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Assessing the impact of China's timber industry on Congo Basin land use change

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Through the rise of global commodity chains, consumer demand in China and the USA has given rise to the extraction of natural resources in the Congo Basin. The Chinese market for high-valued animal products such as elephant ivory and pangolin scales has encouraged poaching, exploitation and trafficking of these goods in Africa. Chinese demand for other African commodities, however, remains less well known. Using data across a 15-year period (2001–2015), we analysed the relationship between Chinese timber imports and tree-cover loss in the Congo Basin. Tree-cover loss was measured via remote sensing and the value of imports was obtained from official trade statistics. Results indicate that the total accumulated export of wood from Congo Basin countries to China doubled between 2001 and 2015, with 50% of exports originating from Cameroon and the Republic of Congo. We found a positive relationship between measures of Chinese logging and the loss of tree cover in the Congo Basin. Further investigation of the timber products market showed that US demand for Chinese-made furniture was positively correlated with Chinese timber imports from the Congo Basin. These findings suggest that US demand for furniture encourages Chinese economic actors to harvest timber from Congo Basin forests. Our results help to illuminate the complex environmental and economic drivers surrounding trade and deforestation and can help inform consumers about more sustainable ways to purchase wood products from one of the world's preeminent biodiversity hotspots.

KEYWORDS
biodiversity, Congo Basin, deforestation, global supply chains, telecoupling

1 | INTRODUCTION

Research on global supply chains has highlighted the importance of understanding cross-border and global consumption demands, material flows and how connections between nature and human beings are growing ever tighter in a more globalised world (Seto et al., 2012; Wiedmann et al., 2015; Yu et al., 2013). Rapid globalisation has led to a spatial disconnect between where products are consumed, and where the materials required to produce such products originate (Meyfroidt et al., 2010). Demand for products in wealthier, more developed, countries can lead to detrimental environmental pressures in resource-rich regions such as the tropics (Rice, 2007; Yu et al., 2013). High US consumption rates and natural resources dependence on other countries has increased consumers' attention on the local/regional environmental impacts of global supply chains (Kissinger & Rees, 2010; Yu et al., 2013). More recently, China's role as a major processing hub of globally sourced primary products (Yu et al., 2013), especially of timber products (Laurance, 2008; Narins, 2015), has gained importance in light of the environmental knock-on effects associated with wooden furniture production (see e.g., Kamps, 1998). While wood products exports (in the form of furniture) from China to the USA illustrate just one example of the broader trend of growing bilateral trade between the Chinese and the US economies, it represents the increasingly prevalent trend of telecoupling (socioeconomic and environmental interactions across distance, see e.g., Liu, 2014) in a complex world.

With growing interest in the market feedback mechanisms associated with deforestation, conservation and land management, this project examines an important set of knock-on effects relating to tropical forest loss in a telecoupled world. The aim of this analysis is to gain a deeper understanding of the linkages between Chinese timber imports from the Congo Basin and the connection that this relationship has to the US furniture market.

After Oceania, Africa was the second largest source of hardwood exports to China in 2016 (Table S1). When considering the place Africa occupies as a major provider of timber products, it is important to note that much of the continent's hardwood timber originates in the Congo Basin of Central Africa. The Congo Basin harbours exceptional biodiversity that represents 20% of the Earth's recognised plant and animal species (Oates et al., 2004; Sonwa et al., 2011). The region is also rich in natural resources, including oil, minerals and timber (Edwards et al., 2014; Huang et al., 2013). In addition to providing carbon sequestration, habitat for terrestrial biodiversity and other crucial ecosystem services, forested areas in the Congo Basin play a crucial role in providing water for hydropower projects, which are the main source of electricity in the region (Nlom, 2011; Power Africa, 2015).

Although a variety of economic activities, including mining and petroleum operations, can have an impact on the biodiversity of the Congo Basin (Thibault & Blaney, 2003), monitoring of these impacts varies across the region, making it difficult to compare trends between countries and identify specific drivers of biodiversity loss. In contrast, tree-canopy cover and tree-cover loss can be measured by remote sensing using a consistent methodology across countries and regions (reviewed in Gillespie et al., 2008). In this way, extractive activities such as logging can be monitored longitudinally.

Over the past 15 years, Chinese economic actors have increased their participation in Congo Basin timber exports (Laurance, 2015; Weng et al., 2014). For example, in 2001, EU imports of Congo Basin wood were 40% greater than those of China, but by 2015 Chinese imports were 10% greater than those of the EU (Figure S1). Congo Basin governments are still adapting to this changing pattern of timber extraction and often have limited resources to develop sustainable management and harvest plans (Bele et al., 2015).

To understand how Chinese wood imports are related to deforestation in the Congo Basin, it is instructive to consider the characteristics of Chinese economic actors in the region, which can be classified into state and private entities (Jiang, 2009). The Chinese government's strategy to access key resource commodity chains is reflected in its development assistance to Sub-Saharan Africa. Chinese development assistance, with its focus on loans-for-infrastructure projects, contrasts with Western government loans to Africa, which are concentrated in healthcare services and environmental protection (Brautigam, 2009; French, 2014; Shinn & Eisenmann, 2012; Strange et al., 2014). In parallel to Chinese government ventures, Chinese private enterprises also play an important role in Congo Basin economies. For instance, Chinese companies harvest timber in the region, ship wood products to factories in eastern China, manufacture furniture from the lumber and export the finished goods to developed countries (Huang et al., 2013). Within the Congo Basin, different Chinese firms use distinct business models, with some carrying out large-scale, industrial timber harvesting and operating under a government-approved management plan, while others conduct smaller-scale artisanal logging (IIED, 2015; Weng et al., 2014).

The impact of Chinese consumption on African biodiversity has been investigated in the context of trafficking of wildlife products such as elephant ivory and pangolin scales (Wittemyer et al., 2011; Wittemyer et al., 2014; Zhou et al., 2014) as well as timber. Given that Chinese demand drives the harvest of other African commodities (Yu et al., 2013), the objectives of this study are to: (1) assess the relationship between wood exports to China and tree-cover loss in the Congo Basin and (2) determine the relative importance of US consumer demand as a driver of wooden furniture production in China.

2 | METHODS

2.1 | Temporal trends in the China–Congo Basin timber trade

We examined wood exports to China from Cameroon, Central African Republic, Democratic Republic of Congo, Gabon and the Republic of Congo, all of which are trading partners with China and receive Chinese development assistance (Strange et al., 2014). We queried the UN Comtrade Database for exports in commodity code 44 "Wood and articles of wood" from these countries to China (UN, 2017). Equatorial Guinea was not included because it did not report such exports. We considered 15 years (2001–2015) because estimates of tree-cover loss based on remote sensing are available for this period from the University of Maryland (UMD) Global Forest Change data set (Hansen et al., 2013). We deflated the yearly values using the Federal Reserve dollar index and standardised timber trade data across years and countries.

2.2 | Drivers of tree-cover loss in Cameroon, Central African Republic, Republic of Congo and Gabon

We investigated the association between tree-cover loss and four predictor variables:

$$y_{it} = b_{0it} + b_{1it}x_{1it} + b_{2it}x_{2it} + b_{3it}x_{3it} + b_{4it}x_{4it} + \alpha_i + \varepsilon_{it} \tag{1}$$

Here y_{it} was the loss of tree cover in country i in year t from 2001 to 2015, defined as conversion of vegetation to less than 30% canopy density as in the UMD data set. Percent tree-cover loss per country in year t was calculated as the hectares of tree-cover lost in t divided by the number of hectares of tree cover from the previous year. Proportions were arcsine square root transformed for normality. Statistical hypothesis tests require normality and this transformation is effective for normalising proportions (Ahrens et al. 1990, Rosner, 2006). x_{1it} was the percent of wood exports from country i to China in year t, defined as the value of wood exported to China in US dollars, divided by the total value of wood exported globally in US dollars from Comtrade. x_{2it} was the demographic growth rate in rural areas in year t (World Bank Group, 2015). x_{3it} was oil palm exports in year t according to Comtrade. We also analysed time-lagged effects of palm oil exports (see Supporting Methods). x_{4it} was the size of the network of logging roads in year t (MOABI & World Resources Institute, 2015). The intercept b_{0it} and the regression coefficients b_{1it} through b_{4it} were estimated from the data. The b coefficients and intercepts vary across years. The sample size was 45 because we had data for four countries over 15 years from 2001 to 2015 and there were 15 missing records. ε_{it} was a random error term.

The term α_i in the regression model represents the effect of forestry regulations in each country on rates of forest loss. For example, this term captures the idea that forestry policies in Cameroon may have affected forest loss differently than the Republic of Congo's policies. This aspect of the analysis excluded the Democratic Republic of Congo, as its forest loss is driven primarily by slash-and-burn agriculture rather than the commercial timber harvest (Potapov et al., 2012). The country term α_i was treated as a fixed effect, meaning that over the period from 2001 to 2015 the effect of a particular country's policies on forest loss did not change from one year to the next.

We fit the model in Equation 1 to the data using the *plm* library in R. The rationale for using *plm* was that if the fixed effects terms α_i were correlated with the predictor variables $x_{1it}, \ldots, x_{4it}$, the use of ordinary least squares could result in estimates of the b terms that could be inconsistent. In other words, as the sample size increases, the estimates would not necessarily approach the true value of the parameter (Gut, 2009). *plm* implements data transformations and computational estimation procedures to ensure that the estimates of b in a fixed effects model will be consistent (Croissant & Millo, 2008).

2.3 | Drivers of Chinese imports from the Congo Basin

We investigated predictor variables that could potentially explain Chinese wood imports from Cameroon, Central African Republic, Gabon and the Republic of Congo from 2001 to 2015 according to Comtrade. Initially, we considered five predictors, which will be referred to as $x_{1t}, \ldots, x_{5t}$. x_{1t} was the value of furniture (Comtrade commodity code 94) imported by the USA from China in year t. Although other markets such as the European Union, Japan, Hong Kong, Australia, Singapore and Canada are major importers of Chinese wood furniture, their imports pale in comparison to US imports of such furniture from China. For example, from 2001 to 2015, US imports of furniture from China were three times greater than those from the EU (Figure S2). x_{2t} was the value of wood consumed domestically in China in year t (SFA, 2013), x_{3t} was labour costs in China in year t (Expansión, 2017), x_{4t} was labour costs in Cameroon in year t, which we used as a proxy for costs across Central Africa (Expansión, 2017). x_{5t} was timber prices in year t (Quandl Core Financial Data, 2017). We constructed linear regression models consisting of subsets of the predictor variables $x_{1t}, \ldots, x_{5t}$ and the dependent variable y_t, defined as the value of Chinese wood imports from Cameroon, Central African Republic, Gabon and the Republic of Congo according in year t from 2001 to 2015. There are 32 possible models consisting of subsets of $x_{1it}, \ldots, x_{5it}$. During exploratory data analysis, we found that US wood imports x_{1t}, labour costs in China x_{3t} and labour costs in Cameroon x_{4t} were highly correlated ($r > .6$). As multicollinearity leads to inaccurate estimates of regression coefficients (Montgomery et al., 2006), we excluded from consideration models that included correlated predictors. We assessed support for the remaining models by calculating Akaike weights (Table S2).

3 | RESULTS

3.1 | Temporal trends in the China–Congo Basin timber trade

From 2001 to 2015, total accumulated exports of wood from Congo Basin countries to China grew 2.1 times (Figure 1). While exports to China increased, exports to the EU declined by half (Figure S1). Wood exports from the individual Congo Basin countries exhibited distinct patterns. In the Democratic Republic of Congo, exports to China were consistently low, comprising less than 10% of total exports from Central Africa. However, in Gabon, there was significant inter-annual variation in commerce with China during the study period. From 2001 to 2009, Gabon supplied 60% of all Congo Basin wood exports to China, but subsequent years saw a substantial decrease in trade following Gabon's ban on the export of unsawn logs in 2010 (Matsuura, 2011). By 2015, Gabon's wood exports to China dropped to only 30% of all Congo Basin wood exports to China, and Cameroon and the Republic of Congo had replaced Gabon as the largest exporters (Figure S5).

3.2 | Drivers of tree-cover loss in Cameroon, Central African Republic, Republic of Congo and Gabon

When we fit the model in Equation 1 to the data on tree-cover loss, the goodness of fit of the model to the data was $R^2 = .44$ ($n = 45$). Of the four predictor variables in Equation 1 – logging roads, palm-oil production, rural population growth and wood exports to China – the only predictor variable that was statistically significant was wood exports to China (Table 1). Figure 2 shows the goodness of fit of a linear model that only includes wood exports to China as a predictor of

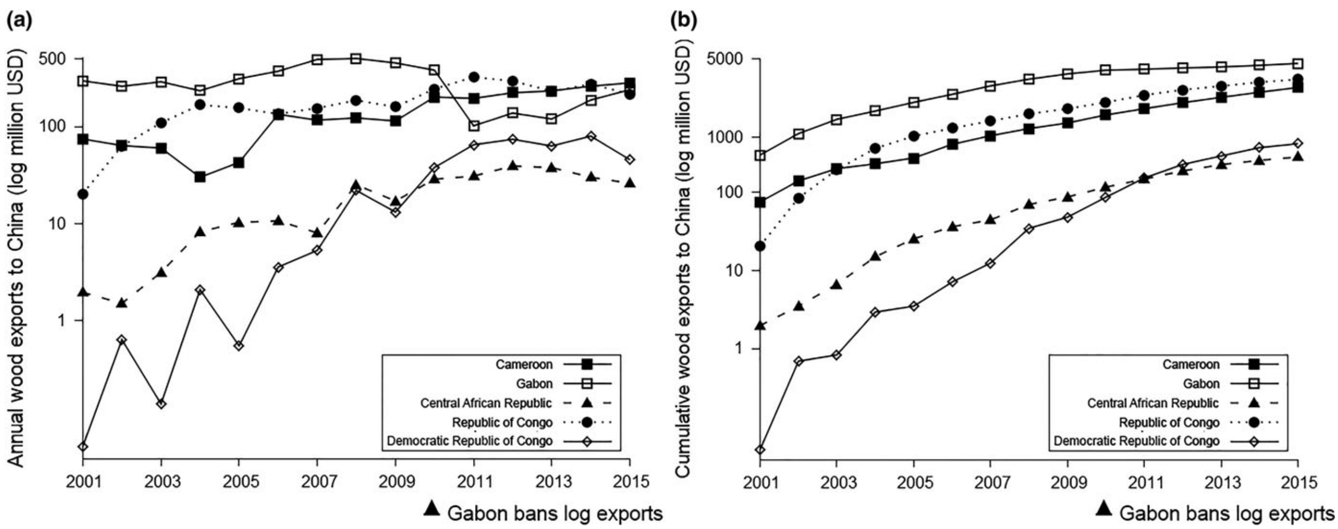

FIGURE 1 Export of wood products from Central Africa to China, 2001–2015. After Gabon banned log exports in 2010, exports from Cameroon and Republic of Congo increased. (a) Yearly exports and (b) cumulative exports.

tree-cover loss in Cameroon, Central African Republic, Republic of Congo and Gabon. Rates of tree-cover loss were significantly higher in Cameroon and Republic of Congo than in Gabon (Figure S3). To assess temporal correlation, we tested whether rates of tree-cover loss were correlated in consecutive years. The results indicated that there was no significant temporal autocorrelation (Durbin Watson test = 1.65, $p > .05$).

3.3 | Drivers of Chinese imports from the Congo Basin

The best-supported model was Chinese wood imports from Cameroon, Central African Republic, Gabon and the Republic of Congo = US demand + Chinese domestic consumption (Akaike weight: 67%, Table S2). The partial correlation coefficient for US demand was .79 and that of Chinese domestic consumption was .1 (Table 2, Figure 3). This suggests that demand from China was less important than US demand in driving Congo Basin timber extraction. To put this analysis in context, we consulted others sources of data on the magnitude of the USA–China furniture trade. According to China's General Administration of Customs, from 2006 to 2016 approximately 40% of Chinese furniture exports were to the USA

TABLE 1 Effect of Chinese wood imports, rural population growth, palm-oil production and logging roads on the loss of tree cover in Central Africa, 2001–2014

Variable	Coefficient	Standard error	*p*
Chinese wood imports (%)	.375	0.0949	4.52×10^{-4}
Rural population growth (%)	−.0675	0.0527	.211
Palm-oil production ($)	-1.16×10^{-9}	2.93×10^{-9}	.695
Logging roads (km)	4.6×10^{-4}	2.67×10^{-4}	.095

This table shows a multivariate model with the four variables below ($R^2 = .44$, $n = 46$). Figure 2a shows the linear regression line for the univariate model that consists of only Chinese wood imports ($R^2 = .3$).

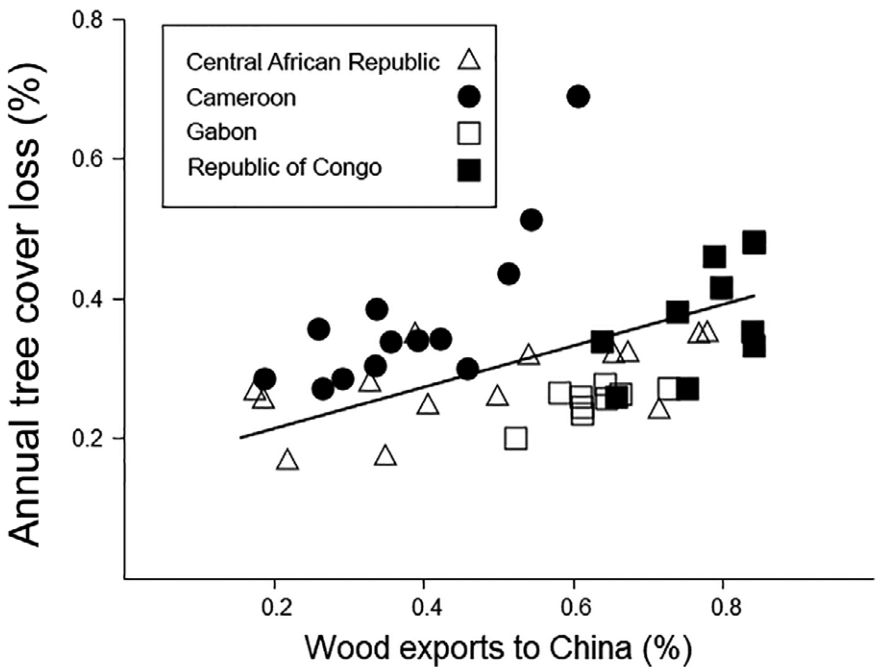

FIGURE 2 Effect of Chinese wood imports on tree-cover loss in the Congo Basin. Yearly tree-cover loss was defined as conversion of vegetation to less than 30% canopy density. We calculated loss as a percentage of the cover that remained in the previous year. Each point represents data from one country for one year from 2001 to 2015, arranged chronologically. The values along the *x*-axis indicate, for a given year, the percentage of the country's wood exports that were sold to China. The black line is a linear regression best-fit line of a univariate model of the effect of Chinese wood imports on loss of tree cover in Central Africa ($R^2 = .3$). The grey line is a broken stick model where the segments correspond to before and after Gabon's ban on unsawn log exports in 2010. Table 1 reports the regression coefficients for a multivariate model based on Chinese wood imports, rural population growth, palm-oil production and logging roads ($R^2 = .44$).

TABLE 2 Effect of US furniture demand and Chinese domestic wood consumption on Chinese wood imports from Central Africa

Variable	Partial R^2	Coefficient	Standard error	*p*
Intercept	–	1.969×10^7	1.057×10^8	.85596
US imports of Chinese wood products ($)	.785	.0304	0.00526	.00017
Chinese domestic consumption of wood products ($)	.103	.00197	0.0102	.851

This model was better supported than linear regression models based on labour costs and timber prices (Table S2).

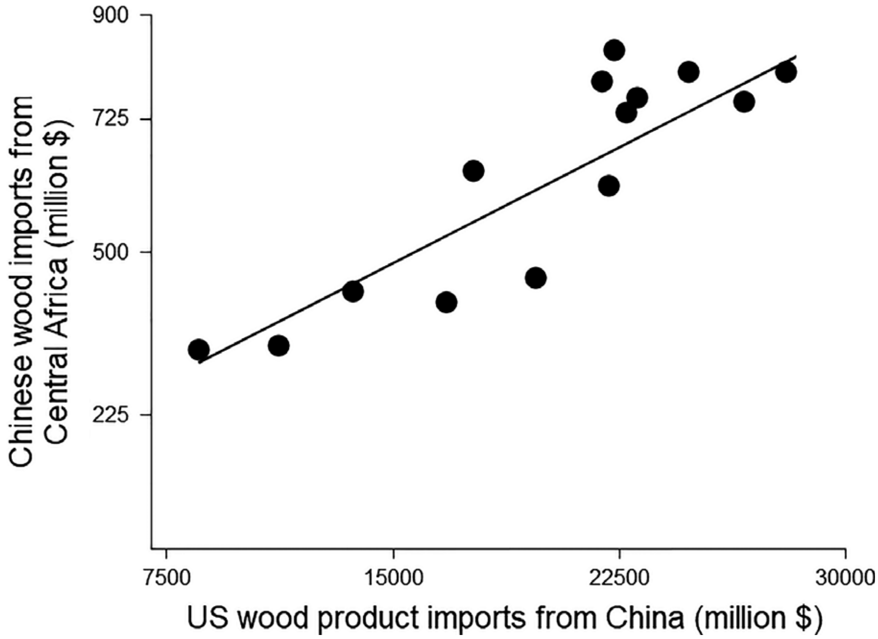

FIGURE 3 Linear regression model of the effect of US furniture imports from China on Chinese wood imports from Central Africa. The regression line is the best-fit line of a univariate model of the effect of US furniture imports on Chinese wood imports from Central Africa. Table 2 reports the regression coefficients for a multivariate model based on US furniture imports and Chinese domestic consumption.

(Figure S2). Further, according to data reported by the USA, the percentage of US furniture imports from China grew from 30% of all furniture imports in 2001 to 50% in 2015 (Figure S4).

4 | DISCUSSION

Wood products exports from China to the USA are an example of the broader trend of increasing bilateral trade that began with Chinese economic reforms in 1978 and continued with China's admittance to the World Trade Organization in 2001 (Morrison, 2015). Our analysis of markets for wood products showed that US demand for Chinese furniture is positively correlated with Chinese wood imports from the Congo Basin. Although we focused on 2001 to 2015, data from the 1990s supported the trends observed in the more recent data to the extent that, when US demand for furniture from China was lower in the 1990s, Chinese wood imports from the Congo Basin were also significantly lower (Supporting Information).

Our analysis reinforces previous findings that have highlighted the role of China as a processing hub (Yu et al., 2013) and suggests that US demand may be encouraging Chinese companies to harvest Congo Basin wood. However, it is important to consider our findings in a manner that is sensitive to the many complexities of international trade and differences in capacity among Congo Basin countries. We found that the Democratic Republic of Congo's trade with China was consistently low across the study period, which could be due to the fact that the limited road network makes timber extraction economically challenging (Ickowitz et al., 2015). Our findings support previous work showing a decline in the trade of wood between Gabon and China, following Gabon's ban on the export of logs in 2010 (Weng et al., 2014). Our study suggests that Gabonese exports were replaced by timber originating in the Republic of Congo and Cameroon. As Cameroon and Gabon's forestry codes are undergoing revision (Eisen et al., 2014), our study aims to bring the drivers of deforestation to the attention of the public and policymakers.

Efforts to conserve Congo Basin forests could include a variety of approaches implemented at different scales. At the local scale within the Congo Basin, such initiatives could include government programmes to improve the sustainability of timber extraction, agroforestry projects (Bhagwat et al., 2008), use of wood fuel alternatives like manure (Smith et al., 2015) and community forest management (Bowler et al., 2012). At the international scale, conservation organisations could expand efforts to educate furniture consumers about the impact of unsustainable timber extraction on biodiversity and ecosystem services.

Congo Basin governments will need to improve the sustainability of timber harvested for furniture production, and there is a need for stringent and transparent permitting processes, improvements in the efficiency of forestry management programmes and a clear directive to strengthen the enforcement of reforestation requirements. In order to implement such programmes, however, major governance challenges must be overcome. Chief among these broad challenges are the need to correct flawed assumptions surrounding the ways to fix failed and weak governments in Africa (many such governments are located in the Congo Basin). The assumptions are that: (1) successful Western state institutions can be transferred to Africa; (2) rebuilding African institutions suggests a "logic of cooperation" between African leaders and Western donors (which assumes a common understanding of success and failure); and (3) Western donors will be able to provide the necessary resources for long-term government strengthening in the region (Englebert & Tull, 2008).

Currently, timber firms operating in the Congo Basin can either choose to implement a reforestation plan or pay a tax, which is supposed to fund reforestation (Wasseige et al., 2010). Approximately 40% of companies choose the second option, but compliance with reforestation requirements is often lacking, hence stricter enforcement is imperative (WRI, 2012). Congo Basin countries could focus on implementing domestic policies to reduce deforestation that ban the export of logs and combat corruption in the forest sector (Weng et al., 2014). Prohibiting log exports would potentially prevent timber harvested illegally from leaving the country, thus deterring harvest in the first place, and would incentivise development of domestic capacity to process wood products.

Several opportunities exist for future research. Although we only examined timber extraction, forest loss in the Congo Basin may be driven by land conversion processes, such as slash-and-burn agriculture. Indeed, while the commercial harvest of wood explained a substantial percentage of tree-cover loss in the Congo Basin, a variety of land-cover change processes not considered here may account for the unexplained variation, including the conversion of forest to agricultural fields or pastures for livestock.

Remote-sensed images of deforestation were available on an annual basis from 2001 to 2015. Due to the limited temporal scope of the data, our sample sizes were small ($n = 45$). We carried out power analysis (Faul et al., 2009) to assess the smallest effect of wood exports to China on tree-cover loss that could be detected with these data. The results indicated that we could have 95% confidence of finding a significant effect of exports on loss of tree cover if every 1% increase in exports causes a decrease of at least 0.1% in tree cover. If the effect of exports on deforestation were any weaker, we could not be confident of detecting it with 45 observations. Further, remote-sensing estimates of deforestation due to logging are subject to a variety of sources of error – including effects of cloud cover, mistakes by the image analyst, errors introduced when correcting for the effects of aerosols and water vapour – that can cause errors of up to 14% in estimates of deforestation (Asner et al., 2005).

Finally, future work should refine the available data sets on land-use change and trade in the Congo Basin. We used the value of timber and furniture sales according to Comtrade, but such figures could be biased due to erroneous records or countries' unwillingness to report trade activity. Such biases could be reduced by using statistical estimation approaches to infer the true flow of these commodities in cases where underreporting is suspected (reviewed in Farhan, 2015).

5 | CONCLUSION

Our results underscore the need to increase US consumers' awareness of the global timber trade and its environmental implications for biodiversity hotspots such as the Congo Basin. Thus far, attempts to raise this knowledge have included the development of certification programmes to help buyers identify furniture that is the end product of a sustainable supply chain (Union of Concerned Scientists, 2013). The path forward for increasing awareness among US consumers could include expanding these programmes, as they currently cover only 12% of tropical forests. In Cameroon, just seven concession operators are responsible for 50% of timber sales (WRI, 2012); certification programmes could target such companies that account for a large fraction of the volume of wood products. Other awareness-raising efforts could include educating consumers about alternatives to tropical hardwoods, such as bamboo, plastic composites and recycled wood (Elias et al., 2012; Forest Peoples Programme, 2014). These approaches show promise for stemming deforestation in the Congo Basin and other ecoregions whose sylvan biodiversity is threatened by unsustainable harvest and are meant to stimulate interest in and discussion of "knock-on" impacts (or network effects) on Congo Basin deforestation.

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DATA ACCESSIBILITY

This study was a re-analysis of existing data that are publicly available from Comtrade at DOI: 10.978.921/1616255 and Google Earth Engine at https://doi.org/10.1126/science.1244693.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Destinations of Central Africa wood exports, 2001–2015.
Figure S2. Destination of Chinese furniture exports, 2006–2016 (Forest Trends, 2017).
Figure S3. Relative rates of tree cover loss among Central African Republic, Cameroon, Gabon and Republic of Congo (2001–2015).
Figure S4. Sources of US furniture imports.
Figure S5. Trends toward increasing reliance on Cameroon and Republic of Congo as wood suppliers to China.
Table S1. Sources of hardwood imported by China in 2016 (Forest Trends, 2017).
Table S2. Effect of imports, labor costs, and Chinese domestic consumption of wood products on Chinese wood imports from the Congo Basin.

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