according to differences in marginal extraction costs. Evidence in pollution control and other settings is also consistent with firm sorting by cost.[21]

For our empirical analysis, we examine changes in production levels following certification for three forest types. We refer to conventional forests as those with the lowest extraction costs, marginal conventional forests as those with higher marginal costs of extraction, but which do not certify, and certified forests as those with the highest extraction costs. These three types of firms correspond to the regions defined by the cutoff points in Figure I.

To identify forest type, we use the predicted forest type score from Doremus (2018), which uses geospatial data corresponding to sustainable harvesting costs to predict forest type. [22] We define Marginal Conventional Forests as those with a forest type score between the certified firm cutoff and 10% below the cutoff.[23] Conventional Forests are those with a score below the Marginal Conventional Forest cutoff (i.e., more than 10% below the certification cutoff), while Certified Forests are those that are observed to certify.

We aggregate the production data from the forest-species-year level to the forest type-species-year level for three reasons. First, this is the most useful level in regard to our model's predictions. The model predicts increases in production for forests with the highest marginal costs. This breakdown gives us a group with little change, on average (Conventional), expected increases (Marginal Conventional) and an ambiguous net effect effect (Certified). Second, for our empirical analysis we need a control group that fails to change in response to treatment. By aggregating Conventional Forests, we create a control group that does not change in response to certification, even if some individual forests do respond. Third, because tree

[21]For example, high emissions predict participation in voluntary pollution abatement programs, e.g. Gamper-Rabindran (2006), which may be because these firms use older pollution abatement technology that is cheaper to replace. Likewise, more frequent inspections by regulators predicts participation, e.g. Blackman et al. (2010), and regulators tend to target inspections to firms with low marginal abatement costs (Hanna and Oliva 2010).

[22]Sustainable harvesting costs can be grouped into five categories: opportunity cost; careful harvesting; administrative; development; and conservation. Of these, opportunity cost was shown to be the most important factor predicting certification.

[23]Results are robust to larger and smaller windows for the cutoffs for marginal conventional forest.

species distribution is random and some species have very low density production at the forest level is sparse. Aggregating our data to Conventional, Marginal Conventional, Certified forest types has the added advantage of allowing us work with a balanced panel. Our aggregation results in up to three observations per species per year. Finally, we restrict the analysis to forest type-species pairs with positive production each year, resulting in 1,554 observations.

4.2 Empirical Framework

The goal of the empirical analysis is to validate the theoretical model and assess whether the competition effect is important in the context of timber production in Cameroon. Under reasonably weak conditions on the market size of countries imposing import restrictions, timber harvest rates may increase for marginal conventional forests (Proposition 1) and for certified forests (Proposition 2) in response to eco-certification requirements that foreclose import markets to uncertified wood products. Moreover, we expect harvest rates to increase post certification for forest species produced in markets served by a small number of firms relative to markets with a high degree of competition.

We follow a difference-in-differences empirical design using a fixed effects OLS regression framework. Our treatment is market segmentation, which occurs after one or more forests producing the species chooses to certify. Our control group is the set of firms with the lowest extraction costs below the certification cutoff. As seen in Figure I, the average among these firms is not expected to differ after market segmentation.[24] Thus, the counter-factual is that Marginal Conventional and Certified production would have moved similarly to Conventional forests, absent certification/

We estimate the change in production for Certified and Marginal Conventional forests after the first firm producing that species certified, e.g. after the market is segmented. Specifically,

[24]Changes after certification by lowest cost firms risks violating the stable unit treatment value assumption. We discuss this threat to identification in the next section and test for it in Table A1.

we estimate the following regression

$$y_{fst} = \beta_0 Marginal_{fs} * Segmented_{st} + +\beta_1 Certified_{fs} * Segmented_{st} + \alpha_{fs} + \gamma_{st} + \delta_t + \epsilon_{fst} \tag{28}$$

where s indicates a species, f a forest type, either Conventional, Marginal Conventional, Certified, and t the year. Fixed effects are at the forest type-species level, α_{fs}, and we include year dummies δ_t and, in certain specifications, species trends γ_{st}. Species trends allow us to relax our identifying assumption, as discussed in greater detail below, by allowing time trends to vary across species. Standard errors are clustered by forest type.

We introduce the dummy variable $LowCompetition_s$ to indicate markets that are not highly competitive. That is, according to our criteria on highly-competitive markets, $LowCompetition_s$ indicates a market in which fewer than 40 firms sell the species prior to eco-certification. We add interactions to Equation (28) to get

$$\begin{aligned} y_{fst} = {} & \beta_0 Marginal_{fs} * Segmented_{st} + \beta_1 [Marginal_{fs} * Segmented_{st} * LowCompetition_s] \\ & + \beta_2 Certified_{fs} * Segmented_{st} + \beta_3 [Certified_{fs} * Segmented_{st} * LowCompetition_s] \\ & + \alpha_{fs} + \gamma_{st} + \delta_t + \epsilon_{fst} \end{aligned} \tag{29}$$

This specification allows us to compare changes for species in less competitive markets relative to outcomes in highly-competitive markets.

4.2.1 Identifying Assumption

Our baseline specification compares output changes after certification across species within a forest type. Thus, the counterfactual is that for treated forest types, changes in species production would have mirrored those of the lowest cost firms after market segmentation. Our identifying assumptions are that production in low and high cost forests have parallel trends prior to market segmentation and that average production among low cost forests does not change in response to market segmentation.

Figure Figure IV uses an event study design to look for evidence regarding our first identifying assumption, that of parallel trends. We estimate the following regression specification

$$y_{fst} = \sum_{k=-3}^{3} \gamma_k \{K_{fst} = k\} + \gamma_{K-} 1\{K_{fst} \leq -4\} + \alpha_{fs} + \delta_t + \epsilon_{fst} \tag{30}$$

The regression includes leads for 3 periods before as well as a single coefficient γ_{K-} for 4 or more periods before treatment. We group Marginal Conventional and Certified forests as treated because their responses move in the same direction.[25] We fail to find evidence of trends prior to treatment. As another robustness check, we relax the first identifying assumption by including species-trends in each regression specification. Species-trends allow the pattern for each species to vary across the panel. In this case, our identifying assumption is that there is no discontinuous change in trend at the time of treatment.

Our second identifying assumption is that, on average, low cost forests do not change production after market segmentation. Our model predicts that, among conventional forests, the lowest cost firms will decrease production and the highest cost firms will increase production (see Figure I). We aggregated forests to three forest types, so that we compare Marginal Conventional Forests and Certified Forests to the lowest cost forests. We did this because, on average, production does not change across the lowest cost forests. To test whether these forests change production after certification, we run a regression with only this forest type, fixed effects, year effects and the $MarketSegmentation$ indicator variable. Results are reported in Appendix Table A1. We fail to find a change in production after market segmentation for these forests.

[25]Results are robust to breaking each group out.

4.3 Results

Table 2 reports results from eight fixed effects panel regressions estimated via OLS. The unit of observation is at the forest type-species-year level. The outcome variable is average firm production in the top panel and total production by forest type in the bottom panel. Columns two and four include species trends.

We focus first on the response by firms with the highest extraction costs, those that certify. Columns one and two show that, across species, average and total production for firms that certify increases after entry into the certified market. Higher total and average production implies a non-binding harvesting constraint, which is consistent with Doremus (2015). An increase in production is contrary to the goals of sustainable harvesting. Yet as we saw in Proposition 2, under weak conditions we might expect an increase in production by certified firms.

In the eco-certification literature, theoretical models have focused on improvements in the production process and restricted production to a single unit (Li and van't Veld (2015); Fischer and Lyon (2014); Amacher et al. (2004)). Our model allows for quantity effects on individual units of land, which highlights dynamic externality effects of unsustainable harvest rates for tropical forest resources.

We turn next to the response by Marginal Conventional Forests, which are those forests closet to the certification threshold among conventional forests in terms of extraction costs. For these forests, we find total production increases following market segmentation when competing, high-cost firms switch into the certified market. The change in average production is also positive, although the estimate has precision only in the specification with species trends. Proposition 2 shows that high cost conventional firms increase production after certified firms exit the market under relatively weak regularity conditions, and our empirical findings support this prediction.

Our findings highlight the fact that segmenting markets through eco-certification standards via import restrictions in industrial countries can result in increased production in uncertified markets. As in the case of certified production, these adverse quantity effects emerge naturally in a Cournot model with heterogeneous marginal harvesting costs. In the case of Cameroon timber production, our findings reveal that modeling quantity effects is essential. Our results are broadly consistent with predictions by Brusselaers et al. (2017) in response to green procurement programs in Europe.

Columns three and four of Table 2 present thge results of our specification with interaction terms on the degree of competition in the market. Recall that there are three competing effects from market segmentation: a reduction in demand, a reduction in competition, and a reallocation of effort in response to changes in the distribution of firm costs in each market. Proposition 3 predicts that certifying firms increase harvest rates post certification for tree species sold in less competitive markets. The interaction terms test this prediction by showing the differential effect of market segmentation for species with fewer producers. Notably, we find that the increase in production is driven by increases in production of species in less competitive markets for both Certified and Marginal Conventional forests.

Next, we turn to Figure IV to check the robustness of these results. Because the Certified and Marginal Conventional forests move in the same direction, the figure shows the differential effect for less competitive species for either forest type. The event study specification allows us to identify whether pre-trends are driving the effect and investigate the pattern of the response to certification across time. Consistent with the table, where estimates were stable when including trends, we fail to find evidence that pre-trends are driving our results. Before the market segments, the estimates hug the zero line. One year after market segmentation, production increases and the increase is persistent.

A delayed response to market segmentation could be driven by three things. First, firms may exit the conventional market and enter into the certified market later in the year, after the bulk of harvesting has occurred. Second, orders for certified timber may not begin until after certification. Third, we have aggregated forests across forest type, so that within the Certified forest type for each year there are forests that have not yet certified but who subsequently certify in the following year or two.

4.4 Welfare Implications

Import restrictions that require eco-certification on imported wood products are ostensibly designed to increase the sustainability of global timber harvesting. As such, the goal of eco-certification restrictions is to address two negative externalities: the dynamic opportunity cost of excessive present consumption and, conditional on the quantity harvested, the marginal external damages associated with unsustainable harvesting practices. The main contribution of our theoretical model is to try to capture both of these effects by allowing for quantity competition and heterogeneous firm costs. Our main finding is that market segmentation led to increased production by high cost forests that certify in Cameroon, particularly in less competitive markets. In this section we explore three potential implications for welfare.

First, we find evidence that the total quantity harvested increased for many tree species after market segmentation, despite the policy goal of reducing total extraction. This is consistent with the finding of Doremus (2015) that certification harvesting restrictions are non-binding due to firms gaming the policy. Given non-binding harvesting restrictions and feedback between certified and conventional markets, market segmentation may lead to no change or even an increase in production. Blackman et al. (2010) reports a similar finding in Mexico in which deforestation rates fail to decrease after firms certify using a matching strategy. One potential explanation is that comparison forests *and* certified forests may on average fail to decrease or even increase harvest rates after eco-certification policy segments the global market.

Second, our findings suggest that market segmentation led to increased harvest rates among forests with higher marginal extraction costs. Ignoring, for the moment, variation in marginal damages from extraction, if we focus instead on just the firm's private extraction costs, market segmentation served to reallocate production in Cameroon to forests with higher private extraction costs. This is inefficient.

Finally, it is helpful to consider variation in marginal damages from extraction across forested areas and how market segmentation shifts production among forests. Marginal damages from extraction come from forest fragmentation, habitat loss for high conservation value areas, soil loss, and water pollution from sedimentation. Based on the findings of Doremus (2018), the forests that certify tend to be further from port, have lower conservation value, have more rivers and waterways, and have less extreme topography, implying that an increase in production in these forests has mixed effects in terms of changing the overall marginal damage of production. Increased production by certifying forests may increase forest fragmentation, since these forests tend to be further from the port, contain more intact concentrations of species, and have more varied topography. Moreover, soil loss and water pollution may worsen, because these forests tend to contain more waterways. These features of certified forests are likely to be associated with higher marginal damages from production when firms increase harvest rates in response to certification. However, less extreme topography, less gorilla habitat, and greater distance to protected areas imply less soil erosion from harvesting on hillsides and a smaller loss, in terms of habitat conservation. Thus, the net effect of market segmentation from import restrictions on marginal damages is ambiguous and deserving of further study.

5 Conclusion

Market-based policies in industrial countries that mandate sustainable production techniques with the use of eco-labels have the potential to address chronic over-exploitation of natural resources. Such polices have been proposed to achieve global environmental objectives for fisheries (Smith et al. 2010) and timber resources (Agrawal et al. 2008), as wealthy countries increasingly rely on import restrictions to mandate certification as a condition for market access. In this paper, we model how entry into a certified timber market - and thus exit from the conventional timber market - segments the global markets for the resource-intensive good, altering harvest incentives in both certified an uncertified markets.

Our results reinforce the predictions of Mattoo and Singh (1994), Sedjo and Swallow (2002), and Zago and Pick (2004), who observed that certification differentiates the renewable resource market, potentially increasing production in an imperfectly competitive market. Our theoretical contribution is to allow for market power, cost heterogeneity and asymmetric information among firms producing resource-intensive goods. This structure allowed us to characterize the main mechanisms driving an increase in production and highlight features of the market that result in increased harvest rates for certified production in response to market segmentation. Our model reveals the potential for a fundamental market failure from import restrictions, both through shifts in production from low-cost to higher cost producers and from increased harvest pressure on the underlying natural resource in producing regions. We provide evidence that import restrictions that limit purchases to eco-labeled wood products in restricting countries result in segmented global market demand, relaxed competition, and production reallocation from low-cost to relatively high cost firms producing on marginal forest lands in Cameroon.

Given that the change in production depends on parameter values, our empirical analysis characterized changes in conventional and certified timber production in Cameroon. Using panel data over the period 2003-2009, an interval in which a large number of forests became certified, we provide evidence that production increased for certifying firms, particularly for species with weaker competition, in response to market segmentation.

Our analysis fills a critical gap in the literature by empirically estimating the mechanisms through which eco-labels change output, an area dominated to date by theoretical work (Bonroy and Constantatos 2014). Understanding these effects is essential to better predict global environmental outcomes under eco-label import restrictions by industrial countries and has applications in other segmented markets. In the case of fisheries, Hallstein and Villas-Boas (2013) find that total fish consumption fell by 15 percent after a supermarket labeled fish with a traffic-light system for sustainable harvest; however, sales of the most ecologically over-exploited species did not change. Similar results have been found for carbon labels (Kortelainen et al. 2016) and junk food in the UK (Sacks et al. 2009) in supermarkets in the UK. Our model helps explain why using eco-labels to segment markets may fail to contribute overall to sustainable production goals. Moreover, the magnitude of our estimation results suggest that this failure, at least in the case of forest management practices in Cameroon, is empirically relevant.

Our attention in this study is limited to timber production in Cameroon, a region with high biodiversity and a large share of certified forests. Our focus on a single country, using detailed panel data, complements the work of Brusselaers et al. (2017), who use a simultaneous equation approach to model changes in global certified and conventional timber supply in response to green procurement programs in Europe and North America.[26] Together, our work suggests that eco-certification increases production for species where certified demand is high and shifts production and consumption of conventional timber, potentially increasing production in areas like tropical forests, where marginal environmental damages from additional exploitation are high.

[26]Brusselaers et al. (2017) predict a global decrease in conventional timber, with a particularly large decrease in Africa. Here our results differ in the sense that we find increased conventional production by some firms in markets with high certified demand. We document a shifting of production across forests, within a country.

References

Agrawal, Arun, Ashwini Chhatre, and Rebecca Hardin, "Changing Governance of the World's Forests," *Science*, 2008, *320* (5882), 1460–1462.

Amacher, Gregory S, Erkki Koskela, and Markku Ollikainen, "Environmental quality competition and eco-labeling," *Journal of Environmental Economics and Management*, 2004, *47* (2), 284–306.

Asner, Gregory P., Thomas K. Rudel, T. Mitchell Aide, Ruth Defries, and Ruth Emerson, "A Contemporary Assessment of Change in Humid Tropical Forests," *Conservation Biology*, 2009, *23* (6), 1386–1395.

Blackman, Allen, Bidisha Lahiri, William Pizer, Marisol Rivera Planter, and Carlos Muñoz Piña, "Voluntary environmental regulation in developing countries: Mexico's Clean Industry Program," *Journal of Environmental Economics and Management*, 2010, *60* (3), 182–192.

Bonroy, Olivier and Christos Constantatos, "On the economics of labels: How their introduction affects the functioning of markets and the welfare of all participants," *American Journal of Agricultural Economics*, 2014, *97* (1), 239–259.

Brusselaers, Jan, Guido Van Huylenbroeck, and Jeroen Buysse, "Green Public Procurement of Certified Wood: Spatial Leverage Effect and Welfare Implications," *Ecological Economics*, 2017, *135*, 91 – 102.

Cerutti, Paolo Omar and Luca Tacconi, "Forests, illegality, and livelihoods: the case of Cameroon," *Society and Natural Resources*, 2008, *21* (9), 845–853.

Chen, Chialin, "Design for the environment: A quality-based model for green product development," *Management Science*, 2001, *47* (2), 250–263.

Clark, David B, Michael W Palmer, and Deborah A Clark, "Edaphic factors and the landscape-scale distributions of tropical rain forest trees," *Ecology*, 1999, *80* (8), 2662–2675.

Crane, Peter R and Scott Lidgard, "Angiosperm diversification and paleolatitudinal gradients in Cretaceous floristic diversity," *Science*, 1989, *246* (4930), 675–678.

Doremus, Jacqueline M., "Three Essays on the Effectiveness of Voluntary Forest Certification." PhD dissertation, University of Michigan 2015.

_ , "How Does Eco-Label Competition affect Environmental Benefits? The Case of Central Africa's Forests," *Working Paper*, 2018.

Edwards, David P, Joseph A Tobias, Douglas Sheil, Erik Meijaard, and William F Laurance, "Maintaining ecosystem function and services in logged tropical forests," *Trends in Ecology & Evolution*, 2014, *29* (9), 511–520.

Estrada, Alejandro, Paul A Garber, Anthony B Rylands, Christian Roos, Eduardo Fernandez-Duque, Anthony Di Fiore, K Anne-Isola Nekaris, Vincent Nijman, Eckhard W Heymann, Joanna E Lambert et al., "Impending extinction crisis of the world's primates: Why primates matter," *Science Advances*, 2017, *3* (1), e1600946.

Fischer, Carolyn and Thomas P Lyon, "Competing environmental labels," *Journal of Economics & Management Strategy*, 2014, *23* (3), 692–716.

Forest Stewardship Council, "FSC principles and criteria for forest stewardship," *Bonn (Germany): Forest Stewardship Council*, 2004.

Gamper-Rabindran, Shanti, "Did the EPA's voluntary industrial toxics program reduce emissions? A GIS analysis of distributional impacts and by-media analysis of substitution," *Journal of Environmental Economics and Management*, 2006, *52* (1), 391–410.

Gibson, Luke, Tien Ming Lee, Lian Pin Koh, Barry W Brook, Toby A Gardner, Jos Barlow, Carlos A Peres, Corey JA Bradshaw, William F Laurance, Thomas E Lovejoy et al., "Primary forests are irreplaceable for sustaining tropical biodiversity," *Nature*, 2011, *478* (7369), 378.

Hallstein, Eric and Sofia B. Villas-Boas, "Can Household Consumers Save the Wild Fish? Lessons from a Sustainable Seafood Advisory.," *Journal of Environmental Economics and Management*, 2013, *66* (1), 52 – 71.

Hamilton, Stephen F and David Zilberman, "Green markets, eco-certification, and equilibrium fraud," *Journal of Environmental Economics and Management*, 2006, *52* (3), 627–644.

Hanna, Rema Nadeem and Paulina Oliva, "The Impact of Inspections on Plant-Level Air Emissions," *B.E. Journal of Economic Analysis and Policy: Contributions to Economic Analysis and Policy*, 2010, *10* (1).

Heyes, Anthony and Steve Martin, "Social labeling by competing NGOs: A model with multiple issues and entry," *Management Science*, 2016, *63* (6), 1800–1813.

Hubbell, Stephen P, *The Unified Neutral Theory of Biodiversity and Biogeography (MPB-32)*, Princeton University Press, 2001.

John, Robert, James W. Dalling, Kyle E. Harms, Joseph B. Yavitt, Robert F. Stallard, Matthew Mirabello, Stephen P. Hubbell, Renato Valencia, Hugo Navarrete, Martha Vallejo, and Robin B. Foster, "Soil nutrients influence spatial distributions of tropical tree species," *Proceedings of the National Academy of Sciences*, 2007, *104* (3), 864–869.

Kortelainen, Mika, Jibonayan Raychaudhuri, and Beatrice Roussillon, "Effects of carbon reduction labels: evidence from scanner data," *Economic Inquiry*, 2016, *54* (2), 1167–1187.

Laporte, Nadine T, Jared A Stabach, Robert Grosch, Tiffany S Lin, and Scott J Goetz, "Expansion of industrial logging in Central Africa," *Science*, 2007, *316* (5830), 1451–1451.

Lepore, Jason J, "Cournot and Bertrand–Edgeworth competition when rivals' costs are unknown," *Economics Letters*, 2008, *101* (3), 237–240.

Li, Yuanhao and Klaas van't Veld, "Green, greener, greenest: Eco-label gradation and competition," *Journal of Environmental Economics and Management*, 2015, *72*, 164–176.

Manel, Stéphanie, Thomas L. P. Couvreur, François Munoz, Pierre Couteron, Olivier J. Hardy, and Bonaventure Sonké, "Characterizing the Phylogenetic Tree Community Structure of a Protected Tropical Rain Forest Area in Cameroon," *PLOS ONE*, 06 2014, *9* (6), 1–12.

Mattoo, Aaditya and Harsha V Singh, "Eco-labelling: Policy considerations," *Kyklos*, 1994, *47* (1), 53–65.

Meyfroidt, Patrick and Eric F Lambin, "Forest transition in Vietnam and displacement of deforestation abroad," *Proceedings of the National Academy of Sciences*, 2009, *106* (38), 16139–16144.

Pauwelyn, Joost, "Carbon leakage measures and border tax adjustments under WTO law," in Denise Prévost Geert van Calster, ed., *Research Handbook on Environment, Health and the WTO*, Edward Elgar, 2013, pp. 448–506.

Putz, Francis E, Dennis P Dykstra, and Rudolf Heinrich, "Why poor logging practices persist in the tropics," *Conservation Biology*, 2000, *14* (4), 951–956.

Robalino, Juan, Alexander Pfaff, and Laura Villalobos, "Heterogeneous local spillovers from protected areas in Costa Rica," *Journal of the Association of Environmental and Resource Economists*, 2017, *4* (3), 795–820.

Sacks, Gary, Mike Rayner, and Boyd Swinburn, "Impact of front-of-pack 'traffic-light' nutrition labelling on consumer food purchases in the UK," *Health Promotion International*, 2009, *24* (4), 344–352.

Sedjo, Roger A and Stephen K Swallow, "Voluntary eco-labeling and the price premium," *Land Economics*, 2002, *78* (2), 272–284.

Shaked, Avner and John Sutton, "Relaxing price competition through product differentiation," *The Review of Economic Studies*, 1982, pp. 3–13.

Smith, Martin D, Cathy A Roheim, Larry B Crowder, Benjamin S Halpern, Mary Turnipseed, James L Anderson, Frank Asche, Luis Bourillón, Atle G Guttormsen, Ahmed Khan et al., "Sustainability and global seafood," *Science*, 2010, *327* (5967), 784–786.

Stevens, James, Mubariq Ahmad, and Steve Ruddell, "Forest products certification: A survey of manufacturers," *Forest Products Journal*, 1998, *48* (6), 43.

Upton, Christopher and Stephen Bass, "The forest certification handbook. St," *Lucie Press, Delray Beach, Fla*, 1996, *18*, 1995.

Walter, Jason and Yang-Ming Chang, "Green certification, heterogeneous producers, and green consumers: a welfare analysis of environmental regulations," *Journal of Regulatory Economics*, 2017, *52* (3), 333–361.

Wassink, Jan Tjibbes, "Choice Patterns for Tropical Timber, Imported in Seven European Countries," in "Tropical Hardwood Utilization: Practice and Prospects," Springer, 1982, pp. 405–429.

Wilkie, David, Ellen Shaw, Fiona Rotberg, Gilda Morelli, and Philippe Auzel, "Roads, Development, and Conservation in the Congo Basin," *Conservation Biology*, 2000, *14* (6), 1614–1622.

Wu, JunJie, "Slippage effects of the conservation reserve program," *American Journal of Agricultural Economics*, 2000, *82* (4), 979–992.

Zago, Angelo M and Daniel Pick, "Labeling policies in food markets: Private incentives, public intervention, and welfare effects," *Journal of Agricultural and Resource Economics*, 2004, pp. 150–165.

Table 1: Summary Statistics

	N	mean	sd	min	max
Volume felled (m^3)	1,554	7,162	29,794	0	357,129
Average volume felled (m^3)	1,554	374.8	1,211	0	13,721
Marginal Conventional * Any Cert	1,554	0.330	0.470	0	1
Marginal Conventional * Any Cert * Low Comp	1,554	0.173	0.378	0	1
Certified * Any Cert	1,554	0.231	0.422	0	1
Certified * Any Cert * Low Comp	1,554	0.173	0.378	0	1
Low Competition	1,554	0.757	0.429	0	1

Notes: The unit of observation is forest type-species-year.

Table 2: Production Response to Certification

	(1)	(2)	(3)	(4)
Panel A: Average Volume, log				
Certified * Market Segmented	0.690***	0.825***	0.141	0.384***
	(0.142)	(0.146)	(0.157)	(0.104)
Certified * Market Segmented * Low Comp			0.951***	0.744***
			(0.204)	(0.215)
Marginal Conventional * Market Segmented	0.230	0.284*	0.257	0.274*
	(0.138)	(0.136)	(0.140)	(0.136)
Marginal Conventional * Market Segmented * Low Comp			0.549**	0.588**
			(0.206)	(0.194)
Constant	3.474***	3.425***	3.332***	3.300***
	(0.0530)	(0.0523)	(0.0650)	(0.0633)
Trends	No	Yes	No	Yes
Observations	1554	1554	1554	1554
R^2	0.761	0.785	0.765	0.788
Panel B: Total Volume, log				
Certified * Market Segmented	1.110***	1.259***	0.336	0.573***
	(0.183)	(0.192)	(0.183)	(0.124)
Certified * Market Segmented * Low Comp			1.311***	1.114***
			(0.251)	(0.278)
Marginal Conventional * Market Segmented	0.373*	0.496**	0.412*	0.483**
	(0.169)	(0.177)	(0.172)	(0.177)
Marginal Conventional * Market Segmented * Low Comp			0.708**	0.761**
			(0.248)	(0.237)
Constant	5.182***	5.107***	4.999***	4.945***
	(0.0667)	(0.0699)	(0.0794)	(0.0798)
Trends	No	Yes	No	Yes
Observations	1554	1554	1554	1554
R^2	0.815	0.834	0.818	0.837

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The table presents results from four fixed effects OLS regressions where a unit of observation is a forest type-species-year. The outcome variable is the natural log of average volume of trees harvested (top panel) and the natural log of the total volume of trees harvested (bottom panel). Standard errors are in parentheses and are clustered by forest type. The panel runs from 2003-2009. Low competition is defined as having fewer than 40 forests produce the species in 2004.

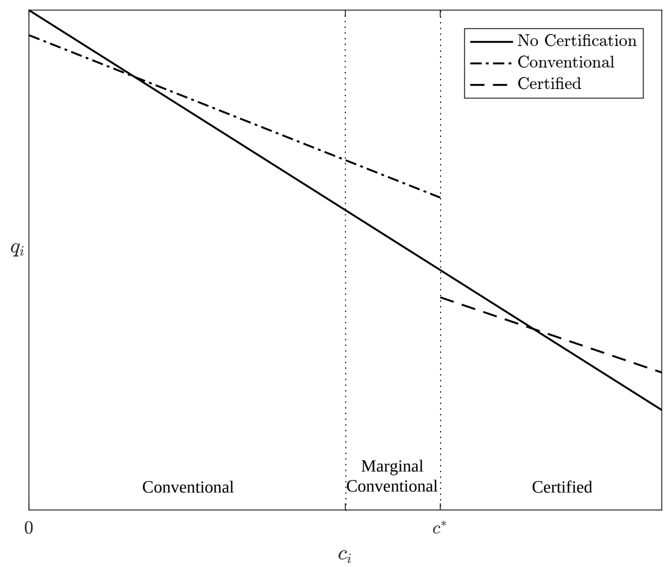

Figure I: Pre- and Post-Certification Equilibria

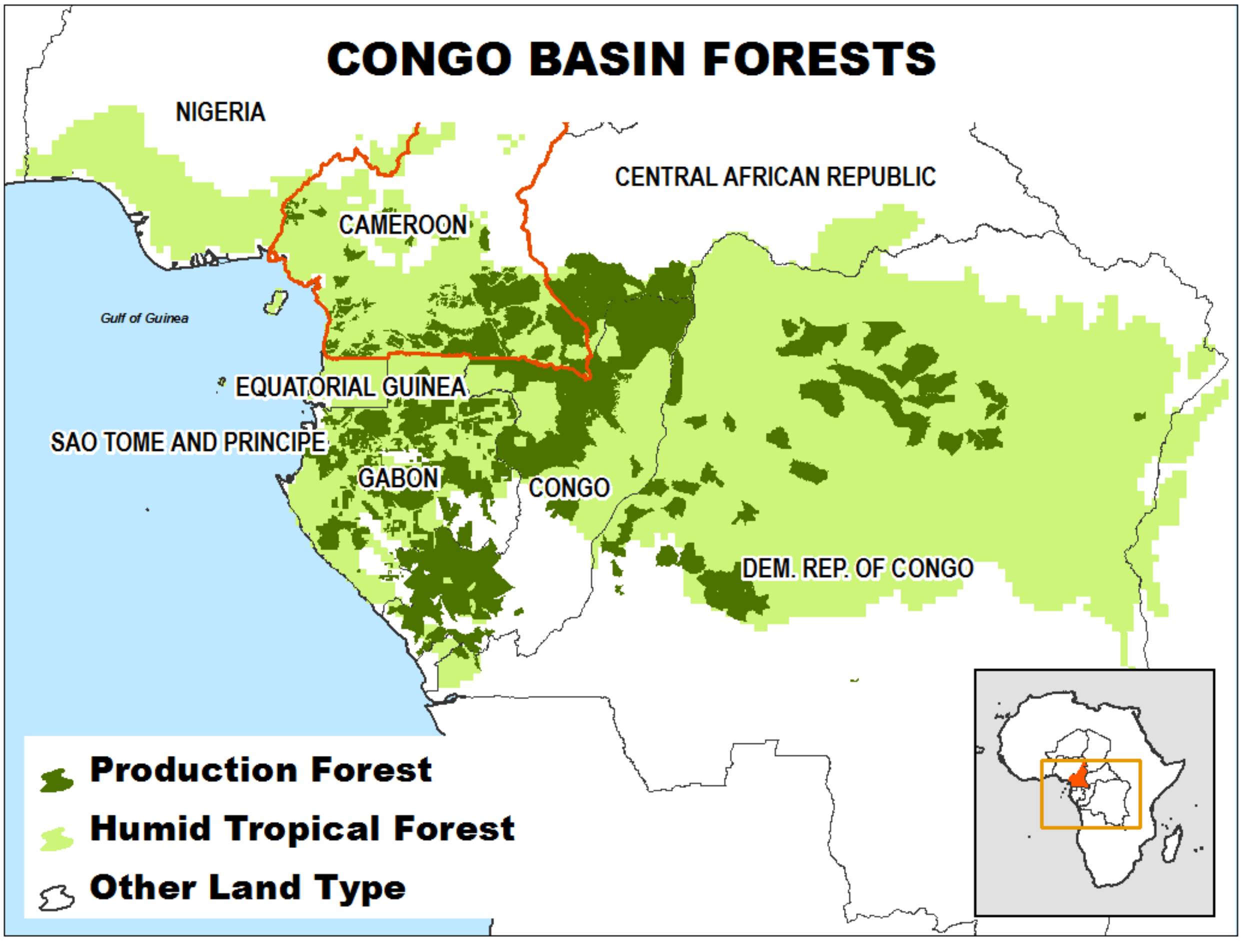

Figure II: Production Forest in Central Africa

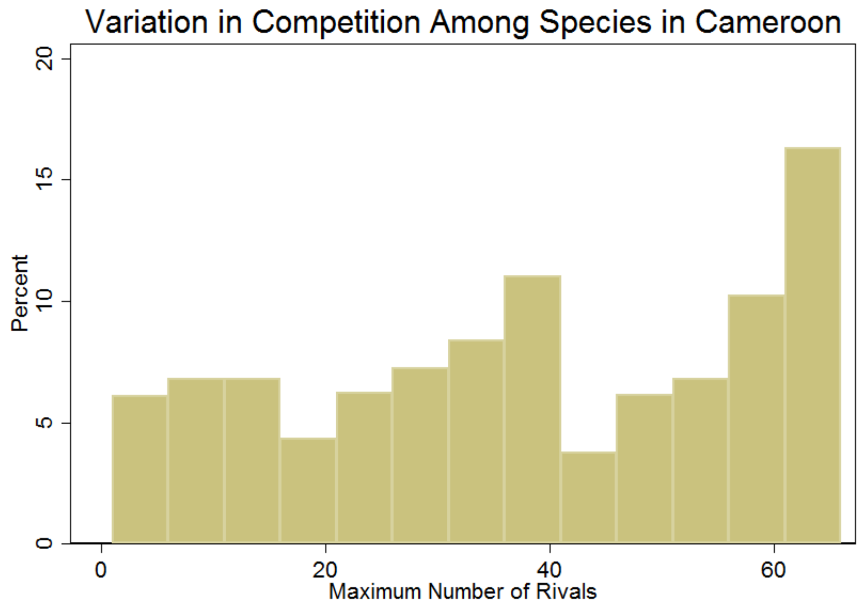

Figure III: Some species produced by many forests, some by few

Notes: The figure displays the frequency of rivals in 2004. An observation is a species in a forest. Note that regressions aggregate across forests to forest type.

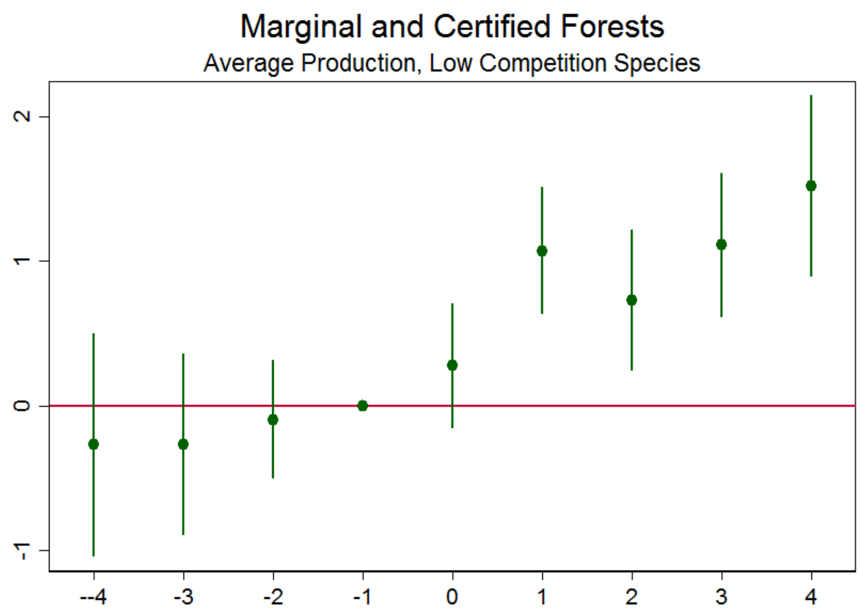

Figure IV: Event Study Graph for High Cost Forests

Notes: The outcome variable is the natural log of the average volume felled by forest type.

6 Appendix

Table A1: Production Response to Segmentation, Conventional Forests

	(1) Total Volume	(2) Average Volume
Market Segmented	-0.117	-0.187
	(0.842)	(0.660)
Constant	5.359***	3.636***
	(0.584)	(0.457)
Observations	518	518
R^2	0.832	0.773

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The table presents results from two fixed effects OLS regressions where a unit of observation is forest type-species-year. In column one the outcome variable is the natural log of the total trees harvested and in column two if is natural log of average trees harvested firm firm. Standard errors are in parentheses and are clustered by forest type. The population is restricted to Conventional forests, those with the lowest cost of extraction.