Import restrictions by eco-certification: Quantity effects on tropical timber production

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A B S T R A C T

Eco-certification standards are increasingly used by industrial countries to restrict imports of foreign goods produced using unsustainable practices. Import restrictions on eco-certified goods limit the trade of goods to the home country, but also serve to segment global demand into separate regions for conventional goods and certified goods, altering market structure and equilibrium prices in a manner that can work against sustainability goals. In this paper, we examine the effect of recent import restrictions in the US, EU, Canada, and Japan that require tropical timber products produced in Central Africa to be eco-certified. 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. Our findings suggest that import restrictions on tropical timber products shifted production to forests with higher extraction costs, exacerbating economic inefficiency and potentially raising marginal damages from timber extraction.

1. Introduction

Import restrictions that require eco-certification as a condition for trade are increasingly used by industrialized countries to address environmental concerns from the unsustainable use of natural resources in developing countries. Import restrictions currently prevent consumers from purchasing foreign goods derived from endangered species, harvested though unsustainable practices (Asner et al., 2009; Crane and Lidgard 1989), and produced using genetically-modified organisms.1 One reason import restrictions have proliferated as a method to influence environmental allocations is that few alternatives exist for industrialized countries to compel producers in developing countries to sustainably harvest globally important natural resources such as tropical forests.

Yet, import restrictions are a blunt instrument for changing production techniques in exporting countries. Producers in developing countries are free to choose whether or not to meet the eco-certification standards of industrialized countries, and can continue to sell goods derived through unsustainable practices in the remaining, non-restricted global markets. The ability to sell unsustainable products elsewhere in the marketplace has the effect of segmenting global demand, providing producers

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1 Import restrictions are also being discussed as a way to limit the carbon-content of trade (Pauwelyn 2013).
with a tool to differentiate their products that can lead to increased exports from resource-extractive industries by raising prices for certified products and softening price competition in both certified and uncertified markets.

In this paper, we examine the effect of import restrictions in the US, EU, Canada, and Japan that require tropical timber products produced in Central Africa to be eco-certified. Our analysis bridges between the environmental economics literature on eco-certification and the literature on international trade of resource-extractive goods. Within the trade literature, Rodrigue and Soumonni (2014) consider a structural model of interactions between investment in forest certification and current and future export demand and find that, while trade liberalization can increase environmental investment, complementarities that arise between export demand and investment can exacerbate deforestation rates.

Within the environmental economics literature, Mattoo and Singh (1994) were among the first to note that eco-certification can increase global market demand for natural resource-extractive goods when consumers of green products have higher willingness-to-pay for certified products. Sedjo and Swallow (2002) examine eco-certification outcomes in a competitive, partial equilibrium model and demonstrate that producers of uncertified products can increase their output levels as certified firms exit the conventional market, reducing supply and raising equilibrium prices for uncertified products. Our analysis builds on this work by theoretically characterizing and empirically identifying the demand and competition effects described in these studies for the case of import restrictions on tropical timber products.

Much of the eco-certification literature to date relies on quality-based, vertical differentiation models, in which heterogeneous consumers derive utility from an environmental attribute (e.g., sustainability) attached to an underlying functional product (e.g., wood). The environmental attribute, itself, is a credence quality that is indistinguishable in consumption, and eco-certification emerges in equilibrium to validate the presence of the attribute in products, resulting in a price premium for certified goods over conventional goods in the market (Chen, 2001; Amacher et al., 2004). The vertical differentiation model has contributed to our understanding of how premium prices are generated by eco-certification standards and how standards emerge in equilibrium as a result of competition among independent and industry labels (Fischer and Lyon, 2014; Li and van’t Veld, 2015; Heyes and Martin, 2016; Fischer and Lyon, 2019; Heyes et al., 2020).

An implicit assumption in vertical differentiation models is that equilibrium prices in each market are determined by consumer substitution on the margin between certified and uncertified products. This logic does not apply to import restrictions, as import restrictions legally prevent consumers residing in countries that implement them from substituting to products that do not meet the import requirement.

Our analysis departs from the eco-certification literature using vertical differentiation models to focus on how import restrictions segment global demand by horizontally differentiating the global marketplace into separate markets for certified and uncertified goods. The key feature of our model is that the products produced in the resource-extractive sector are horizontally differentiated, for instance there are over 70 different tree species harvested in Cameroon, and imposing an import restriction furthers differentiates the marketplace by bifurcating global demand. Formally modeling this element of an import restriction allows us to consider the effect of eco-certification on equilibrium prices and production incentives for firms in exporting regions that can choose whether or not to certify their goods.

We frame our analysis around a model of monopolistic competition in which firms differ according to their marginal costs of production. The import restriction serves to segment global market demand into two, independent populations of consumers according to whether they reside in a country that imposes the eco-certification standard as a condition for trade. In this setting, we formalize three channels of market effects that determine output changes in response to eco-certification. First, eco-labeling provides producers with the means to differentiate their products, thereby relaxing price competition and increasing industry profits in the sense of Shaked and Sutton (1982). The resulting competition effect raises global prices and provides individual producers with an incentive to increase output. Second, introducing an eco-label segments global market demand into separate markets for certified and uncertified products, creating a demand effect that alters output incentives. Finally, the certification decision by producers truncates the cost distribution of firms serving each market, allowing high-cost producers to profitably sell output in the certified market that would otherwise not be profitable to sell at all. This selection effect increases output incentives for firms switching into the certified market, while decreasing output incentives for firms that remain in the uncertified market. An essential contribution of our analysis is that it builds on the work of Sedjo and Swallow (2002) by identifying a novel selection effect that emerges when suppliers have heterogeneous production costs.

We empirically test the predictions of our model using firm-level data that exploits quasi-random variation in the timing of import restrictions on timber producers in Cameroon over the period 2003–2009. Our empirical methodology exploits ecological variation in the geographic ranges of different timber species as well as intertemporal variation in the timing of import restrictions across species. Our findings indicate that high cost producers significantly increase production in response to import restrictions on eco-certified wood. This finding points to the inefficiency of using import restrictions to meet global sustainability goals, both because shifting production towards high cost producers is economically inefficient and because forested regions with high extraction costs often represent areas with high biodiversity benefits (Doremus 2020). Increased production among conventional producers as a result of eco-certification standards can accelerate the loss of primary forests in tropical countries,
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 consumers from buying tropical forest products harvested through unsustainable practices. In Section 3, we present a theoretical model to explain how production incentives change in resource-extractive industries in response to import restrictions that segment global market demand into a certified and a non-certified market. In Section 4, we present our empirical analysis on the effect of global eco-certification programs 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 a greater number of plant species (Crane and Lidgard, 1989) and contain more locally-rare species (Clark et al., 1999) than temperate or boreal forests. Because markets exist for only a small share of the total number of species within tropical forests, commonly used selective logging practices are destructive to the remaining forest (Putz et al., 2000).

Within tropical forests, species randomly vary in their distribution across space. Although recent evidence suggests that some species variation is linked to variation in soil type (John et al., 2007), species variation in Cameroon is best characterized as being randomly dispersed (Manel et al., 2014). For this reason, the pattern of tree species assembly in tropical forests creates exogenous variation in the distribution of a species across firms, which we exploit in our empirical approach as a source of exogenous variation in exposure to market segmentation and its timing.

Eco-certification emerged in Cameroon in the 1990s as a market-based solution to compensate forest managers for engaging in sustainable forest practices. Eco-labels introduced by the Forest Stewardship Council (FSC) provided producers with a way to certify that timber was harvested from Cameroon’s forests in a manner that retains resources for regeneration and future sustainable harvests. While participation in eco-certification programs like the FSC remains voluntary in Cameroon, firms certifying their products typically earn a higher price in the eco-certified market relative to the conventional market.

In recent years, green procurement programs in the European Union (EU) have grown in importance. Green procurement programs impose import restrictions on goods produced using unsustainable practices, which serve to foreclose the EU market to conventional products by requiring consumers in the EU to purchase only eco-certified products (Brusselaers et al., 2017). In the case of timber products, the EU established the Forest Law Enforcement, Governance, and Trade (FLEGT) Action Plan in 2003 to reduce illegal logging practices in tropical countries. Specifically, 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, which are graded according to different levels of quality. Formal FLEGT negotiations between Cameroon and the EU began in 2007 and were finalized in 2011. Prior to 2011, Cameroon had not signed a Voluntary Partnership Agreement and therefore was unable to issue FLEGT licenses, and the 2011 agreement allowed Cameroon producers to issue FLEGT licenses to export timber products to the EU. In exchange for access to the EU market, the agreement required Cameroon producers to receive independent certification of timber practices.

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 break-downs of equipment, and raising the cost of road maintenance. Third, 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. Indeed, Doremus (2020) presents evidence that the cost of complying with sustainable harvesting standards is inversely related to extraction costs in the Cameroon timber market, as higher extraction costs serve to lower the opportunity cost of leaving unharvested trees behind.

This paper assesses changes in certified and conventional production in response to eco-certification. Forest Stewardship Council (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

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2 Increased harvest intensity in remote forests results in a greater road network, increased forest fragmentation, and greater deforestation rates along roads, skid trails, and gaps created by falling trees (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 forest conversion to alternative uses that result in greater carbon emissions (Estrada et al., 2017).

3 Note that though we focus on a simple quantity cap, Judge-Lord et al. (2020) suggests that FSC certification involves a host of criteria that defy simplification. For an example of other FSC criteria in Central Africa, particularly respect for indigenous peoples’ rights, see Doremus (2019).

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

5 Neutral theories of the assembly of tropical trees model tree species dispersion as a random process (Hubbell, 2001).

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); Stevens et al. (1998); Doremus (2020).

7 FLEGT was recently replaced by the Timber Regulation Act (2013), which maintains many of the original provisions, including the requirement that forests seeking to access the EU timber market receive eco-certification of their harvest practices.

8 Doremus (2020) assigns each forest a score that relates their harvesting costs to the overall distribution of harvesting costs among forests in Cameroon and Gabon.
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. Thus it is important to bear in mind that limiting the quantity of timber extracted is only one component of sustainable forestry.

Our focus is on the certification of timber origin and legality of harvesting practices. For firms that operate on high-quality land that allows a large number of trees to be extracted, legal harvesting imposes a maximum quantity constraint that increases the opportunity cost of eco-certification relative to areas where the terrain favors selective harvesting.

3. Theoretical model

We consider incentives for timber producers to adopt forest management practices in response to import restrictions in industrial countries. Import restrictions segment global demand for timber products into two, distinct markets: (i) a certified wood market, in which the sale of unsustainable forest products is prohibited; and (ii) an uncertified wood market comprised of buyers outside the regulated zone. Additionally, we follow Rodrigue and Soummonni (2014) in modeling the global timber market as monopolistically competitive. The monopolistic competition model captures an important element of product differentiation in the Cameroonian timber market, as our data encompass considerable variation in the types of tree species that fall under the FSC standard, and at the same time it provides a highly amenable framework for examining international trade.

We characterize the outcomes under two, separate equilibrium conditions: (1) An equilibrium in which certification is not possible; and (2) an equilibrium in which firms can choose to certify their wood products as sustainably harvested. As we discuss above and in greater detail below, certification allows exporting firms access to consumers in the country imposing the import restriction, but requires that firms limit their harvest to a quantity below the sustainable threshold $q_{\text{max}}$.12

3.1. Monopolistic competition model: No certification

Consider an economy with $L$ consumers that each inelastically supply one unit of labor. Labor is the only factor of production in the competitive input market, which is used to produce timber and a numeraire good that is produced under constant returns to scale with marginal cost equal to 1. Thus, the labor market allocation results in a unit wage.

Absent certification, consumers that care about sustainable timber production cannot differentiate the sustainability attribute in imported wood products. Following Melitz and Ottaviano (2008) and Ottaviano et al. (2002), the representative consumer has the utility function for wood products given by

$$\begin{align*}
U &= x_0 + a \int_{\Omega} x_i \, di - \frac{1}{2} \gamma \int_{\Omega} x_i^2 \, di - \frac{1}{2} \eta \left( \int_{\Omega} x_i \, di \right)^2
\end{align*}$$

where $x_0$ and $x_i$ represent the individual consumption levels of the numeraire good and wood variety $i$, respectively, with positive demand parameters $a$, $\eta$, and $\gamma$. The parameters $\alpha$ and $\gamma$ index the substitution pattern between differentiated wood varieties and the numeraire good: increases in $\alpha$ and decreases in $\gamma$ shift the demand for each differentiated wood variety relative to the numeraire, while the larger values of $\eta$ reduce the degree of product differentiation among wood varieties. Consumers perceive wood products from different tree species to be homogeneous products in the limiting case where $\eta = 1$. It is straightforward to show that the market demand system is linear and satisfies:

$$q_i \equiv Lx_i = \frac{\alpha L}{\eta N + \gamma} - \frac{L}{\gamma} p_i + \frac{\eta N}{\eta N + \gamma} p$$

where $N$ is the (fixed) mass of consumed varieties and $p$ is the average price.13

Firms in the differentiated sector are endowed with constant unit harvest costs that vary according to the distribution $G()$. Letting $c_i$ denote the marginal cost of firm $i$, the firm maximizes profits without taking into account its effect on $p$ and accordingly sets the price $p_i = \frac{1}{2} \left( \frac{\gamma a}{\eta N + \gamma} + \frac{\eta N}{\eta N + \gamma} p + c_i \right)$. Aggregating across firms results in the average price level $p = \frac{(\gamma a + \eta N + c_i)}{\eta N + 2\gamma}$. Therefore,

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9 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).

10 We suppress the possibility of fraudulent sales of non-certified wood in the import market as considered by Hamilton and Zilberman (2006). While illegal logging often coexists with formal industrial logging in tropical forests, the magnitude of illegal production tends to be small when allowable forest practices are stipulated through forest concessions under eco-certification (Cerutti and Tacconi, 2008).

11 There are two important distinctions between our model and that of Rodrigue and Soummonni (2014): (1) While they model (among other things) the effects of trade liberalization, we explore trade restrictions; and (2) Their underlying utility function is CES, while ours is quadratic following Melitz and Ottaviano (2008).

12 As described in Section 2, eco-certification is not just a quantity cap, and instead includes a holistic set of criteria. However lower compliance costs are among the most important determinants of firm participation in voluntary programs, including in FSC certification in Central Africa (Doremus, 2020).

13 One departure from Melitz and Ottaviano (2008) is that we assume there is no free entry and fix the number (mass) of varieties available in the differentiated sector. Fixing $N$ is reasonable in a natural resource model, such as timber, constrained by finite plots of available land.
the equilibrium price and quantity for firm $i$ are

$$p_i = \frac{1}{2} \left( \frac{2\gamma \delta \psi}{\eta N + 2\gamma \psi} + \frac{\eta N_C}{\eta N + 2\gamma \psi} + \epsilon_i \right)$$  \hspace{1cm} (3)

$$q_i = \frac{L}{2\gamma \psi} \left( \frac{2\gamma \delta \psi}{\eta N + 2\gamma \psi} + \frac{\eta N_C}{\eta N + 2\gamma \psi} - \epsilon_i \right) . \psi$$  \hspace{1cm} (4)

3.2. Monopolistic competition model: certification

Now consider the outcome with two markets for wood products, a certified ($C$) market and an uncertified ($U$) market. To participate in the certified market, a firm must agree to limit the quantity of each tree species harvested to a sustainable level $q_i^C \leq q^\text{max}$. Given that high cost firms produce smaller output levels than low cost firms in equation (4), the opportunity cost of meeting the participation constraint for the certified market is accordingly lower for high cost firms.\(^{14}\)

Let $\psi \Delta$ denote the fraction of the global population that reside in the region imposing the import restriction. In our sample of Cameroon timber sales, certified wood products represent a roughly 25 percent share of all timber sales, and we clarify the implications of the model by limiting attention to cases in which $\psi < \psi/2$. Because these consumers tend to reside in wealthier countries, we also consider the possibility that consumers in countries that impose import restrictions have (at least weakly) higher willingness to pay for certified wood products according to the demand parameter $\hat{\alpha} \geq \alpha$. The remaining portion of the consumer population, $(1 - \psi) \Delta$, is assumed to be characterized by a representative consumer with preferences described in the previous section.

Producers in the model decide how much to produce and which market to serve.\(^{15}\) The equilibrium output levels are:

Certified

$$q_i^C = \frac{\psi L}{2\gamma \psi} \left[ \frac{2\gamma \alpha + \eta N_C c_C}{\eta N_C + 2\gamma \psi} - c_i \right]$$  \hspace{1cm} (5)

Uncertified

$$q_i^U = \frac{(1 - \psi) L}{2\gamma \psi} \left[ \frac{2\gamma \alpha + \eta N_U c_U}{\eta N_U + 2\gamma \psi} - c_i \right]$$  \hspace{1cm} (6)

where $N_U$ is the mass of firms supplying uncertified wood and $N_C$ is the mass of firms supplying certified wood. Note that $N = N_U + N_C$.

Absent structural changes to demand that result from eco-certification $\alpha = \hat{\alpha}$, changes in the equilibrium output level of firm $i$ are determined by three tensions in the model. To understand these tensions, consider changes in the equilibrium quantity for firm $i$ in the no-certification case with respect to changes in the consumer population, the number of participating firms, and the average cost per firm in equation (4):

Demand

$$\frac{\partial q_i}{\partial L} = \frac{1}{2\gamma \psi} \left[ \frac{2\gamma \alpha + \eta N_C}{\eta N_C + 2\gamma \psi} - c_i \right] > 0$$  \hspace{1cm} (7)

Competition

$$\frac{\partial q_i}{\partial N} = - \left[ \frac{\eta L (\alpha - c)}{\eta (N + 2\gamma)^2} \right] < 0$$  \hspace{1cm} (8)

Selection

$$\frac{\partial q_i}{\partial c} = \frac{L}{2\gamma \psi} \left[ \frac{\eta N}{\eta N + 2\gamma \psi} \right] > 0 . \psi$$  \hspace{1cm} (9)

We show below that high-cost firms have an incentive to certify while low cost firms do not.\(^{16}\)

**Proposition 1.** Given $\psi < \psi/2$, there exists a critical value of the cost distribution $c^*$ such that the equilibrium profit level of firm $j$ increases from eco-certifying when $c_j \geq c^*$ and decreases from eco-certifying when $c_j < c^*$.

Proposition 1 allows the effect of an import restriction on the equilibrium output level of firm $i$ to be summarized as follows:

\(^{14}\) A homogeneous harvesting constraint $q^\text{max}$ is a simplification. As we discuss in Section 2, harvesting constraints are based, in part, on forest characteristics and vary across forests. However this feature creates incentives for firms to game the auditor to receive a lower constraint (Doremus, 2015). Because firm gaming makes the harvesting constraint non-binding for participating firms, we simplify the model by assuming a homogeneous $q^\text{max}$ that is non-binding in equilibrium.

\(^{15}\) By limiting attention to cases in which each firm serves one market, we implicitly assume there is a one-to-one mapping between a forest and a timber market. In the equilibrium we describe below, it follows that high costs firms will choose to certify. Because firms under monopolistic competition can always sell a marginal unit of output at the choke price greater than marginal cost, it is likely that at least some certifying firms would have an incentive to sell excess capacity to the uncertified market. That said, if certified firms were unconstrained to sell in the uncertified market, there would no change in the aggregate quantity in that market after certification. As certified firms reach their quantity constraint, the market price increases, providing an incentive for conventional firms to increase their output.

\(^{16}\) Proof is available in Appendix.
(1) Demand effect: With two markets, the individual market size decreases after firms choose which market to serve; i.e. the single market size \( L \) reduces to \((1 - \psi)L\) and \(\psi L\) in each new market. This effect is illustrated by equation (7) and implies \(q_i^U \downarrow\) and \(q_i^C \downarrow\).

(2) Competition effect: When firms select into one of two markets, the number of firms serving each market decreases from \(N\) to \(N_U\) and \(N_C\). This effect is illustrated by equation (8) and implies \(q_i^U \uparrow\) and \(q_i^C \downarrow\).

(3) Selection effect: From Proposition 1, it follows that high cost firms choose to certify while low cost firms choose remain uncertified such that \(c_U < c < c_C\). This effect is illustrated by equation (9) and implies \(q_i^U \downarrow\) and \(q_i^C \uparrow\).

In cases where the certification constraint does not bind \( \text{ex post} \) for firms that choose to certify, the equilibrium profit level for each type of firm is:

\[
\pi_i^C = \frac{\gamma \psi c^2}{\psi L} q_i^C
\]

\[
\pi_i^U = \frac{\gamma \psi}{(1 - \psi)L} q_i^{U2} \psi
\]

If a firm chooses to certify, it must agree to produce \(q_i^C \leq q_{\text{max}}\). To the extent that this constraint is binding for at least some low-cost timber producers, it follows that there is a strictly positive opportunity cost to certification for these firms, whereas there is no opportunity cost to certification for high-cost timber producers. Given that costs are distributed on a continuum, it follows that there exists a firm that is indifferent between certifying and not. We define the corresponding cost as \(c^*\) such that \(\pi^* = \pi_i^C = \pi_i^U\)

\[
\Rightarrow \left( \frac{2\gamma \hat{c} + \eta N_C c_C}{\eta N_C + 2\gamma} - c^* \right)^2 = \frac{(1 - \psi)}{\psi} \left( \frac{2\gamma \alpha + \eta N_U c_U - c^*}{\eta N_U + 2\gamma} \right)^2
\]

where \(c_C\) and \(c_U\) is the average cost of certified and uncertified firms respectively. By Proposition 1, this outcome constitutes an equilibrium. We close the model by characterizing the remaining variables: \(N_C = (1 - G(c^*))N\), \(N_U = G(c^*)N\),

\[
c_C = \frac{1}{1 - G(c^*)} \int_{c^*}^{CN} cdG(c), c_U = \frac{1}{G(c^*)} \int_{c^*}^{c} cdG(c) . \psi
\]

3.3. Equilibrium comparison

Now consider the change in quantity for a firm that certifies and does not certify:

\[
\Delta q_i^C = q_i^C - q_i = L \left[ \psi \left( \frac{2\gamma \hat{c} + \eta N_C c_C}{\eta N_C + 2\gamma} \right) - \frac{2\gamma \alpha + \eta N_C}{\eta N + 2\gamma} + (1 - \psi)c \right] \psi
\]

\[
\Delta q_i^U = q_i^U - q_i = L \left[ \left( \frac{2\gamma \alpha + \eta N_U c_U}{\eta N_U + 2\gamma} \right) - \left( \frac{2\gamma \alpha + \eta N_C}{\eta N + 2\gamma} \right) + \psi c \right] \psi
\]

**Lemma 1.** The changes in firm quantity \(\Delta q_i^C\) and \(\Delta q_i^U\) are increasing in the firm’s cost.

**Proof.** Directly calculating these values, \(\frac{\partial \Delta q_i^C}{\partial c_i} = \frac{(1 - \psi)L}{2\gamma} > 0\) and \(\frac{\partial \Delta q_i^U}{\partial c_i} = \frac{\psi L}{2\gamma} > 0\).---

**Lemma 1** reveals that the change in quantity produced by a firm within each group increases for firms with higher marginal cost of production, with the largest output changes going to the highest cost firms; however, it is generally not the case that there is a positive output change for all firms.\(^{17}\) The total production level of firms in each group is

\[
Q_C = N_C \psi L \left( \frac{\hat{c} - c_C}{\eta N_C + 2\gamma} \right)
\]

\[
Q_U = N_U (1 - \psi) L \left( \frac{\alpha - c_U}{\eta N_U + 2\gamma} \right) \psi
\]

where the total production level of firms in each group depends on the share of consumers encompassed by the import restriction \(\psi\). We characterize in the following two lemmas the critical value of \(\psi\)\(\eta\)\(\psi\) which aggregate quantity of each group will increase.\(^{18}\)

**Lemma 2.** Aggregate quantity (and thus average quantity) for noncertified firms increases after certification if

\[
\psi < \frac{\eta N_C}{\eta N + 2\gamma} \left( \frac{2\gamma (\alpha - c_U) - \eta N_U (c_C - c_U)}{2\gamma (\alpha - c_U)} \right) \psi
\]

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\(^{17}\) See Fig. I for a graphical representation.

\(^{18}\) Proofs are available in Appendix.
Lemma 3. Aggregate quantity (and thus average quantity) for certified firms increases after certification if
\[
\left( \frac{\eta N_C + 2\gamma \psi}{\eta N + 2\gamma \psi} \right) \left( \frac{2\gamma (\alpha - c_C) - \eta N_U (c_C - c_U)}{2\gamma (\widehat{\alpha} - c_C)} \right) < \psi \cdot \psi
\]
(17)

Lemma 4. Aggregate quantity for both certified and conventional firms increase after certification if Lemmas 2 and 3 hold and
\[
\left( \frac{\eta N_C + 2\gamma \psi}{\eta N_C} \right) < \psi \left( \frac{\widehat{\alpha} - c_C}{\alpha - c_U} \right) \cdot \psi
\]

The range of $\psi$ that supports the outcome in Lemma 4 is shown by numerical simulation in Fig. 1.\textsuperscript{19} Notice that both $\Delta Q_C > \psi 0$ and $\Delta Q_U > \psi 0$ over the approximate range $\psi \in [0.3, 0.4]$ (see Fig. 2).

Fig. 1 demonstrates an important role for global harmonization of eco-certification standards. When the share of global consumers encompassed by the import restriction is small, total production by uncertified firms expands, while the aggregate output level of certified firms contracts. It is possible in this case that the ecological gains from firms switching to sustainable harvesting techniques is offset by increased production levels among firms remaining uncertified. The aggregate production level of uncertified firms declines in response to eco-certification only when $\psi \psi$ is sufficiently large.

Remark 1. If Lemma 2 holds, there exists a range of uncertified firms with costs $c_i \in [0, \widehat{c}]$ in which their aggregate change in quantity is zero and a range of uncertified firms with marginal cost $c_i \in [\widehat{c}, c^*]$ in which their aggregate change in quantity is strictly positive.

Proof. By Lemma 1, $\Delta q^{iU}$ is increasing in the firm’s individual cost. Note that Lemma 2 does not hold for all values of $\psi$. Thus, there exists a $\psi \psi$ for which $\Delta q^{iU} < 0$ and therefore a $\psi \psi$ which some firms increase their quantity while some firms decrease their quantity.

\[\square\]

4. Empirical analysis

In this section we empirically examine the output effects of eco-certification among timber producers in Cameroon. To do so, we first link our theoretical model to the data by defining the extent of the Cameroonian timber market and conceptualizing the eco-certification standards embodied by import restrictions in an empirically testable way.

Our monopolistic competition framework implies a market definition where goods are similar but differentiated. The empirical analog in the Cameroon timber market is the market for different species of timber, e.g. Khaya ivorensis ("African Mahogany"). Despite genetic similarities, prices vary considerably across species within a genus (see Table A2). Each species has specific characteristics such as color, grain, and workability that differentiates it from other timber species in the market. Moreover, species’ habitat and distribution vary across space in our sample, creating variation in the number of rivals, exposure

\textsuperscript{19} This simulation assumes costs are uniformly distributed over the support $[0, 10]$ with parameter values $\alpha = 100$, $\widehat{\alpha} = 130$, $\gamma = 2$, $\eta = 1.5$ and $N = 30$. 
to certification and its timing. This variation also affects wood quality, as the quality of wood depends on habitat, further differentiating timber products. Within a species, timber produced in different forests varies in its aesthetics, hardness, dryness, and other qualities as a function of the tree’s local environment, much like terroir influences wine quality in viticulture.

Given species’ habitat varies the exposure to certification timing across markets, this setting lends itself to a staggered difference-in-differences empirical design. In our main specification, treatment begins in the year the first producer within a market certifies their forest.\textsuperscript{20} As a robustness check, we then explore whether production responses differ with treatment intensity and the share of forests that certify. Given that certification occurs at the forest level, the moment a forest certifies all species produced by that forest experience market segmentation. Because the likelihood of a firm encountering a species has a random component, from the neutral theory of tropical tree species dispersion (Hubbell, 2001), we assume the timing of exposure to market segmentation varies exogenously across tree species in response to import restrictions.\textsuperscript{21}

Our difference-in-differences design requires a group of treated and control units. For control units, average production is unchanged after treatment. Remark 1 states there exists a cutoff type such that the average output level across the group of low cost conventional forests is unchanged after certification. Thus our control group is the set of forests with lowest extraction costs. Changes after certification by low cost firms risks violating the stable unit treatment value assumption, and we discuss this threat to identification in more detail in a Section 4.2.4. Our treated group is the set of forests with extraction costs that exceed the threshold value for our control group. Lemma 1 predicts that the change in firm production in response to an import restriction is an increasing function of extraction cost.

\textsuperscript{20} An alternative would be to use the timing of country import restrictions; however, not all species are exposed to certification, nor are exported to markets with import restrictions. Furthermore, if treatment occurred at exactly the time of import restrictions, certification would also occur at that moment. Instead, certification occurs over time in our sample.

\textsuperscript{21} There is a risk that the timing of exposure to market segmentation is non-random for the set of species with a large potential market for certified timber. This could affect the simple estimator, which gives units treated first more weight. However, our estimates using the simple and weighted average of the post-treatment period effects avoid this problem. Comparing the simple estimator to these estimators offers an easy way to see whether this is an important threat to identification. Because the three estimates are so similar, we conclude this threat to identification is unlikely to drive our results; e.g., see Table 2.
Table 1
Summary statistics, N = 17,999

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certified</td>
<td>0.740</td>
<td>0.438</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Share Certified</td>
<td>0.249</td>
<td>0.204</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Any Timber</td>
<td>0.510</td>
<td>0.500</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Timber Volume</td>
<td>2.978</td>
<td>3.235</td>
<td>0</td>
<td>12.04</td>
</tr>
</tbody>
</table>

Panel B: Coefficients for Lowest Cost Only, N = 5018

<table>
<thead>
<tr>
<th></th>
<th>$\hat{\beta}$</th>
<th>SE</th>
<th>$R^2$</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any Timber</td>
<td>0.063</td>
<td>(0.074)</td>
<td>0.277</td>
<td>$F + S + Y$</td>
</tr>
<tr>
<td>Timber Volume</td>
<td>0.332</td>
<td>(0.305)</td>
<td>0.327</td>
<td>$F + S + Y$</td>
</tr>
</tbody>
</table>

Notes: Data from 2003 to 2009. A unit of observation is a species-forest-year. Volume is measured using the inverse hyperbolic sine of meters cubed. Panel B presents results from two fixed effects OLS regressions where the population is restricted to conventional forests, those with the lowest cost of extraction. The coefficient $\hat{\beta}$ is the change in production after the first forest certified. Standard errors are in parentheses and are clustered by species. Fixed effects (FE) are at the forest (F), species (S), and year (Y) level.

Fig. 3. Average Production by Forest Type. Notes: The average is of the inverse hyperbolic sine of the volume of timber produced at the species-forest level for each forest type. The panel runs from 2003 to 2009.

4.1. Data

We rely on data from the Cameroon timber market on forest production, certification, and producer cost type to empirically test the predictions of the theoretical model. We describe each of these elements in turn.

**Production Data:** We combine data on forest ownership from the World Resources Institute’s Global Forest Watch Atlas for Cameroon, Version 2, with primary production data from Cameroon’s Ministry of Forestry in their Système Informatique de Gestion de l’Information Forestière (SIGIF) for 2003–2009. Our unit of observation is timber production for a species within a forest management unit in a year. Because SIGIF only records production, not its absence, we infer zero production from the missing records. To account for gaps in production, we assess two outcome variables: (i) a binary variable equal to one if the forest produced any timber of that species in that year; and (ii) the inverse hyperbolic sine of the quantity of production. The end result is a balanced panel for each species within a forest and a total of 17,999 observations. Summary statistics for production are reported in Table 1 and production over time is plotted in Fig. 3.

**Forest Certification Data:** Eco-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 over time among forests. Because species’ ranges and distribution patterns differ, this creates exogenous variation at the species-level in market segmentation timing. Fig. 3 shows the share of all markets exposed to certification during the panel. Certification of forests primarily occurs in waves in 2005, 2007, and 2009, as shown in Figure A1.

22Note, the overall panel is unbalanced because not all forests are active every year between 2003 and 2009.

23Certification includes Forest Stewardship Council, OLB, and TLTV certification.
Predicted Compliance Cost 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 (2020) tested whether this outcome holds for timber firms in Cameroon and Gabon and found that firms sort into strong and weak certification programs according to differences in marginal extraction costs. Evidence that firms sort by cost is consistent with empirical results derived from other pollution control settings. To identify forest compliance cost types, we use the predicted type from Doremus (2020). We assign forests to cost quantiles, where we expect average production to remain unchanged after certification for forests in the lowest cost quantile, $H_j^{IV}$.

4.2. Estimation framework

Using a difference-in-differences framework, we begin by estimating the dynamic treatment effect of market segmentation on production by higher cost forests. After allowing for heterogeneous responses according to forest cost type, we then test our identifying assumptions and discuss limitations of the study.

4.2.1. Dynamic treatment effect

Our treatment for market segmentation occurs at the time the first forest certifies, $K_{st} = 0$, the timing of which varies by species. Letting $s$ indicates a species, $f$ a forest, and $t$ the year, we estimate the dynamic treatment effect as

$$y_{fst} = \alpha + \sum_{k=1}^{4} \tau_k (K_{st} = k) \cdot H_f + \alpha_{fs} + \delta_{st} + \epsilon_{fst}$$  \hspace{1cm} (18)

where $H_f$ is an indicator variable equal to one if the forest’s extraction costs are higher than the bottom quartile, $\alpha_{fs}$ are forest-species fixed effects, and $\delta_{st}$ are market (species) fixed effects by year. We include these interaction terms for event periods with high cost forests. Standard errors are clustered by species.

4.2.2. Average treatment effect

We use two methods to estimate the average treatment effect, a specification that includes a binary indicator variable for the post-period and a calculation of the average across the post-treatment indicator variable coefficients from expression (18). We begin by estimating the average treatment effect in the specification,

$$y_{fst} = \alpha + \beta D_{st} \cdot H_f + \alpha_{fs} + \delta_{st} + \epsilon_{fst}$$  \hspace{1cm} (19)

where $H_f$ is an indicator variable equal to one if the forest has high extraction costs, and $\alpha_{fs}$ are fixed effects at the forest-level. Standard errors are also clustered by species. We also include market (species) by year fixed effects $\delta_{st}$.

de Chaisemartin and d'Haultfoeuille (2019), Goodman-Bacon (2018), Borusyak and Jaravel (2017) and have noted the risks of estimating the average treatment effect using expression (19). The main risk is that the simple estimator negatively weights effects that occur further from the initial response. To address these concerns, we use the approach recommended by Borusyak and Jaravel (2017) and take the average of the post-treatment indicator variables. We do this in two ways. We take the simple average, $\bar{r}$, and the weighted average, $\bar{r}_W$.

$$\bar{r}_W = \frac{1}{5} \sum_{k=0}^{4} \tau_k \cdot \Psi \quad \bar{r}_W = \frac{4}{N} \sum_{k=0}^{4} \tau_k \cdot \varphi_k \cdot \Psi$$  \hspace{1cm} (20)

respectively, where $\varphi_k = \frac{n_k}{N}$ and $n_k$ is the number of observations for post-period $k$ and $N$ is the total number of observations. Standard errors are calculated using the delta method.

4.2.3. Heterogeneity by cost type

We arrange the distribution of forest types according to quartiles of cost types, $H_j^{I}$, $H_j^{II}$, and $H_j^{III}$, with the lowest cost quartile, $H_j^{IV}$, being the omitted category. Heterogeneous effects are incorporated using the estimator,

$$y_{fst} = \alpha + \beta_1 D_{st} \cdot H_j^{I} + \beta_2 D_{st} \cdot H_j^{II} + \beta_3 D_{st} \cdot H_j^{III} + \alpha_{fs} + \delta_{st} + \delta_{f} + \epsilon_{fst}$$  \hspace{1cm} (21)

24 Doremus (2020) uses geospatial data related to sustainable harvesting costs to predict compliance cost type. 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.

25 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).

26 An alternative is to estimate the $\tau_{W}$ with and without the interaction instead of using market-year fixed effects. Our approach allows for greater flexibility across markets in the control group’s response.

27 Results are robust to including $D_{st}$ without the interaction and fixed effects by species and year.
Fixed effects are at the forest-species level, $\alpha_f$, and we include species-year fixed effects $\delta_{st}$. Standard errors are clustered by species.

4.2.4. Threats to identification

To estimate the causal effect of market segmentation on timber production, we make two identifying assumptions. First, we assume that the timing of market segmentation, which occurs when certified forests first exit the conventional market, is unpredictable and not driven by observed trends. Our second identifying assumption is that our control group is unaffected by treatment, which is known as the stable unit treatment value assumption.

To test our first identifying assumption, we use an event study design and an F-test of the coefficients on pre-period event time indicator variables. Following Borusyak and Jaravel (2017), we plot coefficient from an event study where we omit two pre-period event time indicator variables. The plots allow us to look for evidence of pre-trends. The event study specification is identical to Expression (18) with the addition of two terms $\tau_{-3} K_{st} = -3 | H_f$ and $\tau_{-2} K_{st} = -2 | H_f$, pre-period indicator variables for $K = -3$ and $K = -2$, only. This implies that the omitted periods are $K = -1$ and $K \leq -4$, which are as far apart as is possible in our pre-period, consistent with recommendations from Borusyak and Jaravel (2017). We use an F-test on the pre-period indicator variables, $\tau_{-3}$ and $\tau_{-2}$, to test whether they are jointly zero, where a failure of the test indicates that there may be pre-trends (Borusyak and Jaravel, 2017).

The second threat to identification concerns the behavior of our control group. We seek a control group that includes forests whose production is unchanged after market segmentation. As described in our Remark, such control is possible by choosing a cutoff among low cost conventional firms such that the group’s production, on average, is unchanged after certification.28

Our model predicts that the change in firm production from market segmentation is increasing in firm cost (Lemma 1). Given this outcome, it is important to choose a cutoff for our control group such that average production for the group is unchanged after certification. We chose the bottom quartile of the distribution of forest types as our cutoff because the set of forest is bounded by the lowest cost type in Remark 1. The lowest quartile is transparent and easily allows for a heterogeneity analysis of low and high cost forests within each market, conventional and certified.

To test whether forests in our control group change production after certification, we estimate the following regression using the sub-sample of forests in the bottom quartile of compliance costs:

$$ y_{fst} = \alpha + \beta D_{st} + \alpha_f + \alpha_{st} \delta_t + \epsilon_{fst} \tag{22} $$

If our threshold for the control group is too low, their average production may decrease after market segmentation. This would make production appear to increase in other forests, even if they remain unchanged. Alternatively, if our threshold is too high, the estimated change in the average production level for the control group will be positive, which would bias the estimated change in production downward following eco-certification.

Results from expression (22) are reported in Table 1. We fail to find evidence that these forests decreased their production. Instead, we find a noisy, positive coefficient for both outcomes and we cannot reject the null hypothesis that there is no change in production after treatment.

4.3. Results

4.3.1. Dynamic treatment effect

Table 2 reports results for the annual change in production in the first year of eco-certification and each year thereafter for our two outcomes. From our model, we predict that eco-certification splits the Cameroon timber market into two segments, conventional and certified, causing high cost firms to increase production. The entries in Table 2 are consistent with this prediction, indicating that the production response grows over time and stabilizes three to four years after the date of eco-certification.

Fig. 4 confirms the growth in the production response over time and allows us to inspect whether our results are driven by pre-trends. We fail to find strong evidence that pre-trends are driving our results. Before the market segments, the estimates

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28 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.
Fig. 4. Event Study of Change in Production Before and After Market Segmentation. Notes: Coefficients plotted from an event study with two omitted pre-periods. Time zero corresponds to the first year at least one forest certifies. The outcome variables are the inverse hyperbolic sine of the volume of timber produced and an indicator variable for whether or not any timber was produced. To facilitate comparison of coefficients across time and outcomes, the indicator variable was rescaled by 10. The panel runs from 2003 to 2009 and the expression includes forest and species-year fixed effects.

Table 3
Production response to market segmentation by cost types.

<table>
<thead>
<tr>
<th>Cost Type</th>
<th>Certified Hi Cost I</th>
<th>Conventional Hi Cost II</th>
<th>Certified Hi Cost III</th>
<th>Constant</th>
<th>R^2</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any</td>
<td>0.116*** (0.025)</td>
<td>0.133*** (0.028)</td>
<td>0.076*** (0.023)</td>
<td>0.452*** (0.011)</td>
<td>0.306</td>
<td>17,999</td>
</tr>
<tr>
<td>Volume</td>
<td>0.691*** (0.139)</td>
<td>0.704*** (0.149)</td>
<td>0.452*** (0.134)</td>
<td>2.650*** (0.060)</td>
<td>0.383</td>
<td>17,999</td>
</tr>
</tbody>
</table>

Notes: The table presents results from two fixed effects OLS regressions where a unit of observation is a forest-species-year. The outcome for the first row is a binary variable equal to one if any timber was produced. The outcome for the second row is the inverse hyperbolic sine of the volume of timber produced. Fixed effects at the forest and species-year level. Standard errors are in parentheses and are clustered by species. * p < 0.05, ** p < 0.01, *** p < 0.001.

for the binary variable hug the zero line. The estimates for timber volume are positive, though lower in value than the post-period coefficients and with a weakly decreasing trend. One year after market segmentation, production increases and remains persistently higher thereafter. An F-test of the joint significance of the pre-period coefficients fails to reject the null for both outcomes.

4.3.2. Average treatment effect

Results for the average treatment effect are reported in the three final columns of Table 2, which are consistent across different approaches. The likelihood of producing any trees within a species increase by 9.6–10.5 percentage points and the total amount produced increases by 60–64 percent among high-cost forests after eco-certification segments the market under the import restriction. Notice that the coefficient from the simple estimator in equation (19) is similar in magnitude and precision to the average effect calculated from post-event indicator coefficients. The average treatment effect from the dynamic treatment specification is almost one percentage point lower for the extensive margin and about 3.5 percent higher for the intensive margin.

In Table A1 of the Appendix, we allow treatment to vary in intensity. We interact the eco-certification indicator with another indicator for whether there were few (less than half) or many (more than half) forests that exit the conventional market to enter the certified market. We find that the production response does not vary much across different treatment intensities. For the extensive margin, the coefficients are very similar to each other and the average effect. For the intensive margin, the production response by high cost forests is slightly smaller when more forests exit the conventional market, as we would expect.

4.3.3. Production response by cost type

We explore heterogeneous production responses by forest type across four cost quartiles, using the lowest cost quartile of forests as the omitted category. Columns in Table 3 reports the change in production for each cost type. Our estimated coefficients reveal that the magnitudes of the responses are qualitatively similar for the change in the likelihood and volume of production. High cost conventional firms (Type III) increase by less than high cost certified forests (Types I and II) in both cases, with positive changes occurring for all three cost types.
4.4. Discussion

Increased production by certified forests implies a non-binding harvesting constraint, which is consistent with Doremus (2015). This increase in production following eco-certification may be contrary to the goals of sustainable forestry. Yet, as indicated by Lemma 3, we expect an increase in production by certified firms under weak regularity conditions.

The increase in production by high cost conventional forests after certification is surprising, but not inconsistent with our model’s predictions. Eco-certification causes competing, high cost firms to exit the conventional market and enter the certified market. Lemma 2 shows that high cost conventional firms increase production after certified firms exit the market under relatively weak regularity conditions.

Our findings highlight the fact that segmenting global markets through import restrictions based on eco-certification standards can result in increased production by both certified and uncertified producers. Our results are broadly consistent with predictions by Bruselaers et al. (2017) in response to green procurement programs in Europe. Because our model allows for quantity effects on individual units of land, our findings underscore the presence of dynamic externalities from unsustainable harvest of old growth forests.

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. Our analysis captures both of these effects by allowing for quantity competition and cost heterogeneity among firms. Our main finding is that market segmentation led to increased production by high cost forests in Cameroon. In this section we discuss the potential policy implications of our findings.

First, we find evidence that the total quantity harvested increased for many tree species in Cameroon following eco-certification, despite the policy goal of reducing total extraction. This outcome is consistent with the finding of Doremus (2015) that certification restrictions on harvest quantities are frequently non-binding due to firms gaming the policy. Given that harvesting restrictions are non-binding, feedback between certified and conventional markets following the import restriction on certified wood may lead to no change or even an increase in production for such producers. This outcome is consistent with Blackman et al. (2018), who finds deforestation rates failed to decrease in Mexico after eco-certification. Given their use of a propensity score matching model, 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 eco-certification led to increased harvest rates among forests with higher marginal extraction costs. Ignoring, for the moment, variation in marginal damages from extraction across cost types, eco-certification appears to have reduced allocative efficiency in the Cameroon timber market by reallocating production away from low-cost forests and towards forests with higher private extraction costs.

Finally, it is likely that the shift in production from low-cost to high-cost forests has implications for the marginal damage of timber extraction in tropical forest areas. Marginal damage from timber extraction arises from forest fragmentation, from habitat loss in areas with high conservation value, and from soil loss and the resulting water pollution that occurs through sedimentation. Based on the findings of Doremus (2020), 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 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 eco-certification policies that rely on import restrictions on achieving sustainability goals, in terms of forest retention, is ambiguous. Our findings indicate that this subject is 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 policies have been proposed to achieve global environmental objectives for fisheries (Smith et al., 2010), timber resources (Agrawal et al., 2008), and climate change (Pauwelyn, 2013). In this paper, we demonstrated how import restrictions that mandate certification as a condition for market access result in segmented global markets for resource-intensive goods, altering harvest incentives in both certified and uncertified market segments.
Our results reinforce early predictions of Matteo and Singh (1994), Sedjo and Swall (2002), and Zago and Pick (2004), who observed that certification differentiates the renewable resource market, potentially increasing production under imperfect competition. Our theoretical contribution is to allow for market power, cost heterogeneity and heterogeneous quantity responses among firms producing resource-intensive goods. This structure allows 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. 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 that reduce allocative efficiency, and from increased harvest pressure on the underlying natural resources in forested regions. We provide evidence that import restrictions that limit purchases of eco-labeled wood products by consumers in restricting countries reallocate production from low-cost to relatively high cost firms producing on marginal forest lands in Cameroon.

We empirically characterize 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 in response to import 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. It also 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 sold in supermarkets in the UK (Sacks et al., 2009). Our findings suggest that using eco-labels to restrict imports may fail to contribute overall to global sustainability 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 findings point to an important role for global harmonization of eco-certification standards. In cases where the share of global consumers encompassed by an import restriction is small, we demonstrated that total production by uncertified firms expands, while the aggregate output level of certified firms contracts. It is possible under such circumstances that the ecological gains from firms that switch to sustainable harvesting techniques is offset by increased production levels among the remaining uncertified firms. The main culprit driving such a potential outcome is not eco-certification, but a lack of coordination on environmental standards underpinning global trade.

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. 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 tropical forest areas where marginal environmental damages are high.

6. Appendix

6.1. Proofs

Proof of Proposition 1: Given $\psi < \frac{1}{2}$, any conventional firm $j$ with a cost $c_j < \psi c^*$ does not have a profit motive to certify.

Proof. To show this it must be the case that the profit of firm $j$ as a conventional firm is greater than that if it unilaterally chose to certify. Note that each firm has mass zero and thus would not affect $N_U$ or $C$ if it alone certified. For algebraic ease define $1 \equiv \frac{2\gamma_k + n N_U C}{n N_U + 2\psi}$ and $1 \equiv \frac{2\gamma d + nc C}{n C + 2\psi}$.

$$\pi^C_j < \pi^U_j$$

$$\Leftrightarrow \psi(1 - \psi)(Y - c_j)^2 < (1 - \psi)(Y - c_j)^2$$

$$\Leftrightarrow \psi(1 - \psi)^{\frac{1}{2}}(Y - c_j)$$

$$\Leftrightarrow \psi^2 (1 - \psi)(Y - c^*) + \psi^2(c^* - c_j) < (1 - \psi)(Y - c^*) + (1 - \psi)(c^* - c_j)$$

30 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.
Utilizing the fact that $x^C_e = x^U_e \Rightarrow (1 - \psi)(Y - c^*)^2 = \psi(\hat{Y}\psi - c^*)^2$: $x^C_j < x^U_j$

$$\Leftrightarrow \psi \frac{1}{2} (c^* - c_j) < (1 - \psi) \frac{1}{2} (c^* - c_j)$$

$$\Leftrightarrow \left( \frac{\psi}{1 - \psi} \right)^2 < 1$$

$$\Leftrightarrow \psi < \frac{1}{2}$$

Since this is true for when firms are not quantity constrained, it must also be true if the firm is constrained. Thus, no conventional firm wants to deviate from the described equilibrium. Note that it is straightforward to show that a certified firm with $c_j > \psi c^*$ does not want to change to be conventional using the same argument.

**Proof of Lemma 2:**

**Proof.** Aggregate quantity for noncertified firms increases after certification if

$$\hat{Q}_U < Q_U$$

$$\Leftrightarrow \frac{N_u L}{2\gamma \psi} \left( \frac{2\gamma (\alpha - c_U) + \eta N(c - c_U)}{\eta N + 2\gamma \psi} \right) < \frac{N_u (1 - \psi) L}{(\alpha - c_U)} \left( \frac{\eta N_U + 2\gamma \psi}{\eta N_U + 2\gamma \psi} \right)$$

$$\Leftrightarrow \frac{1}{2\gamma \psi} \left( \frac{2\gamma (\alpha - c_U) + \eta N(c - c_U)}{\eta N + 2\gamma \psi} \right) < (1 - \psi) \left( \frac{(\alpha - c_U)}{\eta N_U + 2\gamma \psi} \right)$$

$$\Leftrightarrow \frac{\psi}{\eta N_U + 2\gamma \psi} \left( \frac{(\alpha - c_U)}{\eta N_U + 2\gamma \psi} \right) < \psi \left( \frac{2\gamma N_c (\alpha - c_U) - \eta N(c - c_U)(\eta N_U + 2\gamma)}{2\gamma (\eta N_U + 2\gamma)(\eta N + 2\gamma)} \right)$$

Note that $N(c - c_U) = N_c(c_c - c_U)$

$$\Leftrightarrow \psi < \frac{\eta N_c}{\eta N + 2\gamma \psi} \left( \frac{2\gamma (\alpha - c_U) - \eta N_U (c_c - c_U)}{2\gamma (\alpha - c_U)} \right)$$

**Proof of Lemma 3:**

**Proof.** Aggregate quantity for certified firms increases after certification if

$$\hat{Q}_C < Q_C$$

$$\Leftrightarrow \frac{N_c L}{2\gamma \psi} \left( \frac{2\gamma (\alpha - c_c) + \eta N(c - c_c)}{\eta N + 2\gamma \psi} \right) < \frac{N_c \psi L}{\eta N_c + 2\gamma \psi} \left( \frac{\hat{\alpha} - c_C}{\eta N_c + 2\gamma \psi} \right)$$

$$\Leftrightarrow \left( \frac{\eta N_c + 2\gamma \psi}{\eta N + 2\gamma \psi} \right) \left( \frac{2\gamma (\alpha - c_c) - \eta N_U (c_c - c_U)}{2\gamma (\alpha - c_c)} \right) < \psi \cdot \psi$$

Note that $N(c - c_c) = N_U(c_U - c_c)$.
### Table A1
Production Response by Variation in Share of Forests that Enter the Certified Market

<table>
<thead>
<tr>
<th></th>
<th>Any Timber</th>
<th>Timber Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Split x High Cost</td>
<td>0.105***</td>
<td>0.600***</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.114)</td>
</tr>
<tr>
<td>Split x Few x High Cost</td>
<td>0.105***</td>
<td>0.611***</td>
</tr>
<tr>
<td></td>
<td>(0.021)</td>
<td>(0.119)</td>
</tr>
<tr>
<td>Split x Many x High Cost</td>
<td>0.103***</td>
<td>0.517***</td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
<td>(0.158)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.455***</td>
<td>0.455***</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.010)</td>
</tr>
</tbody>
</table>

Observations 17,999 17,999 17,999 17,999  
R-squared 0.305 0.305 0.383 0.383

FE F + SxY F + SxY F + SxY

Notes: The table presents results from four fixed effects OLS regressions where a unit of observation is a forest-species-year. The outcome for the two three columns is a binary variable equal to one if any timber was produced. The outcome variable for the next two columns in the inverse hyperbolic sine of the volume of timber produced measured in meters cubed. High cost are forests above the bottom quartile in estimated compliance costs. Few is an indicator variable equal to one if the share of forests certified is greater than 50%. Many is if the share of forests certified is greater than 50%. Standard errors are in parentheses and are clustered by species type. * p < 0.05, ** p < 0.01, *** p < 0.001.

### Table A2
Variation in Price within Genus

<table>
<thead>
<tr>
<th>Genus</th>
<th>Common Name</th>
<th>FOB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afzelia</td>
<td>Doussié blanc/Pachyloba</td>
<td>$22.58</td>
</tr>
<tr>
<td>Afzelia</td>
<td>Doussié rouge</td>
<td>$177.66</td>
</tr>
<tr>
<td>Aningeria</td>
<td>Aningré</td>
<td>$34.50</td>
</tr>
<tr>
<td>Aningeria</td>
<td>Aningré A</td>
<td>$185.02</td>
</tr>
<tr>
<td>Erythrophleum</td>
<td>Tali Yaoundé</td>
<td>$94.84</td>
</tr>
<tr>
<td>Erythrophleum</td>
<td>Tali</td>
<td>$1164.62</td>
</tr>
<tr>
<td>Guarea</td>
<td>Bossé foncé</td>
<td>$26.95</td>
</tr>
<tr>
<td>Guarea</td>
<td>Bossé clair</td>
<td>$141.05</td>
</tr>
<tr>
<td>Khaya</td>
<td>Acajou à grandes folioles</td>
<td>$2.20</td>
</tr>
<tr>
<td>Khaya</td>
<td>Acajou blanc</td>
<td>$2.90</td>
</tr>
<tr>
<td>Khaya</td>
<td>Acajou de bassam/Ngollon</td>
<td>$385.80</td>
</tr>
<tr>
<td>Pterocarpus</td>
<td>Padouk blanc</td>
<td>$92.39</td>
</tr>
<tr>
<td>Pterocarpus</td>
<td>Padouk rouge</td>
<td>$302.84</td>
</tr>
</tbody>
</table>

Notes: FOB is Free on Board price used in 2006 by Cameroon customs when assessing export value, reported in 2006 US dollars. List includes all genus with at least two species where both species had an FOB price listed by customs.
Fig. A1 Density of Treatment Intensity by Year

References


