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Crop Prices and Deforestation in the Tropics

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Abstract

Global food demand is rising, pushed by growing world population and dietary changes in developing countries. This encourages farmers to increase crop production which, in turn, increases worldwide demand for agricultural land and the pressure on tropical forests. With a possible doubling of world food demand by 2050, this pressure is not likely to decrease in the next decades. While the impact of food demand on deforestation has been pushed forward in the medias, rigorous evidence using large-N data estimating the causal impact of crop price variations on deforestation remains scarce. Here, we quantify this impact over the twenty first century using high resolution annual forest loss data across the tropics, combined with information about crop-specific agricultural suitability and annual international commodity prices. We find a sizeable impact of price variations on deforestation: crop price variations are estimated to have contributed to 35% of the total predicted deforestation in the tropics over the period 2001-2018. We also highlight that the degree of openness to international trade and level of economic development are first-order local characteristics to explain the magnitude of the impact of crop prices on deforestation.

1 Introduction

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Tropical deforestation is one of the main causes of recent global environmental changes. Recent assessments revealed that food systems are responsible for a third of global anthropogenic GHG emissions [1] and that 17% of tropical moist forests have disappeared since 1990, with a remaining area of about one billion hectares in 2019, from which 10% are degraded [2]. Deforestation threatens crucial ecosystem services, such as biodiversity richness, climate regulation, carbon storage, water supplies, and leads to more infectious diseases [3, 4, 5, 6, 7, 8]. Market forces are among the most prominent determinants of tropical deforestation [9, 10], as they largely drive agricultural expansion [11, 12]. Forecasts point to a sharp increase in food demand over the next decades, with a possible doubling between 2017 and 2050 [13], which would drag crop prices in its wake. This will likely lead to a strong increase in land demand as private actors relate the amount of deforested area to the difference between the private value of forested and agricultural land [14].

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In this paper, we estimate the effect of crop price variations to deforestation in the tropics. We combine different datasets at the spatial resolution of 0.5 degree latitude and longitude grid cells (approximately 55×55 kilometers at the equator) covering the tropics from 2001 to 2018. First, we make use of fine-grained estimates of yearly deforestation of 1 arc-second pixels (approximately 30 meters \times 30 meters at the equator) [15]. For each cell, we compute the total number of pixels that are deforested during a year. Second, we gather cell-specific information on the agronomic suitability of 15 crops to proxy the potential crop specialization at the cell-level (Global Agro-Ecological Zones, [16]). We combine these data with the international prices of crops traded on international markets to construct a cell-specific, time-varying crop price index. This index is computed as the sum of the international prices of each crop in a given year, weighted by the relative agronomic suitability of each crop in the cell (see Methods in Section 4.1 and Supplementary Information (SI, hereafter) Section 9.1 and 9.2). Our final sample includes around fourteen thousands 0.5×0.5 degree cells over the period 2001-2018.

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Our identification strategy uses within-cell variations in the crop price index and deforestation over time. We control for a large array of unobserved factors, namely all time-invariant cell characteristics and national time-varying shocks, that may correlate with both deforestation and world crop prices. We find that changes in crop prices significantly affect deforestation in the tropics. The effect is sizeable: the variations of our price index contribute to 35% of the total predicted deforestation over the period. We find that the effect of price variations significantly varies within countries depending on crop suitability and initial forest cover, as well as on the degree of exposure to international trade (proxied by distance to seaports), on the level of economic development (nightlight luminosity) and, to a lesser extent, state capacity (distance to the capital).

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The presumption that international crop prices, boosted by global demand, contribute to tropical deforestation is not new. However, the empirical evidence to date continues to be largely based on cross-national comparisons [17, 18, 19, 20, 21, 22], focusing on a single country [23, 24, 25, 26], region [18], and with a limited number of commodities [27]. The usual approaches in global studies encompasses spatial attribution (based on crop-specific production maps [27] or spatial patterns recognition [10, 28]) and input-output [29, 30, 31] or trade and land-balance modelling [12, 32, 33]. These contributions typically use supply side models at the national level and downscale national trade or production data at the local-level. Our approach has several advantages: it is less data-demanding¹; it is agnostic in terms of scale of agricultural production contrary to contributions based on spatial attribution or classifications methods [10, 28] that oppose large scale commodity driven deforestation to shifting agriculture²; it uses a sample based on forested areas at the beginning of the study period, rather than deforested areas at the end of the period, which facilitates causal interpretation; and it does not suffer from leakage effects since it is not limited to a single crop or geography [35].

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Our study differs from this literature on other dimensions. First, we precisely estimate both the effect and the contribution of international crop prices variations to tropical deforestation over two decades, at a fine-grained level, yet at a global scale. Second, our approach combines exogenous local crops suitability – rather than production – with international crop prices, and controls for a large range of

¹National data have well-known limitations. They are subject to omission bias stemming from undeclared activities such as home-based and locally-consumed agricultural production. A large share of smallholder production is consumed locally and not traded on international markets, such as oil in Sub-Saharan Africa [34]. Trade flow analyses and trade accounting methods are also limited by their lack of spatial explicitness, leading to imprecise links between consumption patterns and socio-environmental impacts in production regions [31]

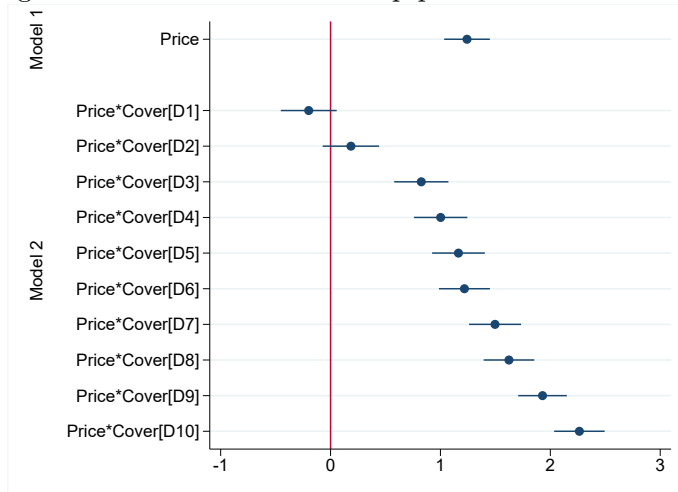
²Because they rely on the recognition of spatial patterns these methods cannot be used to link production of – or demand for – commodities to small scale deforestation that may however also be, directly or indirectly, related to demand on international markets.

71 possible confounding factors not accounted for in previous studies. Finally, we highlight a number of
 72 policy-relevant local factors affecting how fluctuations in crop prices trigger deforestation.

73 2 Results

74 **Crop prices and deforestation in the tropics.** Figure 1 displays the main results estimated with an
 75 Ordinary Least Square (OLS) estimator³: the cell-specific crop price index is positively and significantly
 76 correlated to deforestation (the estimated coefficient is equal to 1.24 and the standard error to 0.08). The
 77 effect is sizeable: a 10% increase in the price index leads to a 12.4% [$\pm 1.6pp$] increase in deforestation
 78 (Figure 1, Model 1). As the potential for deforestation mechanically depends on the proportion of forest
 79 cover at the beginning of the period (SI Figure 7 maps the forest cover in 2000), we allow the effect of
 80 crop prices to vary across deciles of cell-specific forest cover in 2000 (Figure 1, Model 2). We find that
 81 the effect of crop prices increases with initial cover. For the first two deciles, the point estimate is not
 82 significantly different from 0; the coefficient then nearly triples between the third and the last decile.
 83 These results are robust to various sensitivity checks (SI Section 10.2): i) using an alternative threshold
 84 for the canopy cover at the beginning of the period; ii) excluding potentially influential observations
 85 (outliers); iii) estimating the model through a Poisson Pseudo-Maximum Likelihood (PPML) estimator;
 86 iv) allowing the standard errors for both cross-sectional spatial correlation and location-specific serial
 87 correlation [36] and v) focusing on countries which market share in agricultural commodities is low at the
 88 world level. This last exercise is particularly relevant: despite the fine-grained level of our analysis, and
 89 using potential rather than actual agricultural production, we cannot fully rule out that both deforestation
 90 and international commodity prices are simultaneously caused by supply-side shocks in large producing
 91 countries. Our results is largely unchanged when focusing only on small producers, which comforts our
 92 demand-side interpretation of the results.

Figure 1: Baseline effects of crop prices on deforestation

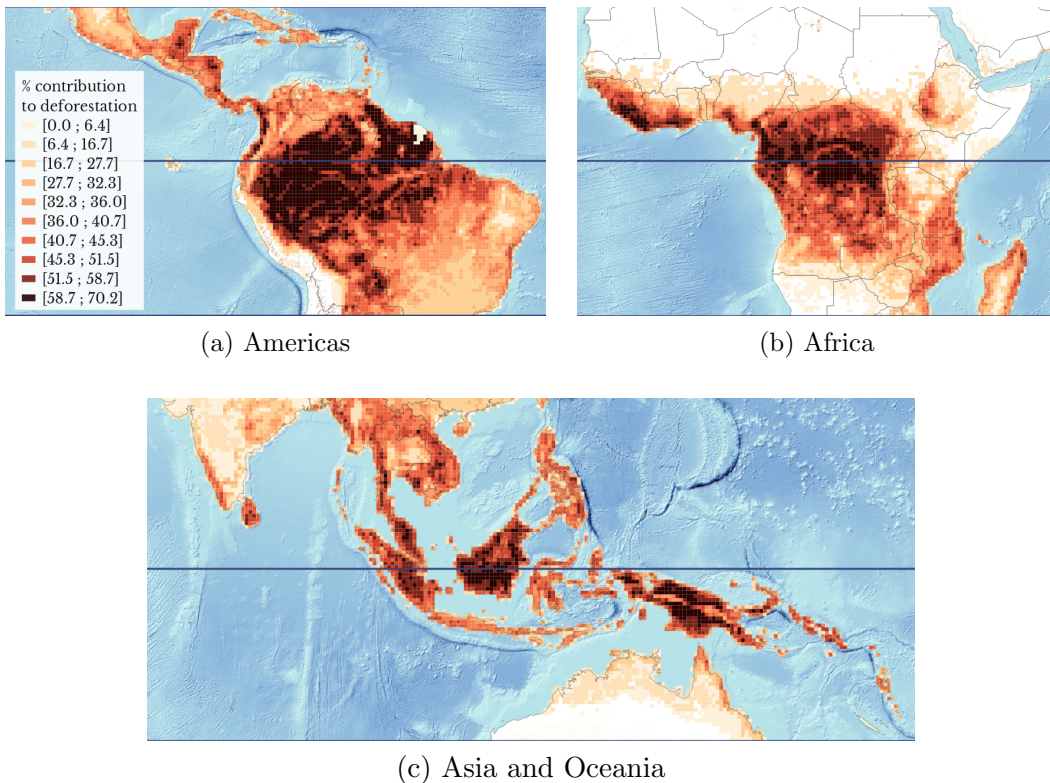


Note: Model 1 is the baseline estimate of the effect of the crop price index on deforestation, while Model 2 allows the effect of crops on deforestation to differ across deciles of forest cover at the beginning of the period (2000). See Section 4 and SI Section 10.1 for more details.

93 From 2001 to 2018, our crop price index has increased by more than 40% on average and the price
 94 of major crops such as maize, rice, oil-palm, soybean has increased by 45% to 85%. To get a sense of
 95 the role of this historical rise in crop prices, we use our estimates of Figure 1, Model 2 to estimate the
 96 total contribution of crop price variations to the observed predicted deforestation over this period. We
 97 find that the historical rise in crop prices contributed to 35% of predicted forest loss. Figure 2 reports
 98 spatial heterogeneity in the contributions across cells over the 2001-2018 period. Two features explain
 99 this pattern: heterogeneous crop suitability and hence variations of world prices (SI Figure 6), and the
 100 initial forest cover of the cell (SI Figure 7). A visual inspection reveals that the contribution of crop
 101 price variations has been the strongest in the three main tropical moist forest biomes: the Amazon,
 102 South-East Asia and, to a smaller extent West and Central Africa. Interestingly, and contrary to previ-
 103 ous evidence, we find that all tropical forests are subject to land pressure stemming from shocks in the

³Full estimations results available in SI Table 2.

Figure 2: Contribution of crop prices variations to deforestation, 2001-2018



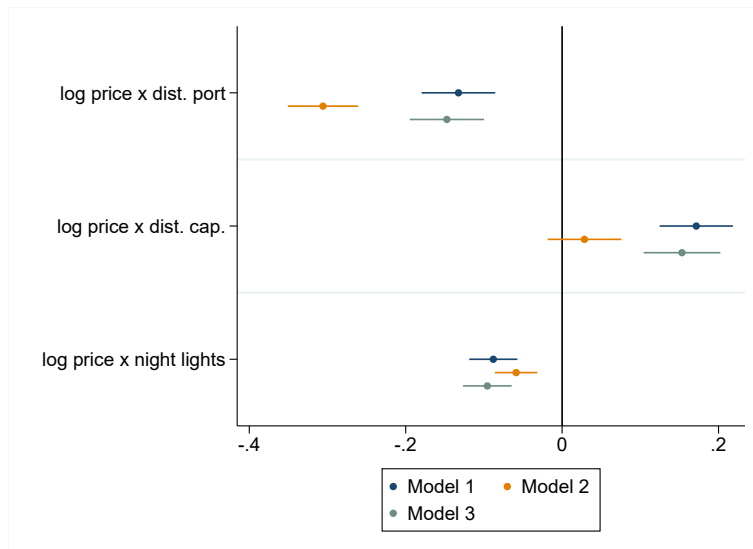
Note: Contribution of crop price variations to deforestation. Quantification based on the estimation results of Model 2 (see Methods in Section 4.1). We first compute the predicted level of deforestation using observed prices, our benchmark). Then we compute a counterfactual level of deforestation assuming fixing prices at their 2001 level. Finally, we sum these predictions by cell over the period, and compute for each cell the contribution of prices as the difference between the benchmark and the counterfactual predictions, divided by the counterfactual.

104 prices of internationally traded commodities. For instance, our results tend to validate recent evidence
 105 indicating that, despite cropland expansion in sub-Saharan Africa being still dominated by production
 106 for domestic markets, there is a growing influence of global markets on change in land use in the region [18].
 107

108 **Trade costs and other local characteristics.** Our main results suggest that areas witnessing stronger
 109 increases in the prices of locally suitable crops experience faster deforestation. It is likely, however,
 110 that other local characteristics may dampen or exacerbate the contribution of crop price variations to
 111 deforestation. First, as suggested by the literature [14, 37, 38], we expect openness to international trade
 112 to exacerbate the role played by crop prices. Second, local institutional quality and the capacity of states
 113 to enforce property rights may also affect the sensitivity of deforestation to crop prices [11]. Indeed, under
 114 open access regimes for instance, rational farmers should theoretically rush to exploit land and cut forest
 115 more quickly [37, 39]. The impact of the formalisation of land rights and land tenure on forest loss has
 116 been demonstrated in the case of a land registration program in Benin [40], in the case of a land titling
 117 program in the Brazilian Amazon [41] and the role of customary tenure systems on deforestation has also
 118 been exposed in the case of Cameroon [42].

119 We consider these potential mitigation factors by interacting cell-specific characteristics with our
 120 price index in our baseline models. To measure the cell-specific exposure to international trade, we use
 121 information on the distance of the cell's centroid to the closest major seaport as a proxy of transportation
 122 costs [14]. To measure institutional quality at the local-level, we use the distance between the cell's
 123 centroid and the capital city of the country. Rule of law, property rights protection and more generally
 124 institutional quality are expected to be weaker in places located far from the capital [43]. Finally, we
 125 consider a measure of nighttime luminosity to proxy local economic development [44, 45], taken at the
 126 beginning of the sample period to avoid reverse causality concerns. State capacity and institutional quality
 127 are also expected to be stronger in wealthier locations. All cell-specific variables have been standardized
 128 to make coefficients comparable.

Figure 3: Cell-level characteristics



Note: The figure displays the point estimates and confidence interval of the effect of the interaction between cell-specific characteristics and our prices index. Model 1 uses the baseline specification, augmented with interaction terms between the price index and (standardized) cell-characteristics variables (see SI Sections 4 and 10.1). Model 2 allows the effect of crop price on deforestation to vary across the deciles of the initial forest cover distribution. Model 3 controls for a full set of interaction terms between country dummies and the price index.

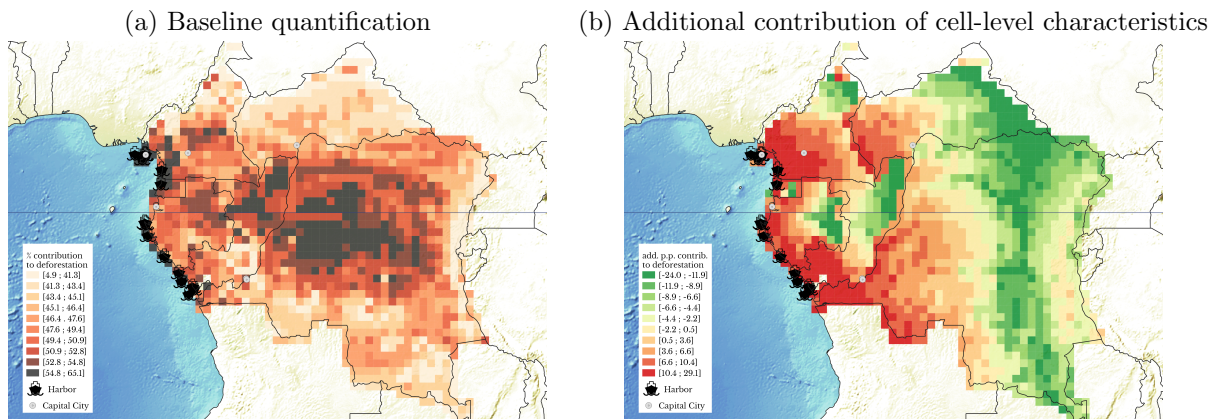
129 The standardized estimates of the interaction terms between cell-level characteristics and crop prices
 130 are plotted in Figure 3 (the full estimates are available in SI Table 3). Figure 3 considers three models:
 131 Models 1 and 2, as in Figure 1; and Model 3, which enables for heterogeneous effects of the price index
 132 between countries. In the latter, we purge the estimates of the interaction terms from their country-wide
 133 component (e.g., differences in country size), focusing solely on within-country variations in cells charac-
 134 teristics. First, we find that the positive effect of crop price variations on deforestation is significantly
 135 stronger in cells that are close to a seaport, suggesting that openness to international trade exacerbates
 136 the effect of crop prices variations on deforestation. Second, cells that are less economically developed
 137 display a stronger sensitivity to crop price variations. Finally, though the significance of the estimates
 138 fluctuates more, our results point to larger commodity-driven deforestation in cells that are more distant
 139 from the capital city – i.e. locations with weaker state capacity. On average across specifications, distance
 140 to port has the stronger effect. This supports the key role of access and exposure to international trade.
 141 The effect of trade costs and economic development are barely affected by our sensitivity checks; the effect
 142 of local state capacity is less robust (SI Section 10.2.2).

143 To illustrate these results, we focus on the Congo Basin, a major tropical moist forest biome spanning
 144 several countries. We first repeat the quantification exercise of Figure 2, restricting the sample to countries
 145 of the Congo Basin. The results are shown in Figure 4.a, which displays for each cell the contribution of
 146 crop price variations to predicted deforestation over the period, as well as the location of major seaports
 147 and of the capital cities of each country. Second, we repeat this quantification exercise but using the
 148 specification that includes interactions with cell characteristics (Model 2 of Figure 3). Figure 4.b plots
 149 the difference in percentage points between the two quantification exercises. Clearly, being close to a port
 150 has the strongest effect on commodity-driven deforestation. However, regions extremely distant from the
 151 capital city, though they are less exposed to international trade (e.g. the border between Cameroon and
 152 Central African Republic), also display significant effects. Having a visual inspection of the same exercise
 153 for the full set of regions in the tropics delivers the same striking spatial patterns (Figure 8 in SI Section
 154 10.3)

155 3 Discussion

156 We find that changes in crop prices significantly affect deforestation in the tropics at the local-level;
 157 this confirms the key role of market forces [12]. We bring robust statistical evidence that the many farm
 158 commodities and products traded daily on international markets are contributing to a large share of global

Figure 4: Focus on the Congo Basin



Note: Figure (a) shows the contribution of crop price variations to forest loss, sample restricted to the Congo Basin. Quantification based on the estimation results of Model 2 (see Methods in section 4). We first compute the predicted level of deforestation using observed prices, our benchmark. Then we compute a counterfactual level of deforestation assuming fixing prices at their 2001 level. Finally, we sum these predictions by cell over the period, and compute for each cell the contribution of prices as the difference between the benchmark and the counterfactual predictions, divided by the counterfactual. Figure (b) shows the difference in p.p. between Figure (a) and the sample quantification based on a specification where interaction terms between prices and cell characteristics are included.

159 deforestation. As the demand for these products increases, new arable land is required for commodity
160 crops. In this context, the natural solution to tackle deforestation goes through the demand side: if
161 consumers reduce their demand for agricultural products, crop prices will stabilize and deforestation
162 will likely slow down. However, forecasts about the evolution of demand over the next decades suggest
163 that a drop in demand is unlikely [13]. Policies targeting consumers' preferences and behavior should
164 therefore be combined with measures aiming at directly slowing down deforestation. Such measures
165 involve multiple actors – companies, NGOs and governments. Firms can implement strategies such as
166 supply chain initiatives promoting larger transparency, or adopt unilateral or multilateral commitments.
167 The complexity of the supply chains, the possibility of leakage, low and selective adoption, and the risk
168 of marginalization of smallholders make the impact of these actions uncertain [46] – as illustrated, for
169 instance, by the case of palm oil supply chains [47]. On the other hand, national and local governments,
170 with the help of NGOs, can implement various policies to reduce deforestation. These policies include
171 encouraging dietary changes, mandating transparency in supply chains, incentivizing companies to adopt
172 effective anti-deforestation strategies, penalizing companies responsible for significant deforestation, or
173 implementing programs to reduce the sensitivity of community incomes to international crop prices. The
174 development of monitoring tools such as the Trase initiative (*Transparency for Sustainable Economies*)⁴
175 and more generally the development of real-time information on areas at risk of deforestation, by improving
176 monitoring by local and national actors, could facilitate the application of anti-deforestation policies.

177 4 Methods

178 4.1 Data

179 We consider a full set of grid cells of the tropics, i.e. the area between the Tropic of Cancer at 23°26' N
180 and the Tropic of Capricorn at 23°26' S, divided in sub-national units of 0.5×0.5 degrees latitude and
181 longitude. Our unit of observation in our dataset is a cell-year; that is, we estimate how variations in
182 crop prices affect deforestation in a given cell during a given year, over the 2001-2018 period.

183
184 **Deforestation.** We use the tree cover loss data from Hansen *et al.* [15]. Thanks to Landsat data, they
185 define a tree cover loss as a stand-replacement disturbance or the complete removal of tree cover canopy
186 at the pixel scale. The original data contain an estimation of the annual tree cover loss for the period
187 2001-2018 (see SI Section 9.1), relative to the 2000 forest cover, for pixels at a spatial resolution of 1
188 arc-second (around 30 meters). In the baseline estimates, we consider a 1 arc-second pixel as being a

⁴The Transparency for Sustainable Economies initiative is an online platform aimed at improving the transparency, clarity and accessibility of information on the commodity supply chains that drive tropical deforestation.

189 forest when the forest cover in year 2000 is larger than 25%, as in global studies using the same data
 190 [48, 49, 50]. Alternatively, we use a 50% canopy threshold in our sensitivity analysis (see SI Section 10.2).
 191 For each of these thresholds, we count the number of pixels defined as deforested within each 0.5×0.5
 192 degrees cell-year – this is our baseline measure of deforestation.

193
 194 **Crop Price Index.** We rely on information on international crop prices and agronomic suitability to
 195 build our price index. Our index uses information for 15 crops, traded on international market places, for
 196 which both annual international price and suitability data are available: banana, barley, cocoa, coconut,
 197 coffee, cotton, maize, oil palm, rice, sorghum, soybean, sugar, tea, tobacco and wheat. International
 198 crop prices (base 100 in 2000) come from the World Bank Commodity Dataset [51]. The time-invariant
 199 agronomic suitability [16] comes from the Global Agro-Ecological Zones (GAEZ, FAO⁵). It is defined as
 200 the percentage of the maximum yield that can be attained in each grid cell. For each cell c and year t ,
 201 we compute the international market price of crops based on the cell-specific relative suitability of each
 202 crop i , i.e. for each cell, the suitability of the crop divided by the sum of the suitability of all the crops:

$$\text{Price}_{c,t} = \sum_{i=1}^{15} \alpha_c^i \times P_t^i, \quad (1)$$

203 where α_c^i is the relative suitability of crop i in cell c and P_t^i is the average price of crop i during year t .
 204 Our first identification assumption is therefore that fluctuations in the prices of, say, rice, affects primarily
 205 areas suitable to grow rice. Our second identification assumption is that $\text{Price}_{c,t}$ is not affected by de-
 206 forestation or by other time-varying determinants of deforestation. Suitability (α_c) being mostly related
 207 to natural soil characteristics, and not to actual crop production, it is arguably exogenous to changes in
 208 deforestation. We assume that prices (P_t^i) are also exogenous to cell-year deforestation and its drivers,
 209 given our level of spatial aggregation. However, because we cannot rule out the possibility that supply
 210 side shocks in large producing countries affect world prices, we also show that all our results are largely
 211 insensitive to the exclusion of large producers (SI Table 10).

212
 213 **Final Sample.** Our final sample covers the period 2001-2018 and is composed of 13,999 cells, for which
 214 agronomic suitability data is available and forest cover in 2000 is strictly positive, i.e, at least 1 arc-second
 215 pixel as forest when the canopy threshold is larger than 25% of the cover. Our dataset is therefore a bal-
 216 anced panel of 251,982 observations. Summary statistics appear in SI Table 1.

217
 218 **Preliminary evidence.** Over the 2001-2018 period, the SI Figure 5 shows the accumulated deforestation
 219 for each pixel and the SI Figure 6 displays the average price index variations. Interestingly, South America
 220 (the Amazon) and South-East Asia (Indonesia forests) display both the highest deforestation rates and
 221 the highest price index variations over the period.

222 4.2 Estimation

223 **Estimated models.** In the Model 1, we estimate the impact of the log of the crop price index ($\ln \text{Price}_{c,t}$)
 224 on the inverse hyperbolic sine transformation of the number of deforested pixels ($\text{Deforest}_{c,t}$)⁶ in cell c
 225 during year t , controlling for cell and for country \times year fixed effects (η_c and $\nu_{country,t}$, respectively):

$$\text{Deforest}_{c,t} = \beta \ln \text{Price}_{c,t} + \eta_c + \nu_{country,t} + \varepsilon_{c,t}, \quad (2)$$

226 where ε_{ct} is the error term. Standard errors are clustered by cell in the baseline, and in our sensitivity
 227 analysis we allow for spatially correlated errors within larger radius. The aim of the cell fixed effects is to
 228 control for any time-invariant cell characteristics which may correlate with both the average deforestation
 229 rates and crop prices (e.g. geography, topography, soil characteristics). The inclusion of country \times year
 230 fixed effects ($\nu_{country,t}$) accounts for any time-variant country characteristics such as global trends in over-
 231 all crop prices, nation-wide shocks or policy changes that may trigger or hamper deforestation. To study
 232 the role of local characteristics, with use specifications where (2) is augmented with interactions terms
 233 between $\ln \text{Price}_{c,t}$ and cell-specific proxies of trade openness, development or state capacity. Throughout
 234 the paper, as deforestation is bounded by the initial forest cover, we allow the effect of price ($\ln \text{Price}_{c,t}$)
 235 to vary across deciles of forest cover (Model 2); we also allow it to vary across countries (Model 3) when

⁵GAEZ, FAO data, available here: <http://www.fao.org/nr/gaez/about-data-portal/en/>

⁶This transformation is frequently used in applied econometric work, because it approximates the natural logarithm while allowing to keep zero-valued observations in the estimation [52, 53, 54].

236 looking at the effect of cell characteristics. We estimate the models through an Ordinary Least Square
237 (OLS) estimator in the baseline estimates and use a Poisson Pseudo Maximum Likelihood (PPML) esti-
238 mator in our sensitivity exercises.

239
240 **Sensitivity analysis.** The sensitivity analysis of the estimates of Models 1 and 2, and their versions
241 augmented with cell characteristics, are displayed in SI Section 10.1. For each estimation, we consider
242 the following robustness:

- 243 • As our main dependent variable is a count of the number of deforested pixels, we estimate the model
244 through a Poisson Pseudo-Maximum Likelihood (PPML) estimator.
- 245 • We consider an alternative canopy threshold that defines the tropical forest biome at 50% instead
246 of 25%. This second definition of forest is more conservative and ensures that 30m pixels contain
247 enough tree cover in 2000 to be considered as a forest biome.
- 248 • We assess the robustness of the main results to potential outliers, i.e. we check that our results are
249 not driven by a small number of extreme observations. We exclude observations that are 1, 2 and 3
250 standard deviations away from the residual mean.
- 251 • Another concern is that our results could be driven by a small number of countries, especially those
252 who might influence the world price of agricultural commodities. For each country and crop, we
253 compute the average market share in world trade over our period of study, and drop from our
254 estimations the countries belonging to the top 10%, 25% and 50% of our sample in terms of world
255 market share.
- 256 • The fine-grained dimension of our analysis makes it likely that the error term exhibits both spatial
257 and serial correlation. To address this, we check that our results are robust to a non-parametric stan-
258 dard errors estimation [36, 55], allowing for both cross-sectional location-specific serial correlation,
259 as well as spatial correlation within a 500 or 1000km radius.

260 5 Data availability

261 The data that support the findings of this study is openly available at <http://doi.org/10.5281/zenodo.4916785>

262 6 Code availability

263 The code that support the findings of this study is openly available at <http://doi.org/10.5281/zenodo.4916785>

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381 **7 Author contributions**

382 All authors contributed equally to the study.

383 **8 Competing interests**

384 The authors declare no competing interests.

9 Data

9.1 Tree cover and deforestation

Information on tree cover for the year 2000 is available at a resolution of 1 arc-second (around 30m×30m). The tree cover is defined by Hansen *et al.* [15] as canopy closure for all vegetation taller than 5m in height. We consider two thresholds to consider a pixel as a forest: a canopy cover threshold of 25 and 50% of a pixel in year 2000. The main results define forest pixel as having at least 25% of forest cover, while robustness checks were run for a threshold of 50% (SI Section 10.2). Hansen *et al.* [15] estimates tree cover loss annually over the 2001-2018 period (version 1.6), defined as a stand-replacement disturbance, or a change from a forest to non-forest state. The data provides a year of tree cover loss for every pixel with more than 1% of forest cover (vegetation taller than 5m height) in 2000 that is estimated to endure a loss of more than 50% of the 2000 forest cover between 2001 and 2018. We consider that the whole pixel (30x30m) tree cover was reduced to zero when losses occur. Forest degradation, for example selective removals from within forested stands that do not lead to a non-forest state, was not included in the change characterisation. Moreover, the data does not allow to distinguish quality of the canopy and select every vegetation higher than 5m, potentially leading to consider secondary forest loss as deforestation.

9.2 Suitability

A crucial information to define our cell-specific price crop index is the crop-specific agronomic suitability of a cell. The FAO provides for the suitability for 45 crops at a resolution of 5 arc minute (FAO's global agroecological zones, GAEZ). These data are constructed from models that use location characteristics, such as climate information (rainfall and temperature, for instance) and soil characteristics. This information is then combined with crops' characteristics (in terms of growing requirements) to generate a global GIS raster of the suitability for each of the 45 crops. Constrained by the availability of international price data, our final sample encompasses 15 crops.

9.3 Other data

Throughout the manuscript we make use of different datasets. First, we use yearly information on night-time lights aiming to approximate local economic development.⁷ Second, we compute the geodesic distances between each grid cell of 0.5×0.5 degree longitude and latitude and the closest port. We use location of ports around the World from *World Port Index* dataset⁸ that provides GPS location of ports with a depth larger than 11 meters. Third, we compute the geodesic distance between each grid cells and the capital city of each country from PRIO-GRID.⁹ Fourth, to compute the crop-specific country market share in world trade, we make use of the dataset on exports and imports from the FAO.¹⁰

9.4 Summary statistics

Table 1 displays the summary statistics of all variables used in the paper.

⁷Data from the DMSP-OLS, Nighttime Lights Time Series Version 4 (Average Visible, Stable Lights, & Cloud Free Coverages), as available in PRIO-GRID.

⁸Available at the following link: <https://msi.nga.mil/Publications/WPI>

⁹We use the distance to the capital city at the beginning of the period, as in a very small number of cases the capital city has changed during the period.

¹⁰Faostat data site: <http://www.fao.org/faostat/en>

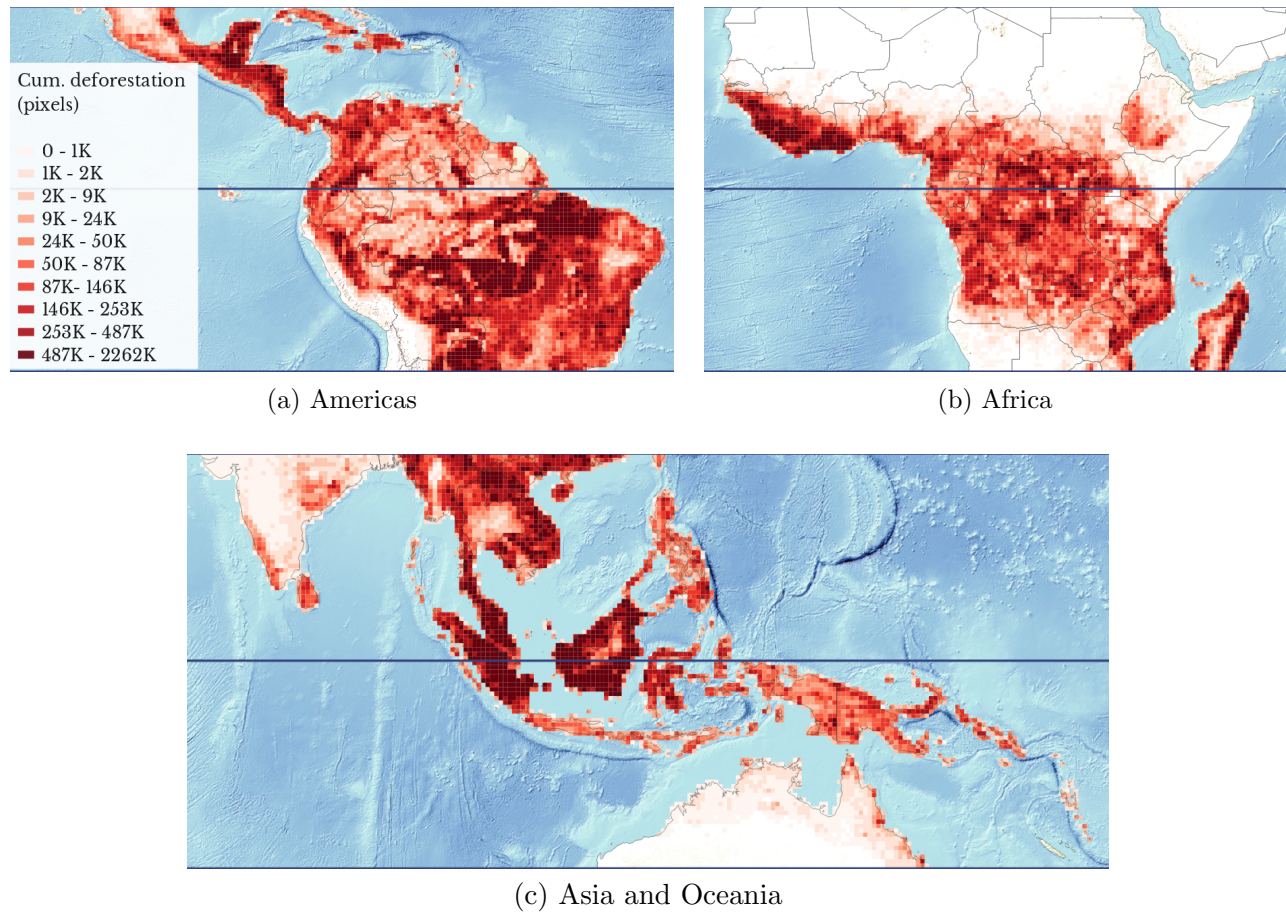
Table 1: Summary statistics

| Variable | Mean | Std. Dev. | Min. | Max. | N |
|--|-------------|------------------|-------------|-------------|----------|
| Forest cover in 2000 (forest: $\geq 25\%$) | 1899521.45 | 1543807.74 | 1 | 4000000 | 251982 |
| Forest cover in 2000 (forest: $\geq 50\%$) | 1523987.16 | 1528444.94 | 0 | 4000000 | 251982 |
| Deforestation (pixel share, forest: $\geq 25\%$) | 0.006 | 0.028 | 0 | 1 | 251982 |
| Deforestation (pixel share, forest: $\geq 50\%$) | 0.008 | 0.033 | 0 | 1 | 240750 |
| Deforestation (pixel count, forest: $\geq 25\%$) | 9276.58 | 21691.43 | 0 | 749160 | 251982 |
| Deforestation (pixel count, forest: $\geq 50\%$) | 7977.64 | 20306.19 | 0 | 746363 | 251982 |
| Inverse hyperbolic sine transformation of Deforestation (pixel count, forest: $\geq 25\%$) | 7.225 | 3.406 | 0 | 14.22 | 251982 |
| Inverse hyperbolic sine transformation of Deforestation (pixel count, forest: $\geq 50\%$) | 6.636 | 3.688 | 0 | 14.216 | 251982 |
| Price index | 66.04 | 20.91 | 1.55 | 223.03 | 251982 |
| Log Price index (ln Price) | 4.14 | 0.32 | 0.436 | 5.41 | 251982 |
| Distance to nearest seaport in km (dist. port) | 596.35 | 431.63 | 1.81 | 1893.287 | 251982 |
| Distance to capital city in km (dist. cap.) | 911.47 | 817.44 | 1.77 | 7958.346 | 195986 |
| Stable night-time lights in 2000 (night lights) | 0.834 | 2.55 | 0 | 44.55 | 251982 |

Note: See SI Sections 9.1, 9.2 and 9.3 for more details.

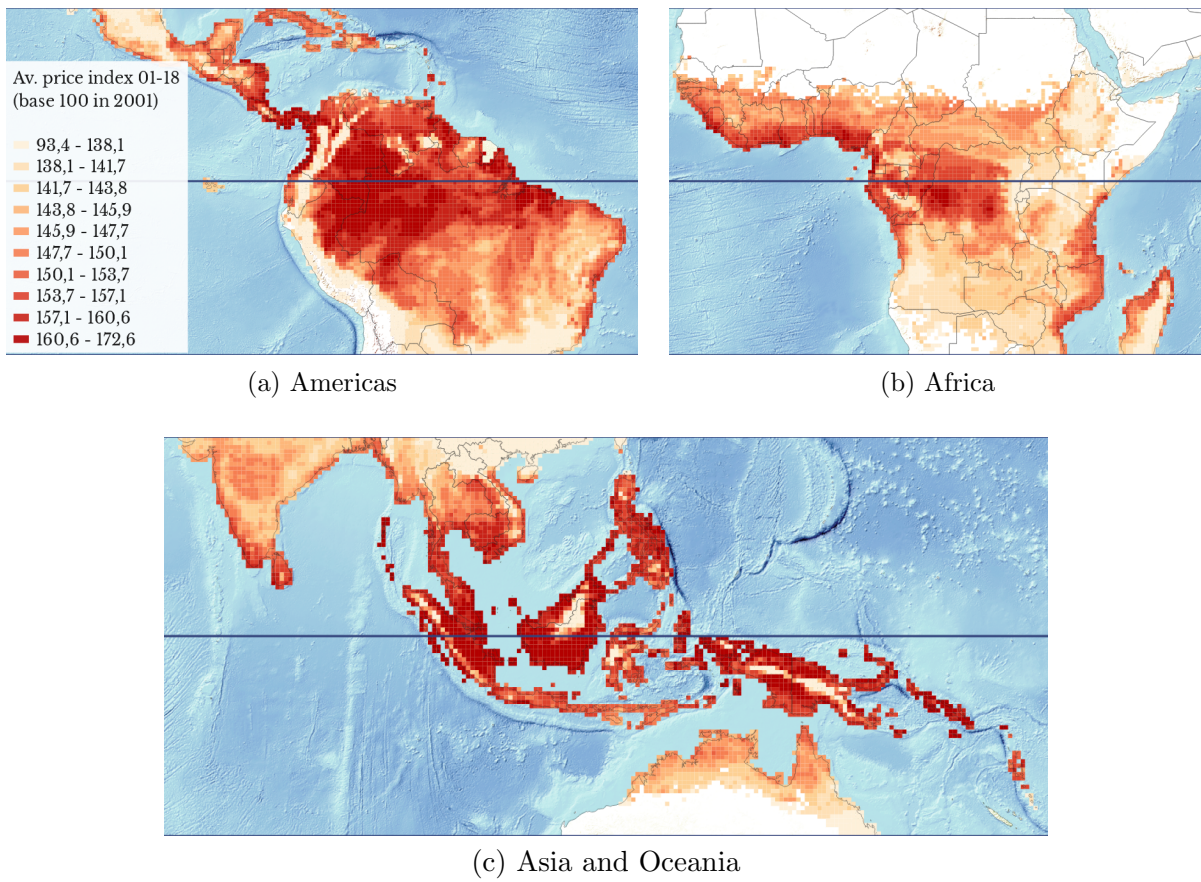
9.5 Descriptive maps

Figure 5: Accumulated deforestation, 2001-2018



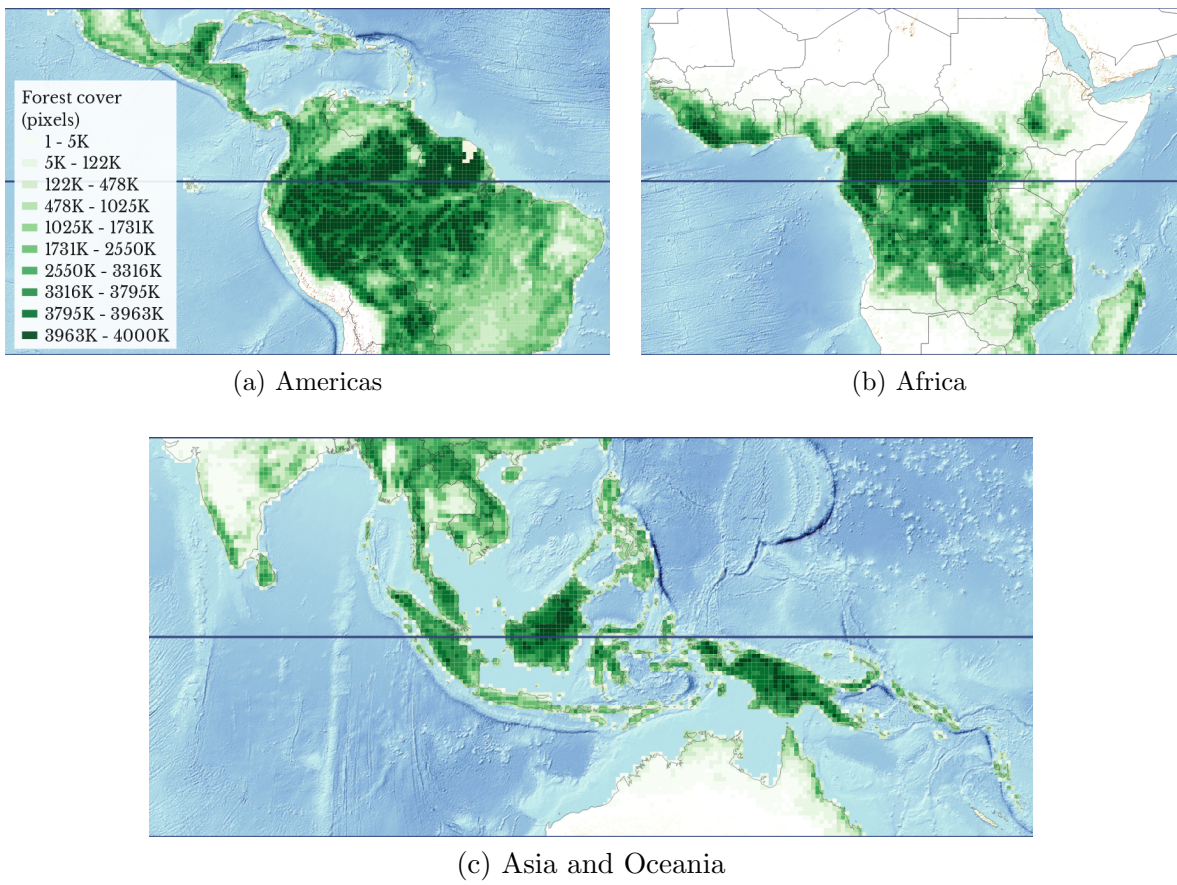
Note: Accumulated deforestation, in number of pixels (max. total of land pixel in a cell is 4000K), forest defined with a 25% threshold. Source: Hansen et al. (2013).

Figure 6: Average price index, 2001-2018



Note: Average value of the crop price index over the 2001-2018 period, taking 2001 as a base year.

Figure 7: Forest cover in 2000



Note: Number of pixels covered by forest, using a 25% canopy cover threshold. Year: 2000. The maximum total of land pixels per cell is 4000K pixels.

10 Statistical analysis

10.1 Baseline estimates

This sub-section contains the two Tables related to the Figures displaying the baseline estimates in the manuscript. Table 2 displays the estimates used to construct Figure 1, Model 1 (Column 1) and Model 2 (Column 2). Table 3 shows the estimates used in Figure 3. Column (1) provides the estimates of Model 1, that is of specification (2) when we include interaction variables between the price index and cell characteristics (distance to the closest port, distance to the capital city and the intensity of nighttime lights). In column (2), we provide the estimates of the same specification, but with the price index interacted with a binary variable for each decile of the initial forest cover distribution. Finally, in column (3) we control for a full set of interactions between country dummies and the price index.

Table 2: Baseline results

| Model | (1) Model 1 | (2) Model 2 |
|-------------------|-------------------------------|--------------------------------|
| ln Price | 1.242 ^a (0.081) | |
| × Cover[D1] | | -0.199 ^b (0.099) |
| × Cover[D2] | | 0.185 ^c (0.100) |
| × Cover[D3] | | 0.826 ^a (0.096) |
| × Cover[D4] | | 1.002 ^a (0.094) |
| × Cover[D5] | | 1.164 ^a (0.093) |
| × Cover[D6] | | 1.218 ^a (0.090) |
| × Cover[D7] | | 1.497 ^a (0.092) |
| × Cover[D8] | | 1.623 ^a (0.089) |
| × Cover[D9] | | 1.929 ^a (0.086) |
| × Cover[D10] | | 2.265 ^a (0.089) |
| Cell FE | Yes | Yes |
| Country × Year FE | Yes | Yes |
| Observations | 251982 | 251982 |
| Countries | 119 | 119 |
| Period | 2001-2018 | 2001-2018 |
| R^2 | 0.910 | 0.911 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (2). Cover[x] are bins for deciles of forest cover in 2000.

Table 3: Baseline results with cell characteristics

| | (1) | (2) | |
|--------------------|--------------------------------|--------------------------------|--------------------------------|
| | Model 1 | Model 2 | Model 3 |
| ln Price | 1.165 ^a (0.080) | | |
| × ln dist. port | -0.133 ^a (0.024) | -0.306 ^a (0.023) | -0.147 ^a (0.024) |
| × ln dist. cap. | 0.172 ^a (0.024) | 0.029 (0.024) | 0.153 ^a (0.025) |
| × night lights | -0.088 ^a (0.016) | -0.059 ^a (0.014) | -0.096 ^a (0.016) |
| × Cover[D1] | | -0.242 ^b (0.098) | |
| × Cover[D2] | | 0.120 (0.099) | |
| × Cover[D3] | | 0.759 ^a (0.095) | |
| × Cover[D4] | | 0.938 ^a (0.093) | |
| × Cover[D5] | | 1.113 ^a (0.092) | |
| × Cover[D6] | | 1.173 ^a (0.089) | |
| × Cover[D7] | | 1.446 ^a (0.091) | |
| × Cover[D8] | | 1.639 ^a (0.089) | |
| × Cover[D9] | | 2.004 ^a (0.087) | |
| × Cover[D10] | | 2.380 ^a (0.091) | |
| Cell FE | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes |
| Country FE × price | No | No | Yes |
| Observations | 251982 | 251982 | 251982 |
| Countries | 119 | 119 | 119 |
| Period | 2001-2018 | 2001-2018 | 2001-2018 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (2). Cover[x] are bins for deciles of forest cover in 2000. ln dist. port is the log of distance from the closest seaport. ln dist. cap. is the log of the distance from the country's capital city at the beginning of the period. night lights is the average amount of nighttime lights emitted in the cell in 2000.

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10.2 Sensitivity analysis

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Here we discuss a set of exercises to assess the sensitivity of our analysis. All exercises are implemented for Models 1 and 2. First, we consider an alternative canopy threshold that defines the tropical forest biome at 50% instead of 25%. Note that it reduces slightly the number of observations as few grid of 0.5 degree do not include any pixels of 30 meters with a 50% canopy cover in 2000 (Table 4, columns 1 and 2). Second, as our main dependent variable is a count of the number of deforested pixels, we estimate the models through a Poisson Pseudo-Maximum Likelihood (PPML) estimator instead of a Least Square Estimator (Table 4, columns 3 and 4). Third, we assess the sensitivity of the estimates of Models 1 and 2 to potential outliers (Table 5). Our main concern is that a small number of observations could drive our results. We exclude observations that are 3 (columns 1 and 4), 2 (columns 2 and 5) and 1 standard deviation (columns 3 and 6) away from the residual mean. Fifth, in the same vein, we want to ensure that our results are not driven by a small number of countries, especially those who might influence the world price of agricultural commodities (Table 6). Doing so, we exclude countries from the sample having the largest crop market shares: top 10% (columns 1 and 4), 25% (columns 2 and 5), and 50% (columns 3 and 6) largest crop market shares. The crops considered to compute the market shares are those included in our analysis: banana, barley, cocoa, coconut, coffee, cotton, maize, oil palm, rice, sorghum, soybean, sugar, tea, tobacco, wheat. Finally, the fine-grained dimension of our analysis makes it likely that the error term exhibits both spatial and serial correlation. To address this, we check that our results are robust to a non-parametric standard errors estimation [36, 55], allowing for both cross-sectional location-specific serial correlation, as well as spatial correlation within a 500 or 1000km radius (Table 7).

In section 10.2.2, from Table 8 to 11, we provide the same sensitivity analysis for the estimates including the cell-characteristics (Table 3, column 1 and 2).

10.2.1 Sensitivity: baseline specifications

Table 4: Sensitivity analysis of baseline estimates: canopy threshold & PPML

| | (1) | (2) | (3) | (4) |
|-------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------------|
| Model | Model 1 | Model 2 | Model 1 | Model 2 |
| Canopy threshold | 50% | 50% | 25% | 25% |
| Estimator | OLS | OLS | PPML | PPML |
| ln Price | 1.343 ^a (0.082) | | 1.379 ^a (0.117) | |
| × Cover[D1] | | 0.494 ^a (0.099) | | -1.925 ^a (0.278) |
| × Cover[D2] | | 0.299 ^a (0.100) | | 0.476 ^a (0.157) |
| × Cover[D3] | | 0.614 ^a (0.099) | | 0.929 ^a (0.142) |
| × Cover[D4] | | 0.881 ^a (0.097) | | 0.967 ^a (0.131) |
| × Cover[D5] | | 1.022 ^a (0.097) | | 1.164 ^a (0.133) |
| × Cover[D6] | | 1.152 ^a (0.093) | | 1.067 ^a (0.127) |
| × Cover[D7] | | 1.503 ^a (0.093) | | 1.234 ^a (0.125) |
| × Cover[D8] | | 1.686 ^a (0.091) | | 1.413 ^a (0.126) |
| × Cover[D9] | | 2.024 ^a (0.087) | | 1.768 ^a (0.124) |
| × Cover[D10] | | 2.347 ^a (0.090) | | 1.899 ^a (0.147) |
| Cell FE | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes |
| Observations | 240732 | 240732 | 246559 | 246559 |

Note: Least square estimator in columns (1) and (2), PPML in columns (3) and (4). ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000.

Table 5: Sensitivity analysis of the baseline estimates: dropping outliers

| Model | (1) Model 1 | (2) Model 1 | (3) Model 1 | (4) Model 2 | (5) Model 2 | (6) Model 2 |
|---------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Sample: Excluded outliers | 3 σ | 2 σ | 1 σ | 3 σ | 2 σ | 1 σ |
| ln Price | 1.100 ^a (0.067) | 0.974 ^a (0.057) | 0.899 ^a (0.039) | | | |
| × Cover[D1] | | | | -0.300 ^a (0.085) | -0.298 ^a (0.071) | -0.311 ^a (0.047) |
| × Cover[D2] | | | | 0.047 (0.083) | 0.019 (0.069) | -0.086 ^c (0.047) |
| × Cover[D3] | | | | 0.675 ^a (0.079) | 0.586 ^a (0.067) | 0.478 ^a (0.045) |
| × Cover[D4] | | | | 0.834 ^a (0.078) | 0.720 ^a (0.066) | 0.608 ^a (0.045) |
| × Cover[D5] | | | | 0.973 ^a (0.078) | 0.851 ^a (0.067) | 0.697 ^a (0.046) |
| × Cover[D6] | | | | 1.035 ^a (0.077) | 0.941 ^a (0.067) | 0.810 ^a (0.045) |
| × Cover[D7] | | | | 1.287 ^a (0.078) | 1.168 ^a (0.067) | 1.051 ^a (0.046) |
| × Cover[D8] | | | | 1.429 ^a (0.076) | 1.320 ^a (0.066) | 1.184 ^a (0.045) |
| × Cover[D9] | | | | 1.739 ^a (0.073) | 1.603 ^a (0.063) | 1.465 ^a (0.043) |
| × Cover[D10] | | | | 2.106 ^a (0.076) | 1.961 ^a (0.066) | 1.761 ^a (0.045) |
| Cell FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 248299 | 239166 | 194598 | 248290 | 239175 | 194634 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000.

Table 6: Sensitivity analysis of the baseline estimates: dropping countries with a large crop market share

| | (1) | (2) | (3) | (4) | (5) | (6) |
|-------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Model | Model 1 | Model 1 | Model 1 | Model 2 | Model 2 | Model 2 |
| Sample: Excluded | Top 10% | Top 25% | Top 50% | Top 10% | Top 25% | Top 50% |
| ln Price | 1.391 ^a (0.088) | 0.976 ^a (0.101) | 1.126 ^a (0.132) | | | |
| × Cover[D1] | | | | 0.170 (0.109) | 0.060 (0.116) | -0.228 (0.168) |
| × Cover[D2] | | | | 0.382 ^a (0.109) | 0.247 ^b (0.118) | 0.419 ^b (0.169) |
| × Cover[D3] | | | | 0.901 ^a (0.105) | 0.768 ^a (0.116) | 0.835 ^a (0.161) |
| × Cover[D4] | | | | 1.010 ^a (0.103) | 1.065 ^a (0.118) | 1.113 ^a (0.160) |
| × Cover[D5] | | | | 1.148 ^a (0.103) | 1.157 ^a (0.119) | 1.352 ^a (0.167) |
| × Cover[D6] | | | | 1.213 ^a (0.099) | 1.209 ^a (0.112) | 1.307 ^a (0.156) |
| × Cover[D7] | | | | 1.491 ^a (0.102) | 1.510 ^a (0.117) | 1.566 ^a (0.163) |
| × Cover[D8] | | | | 1.624 ^a (0.099) | 1.648 ^a (0.117) | 1.715 ^a (0.159) |
| × Cover[D9] | | | | 1.985 ^a (0.094) | 1.793 ^a (0.111) | 1.894 ^a (0.150) |
| × Cover[D10] | | | | 2.420 ^a (0.098) | 1.983 ^a (0.125) | 2.078 ^a (0.163) |
| Cell FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 196506 | 146286 | 73782 | 196506 | 146286 | 73782 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000. In columns (1) and (4), we dropped the top 10% of the countries with respect to their average market share in our sample's crops post-2000 (top 25% in columns (2) and (5) and top 50% in columns (3) and (6)).

Table 7: Sensitivity analysis of the baseline estimates: Conley's standard errors

| | (1) | (2) | (3) | (4) |
|-------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Model | Model 1 | Model 1 | Model 2 | Model 2 |
| Spatial threshold | 500km | 500km | 1000km | 1000km |
| ln Price | 1.242 ^a (0.286) | | 1.242 ^a (0.363) | |
| × Cover[D1] | | -0.199 (0.288) | | -0.199 (0.352) |
| × Cover[D2] | | 0.185 (0.285) | | 0.185 (0.342) |
| × Cover[D3] | | 0.826 ^a (0.271) | | 0.826 ^a (0.320) |
| × Cover[D4] | | 1.002 ^a (0.270) | | 1.002 ^a (0.316) |
| × Cover[D5] | | 1.164 ^a (0.271) | | 1.164 ^a (0.318) |
| × Cover[D6] | | 1.218 ^a (0.273) | | 1.218 ^a (0.323) |
| × Cover[D7] | | 1.497 ^a (0.279) | | 1.497 ^a (0.330) |
| × Cover[D8] | | 1.623 ^a (0.282) | | 1.623 ^a (0.334) |
| × Cover[D9] | | 1.929 ^a (0.282) | | 1.929 ^a (0.345) |
| × Cover[D10] | | 2.265 ^a (0.295) | | 2.265 ^a (0.356) |
| Observations | 251982 | 251982 | 251982 | 251982 |
| R^2 | 0.001 | 0.012 | 0.001 | 0.012 |
| Cell FE | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes |
| Observations | 240732 | 240732 | 246559 | 246559 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. [36] standard errors allowing for infinite serial correlation and spatial correlation within a 500km or 1000km radius. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000.

10.2.2 Sensitivity: specifications with cell characteristics

Table 8: Sensitivity analysis of specifications with cell characteristics: canopy threshold & PPML estimator

| | (1) | (2) | (3) | (4) |
|-------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Model | Model 1 | Model 2 | Model 1 | Model 2 |
| Canopy threshold | 50% | 50% | 25% | 25% |
| Estimator | OLS | OLS | PPML | PPML |
| ln Price | 1.259 ^a (0.081) | | 1.119 ^a (0.111) | |
| × ln dist. port | -0.109 ^a (0.026) | -0.318 ^a (0.025) | -0.413 ^a (0.035) | -0.481 ^a (0.035) |
| × ln dist. cap. | 0.178 ^a (0.025) | 0.007 (0.025) | 0.210 ^a (0.039) | 0.107 ^a (0.038) |
| × night lights | -0.096 ^a (0.016) | -0.059 ^a (0.015) | -0.091 ^a (0.017) | -0.043 ^b (0.017) |
| × Cover[D1] | | 0.447 ^a (0.098) | | -2.114 ^a (0.273) |
| × Cover[D2] | | 0.238 ^b (0.099) | | 0.197 (0.154) |
| × Cover[D3] | | 0.552 ^a (0.097) | | 0.579 ^a (0.137) |
| × Cover[D4] | | 0.819 ^a (0.096) | | 0.606 ^a (0.124) |
| × Cover[D5] | | 0.973 ^a (0.096) | | 0.860 ^a (0.127) |
| × Cover[D6] | | 1.111 ^a (0.092) | | 0.783 ^a (0.122) |
| × Cover[D7] | | 1.460 ^a (0.092) | | 0.927 ^a (0.120) |
| × Cover[D8] | | 1.716 ^a (0.091) | | 1.165 ^a (0.120) |
| × Cover[D9] | | 2.120 ^a (0.088) | | 1.578 ^a (0.120) |
| × Cover[D10] | | 2.491 ^a (0.093) | | 1.791 ^a (0.141) |
| Cell FE | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes |
| Observations | 240732 | 240732 | 246559 | 246559 |

Note: Least square estimator in columns (1) and (2), PPML in columns (3) and (4). ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000. ln dist. port is the log of distance from the closest seaport. ln dist. cap. is the log of the distance from the country's capital city at the beginning of the period. night lights is the average amount of nighttime lights emitted in the cell in 2000.

Table 9: Sensitivity analysis of specifications with cell characteristics: dropping outliers

| Model | (1) | (2) | (3) | (4) | (5) | (6) |
|---------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Sample: Excluded outliers | Model 1 3 σ | Model 1 2 σ | Model 1 1 σ | Model 2 3 σ | Model 2 2 σ | Model 2 1 σ |
| ln Price | 1.016 ^a (0.067) | 0.901 ^a (0.057) | 0.833 ^a (0.039) | | | |
| × ln dist. port | -0.134 ^a (0.021) | -0.128 ^a (0.018) | -0.109 ^a (0.012) | -0.300 ^a (0.020) | -0.289 ^a (0.018) | -0.265 ^a (0.012) |
| × ln dist. cap. | 0.203 ^a (0.020) | 0.193 ^a (0.018) | 0.160 ^a (0.012) | 0.054 ^a (0.020) | 0.047 ^a (0.017) | 0.022 ^c (0.012) |
| × night lights | -0.097 ^a (0.014) | -0.083 ^a (0.012) | -0.070 ^a (0.008) | -0.064 ^a (0.013) | -0.051 ^a (0.011) | -0.045 ^a (0.008) |
| × Cover[D1] | | | | -0.340 ^a (0.084) | -0.367 ^a (0.071) | -0.359 ^a (0.047) |
| × Cover[D2] | | | | -0.018 (0.082) | -0.062 (0.069) | -0.151 ^a (0.047) |
| × Cover[D3] | | | | 0.617 ^a (0.078) | 0.515 ^a (0.067) | 0.423 ^a (0.045) |
| × Cover[D4] | | | | 0.783 ^a (0.077) | 0.657 ^a (0.066) | 0.560 ^a (0.045) |
| × Cover[D5] | | | | 0.932 ^a (0.077) | 0.800 ^a (0.067) | 0.658 ^a (0.046) |
| × Cover[D6] | | | | 0.999 ^a (0.076) | 0.891 ^a (0.066) | 0.770 ^a (0.045) |
| × Cover[D7] | | | | 1.241 ^a (0.078) | 1.109 ^a (0.067) | 1.004 ^a (0.046) |
| × Cover[D8] | | | | 1.437 ^a (0.076) | 1.322 ^a (0.066) | 1.203 ^a (0.045) |
| × Cover[D9] | | | | 1.803 ^a (0.074) | 1.654 ^a (0.064) | 1.533 ^a (0.044) |
| × Cover[D10] | | | | 2.198 ^a (0.078) | 2.038 ^a (0.067) | 1.857 ^a (0.046) |
| Cell FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 248293 | 239160 | 194649 | 248280 | 239200 | 194709 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000. ln dist. port is the log of distance from the closest seaport. ln dist. cap. is the log of the distance from the country's capital city at the beginning of the period. night lights is the average amount of nighttime lights emitted in the cell in 2000.

Table 10: Sensitivity analysis of specifications with cell characteristics: dropping countries with a large crop market share

| | (1) | (2) | (3) | (4) | (5) | (6) |
|-------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| Model | Model 1 | Model 1 | Model 1 | Model 2 | Model 2 | Model 2 |
| Sample: Excluded | Top 10% | Top 25% | Top 50% | Top 10% | Top 25% | Top 50% |
| ln Price | 1.271 ^a (0.087) | 0.959 ^a (0.101) | 1.190 ^a (0.146) | | | |
| × ln dist. port | -0.067 ^b (0.027) | -0.045 (0.043) | -0.152 ^b (0.063) | -0.279 ^a (0.026) | -0.186 ^a (0.041) | -0.321 ^a (0.061) |
| × ln dist. cap. | 0.185 ^a (0.025) | -0.134 ^a (0.034) | 0.201 ^c (0.117) | 0.028 (0.025) | -0.128 ^a (0.033) | 0.096 (0.118) |
| × night lights | -0.115 ^a (0.017) | -0.141 ^a (0.018) | -0.104 ^a (0.035) | -0.077 ^a (0.016) | -0.104 ^a (0.018) | -0.059 ^c (0.035) |
| × Cover[D1] | | | | 0.105 (0.109) | 0.009 (0.117) | -0.285 (0.177) |
| × Cover[D2] | | | | 0.306 ^a (0.108) | 0.185 (0.118) | 0.396 ^b (0.181) |
| × Cover[D3] | | | | 0.834 ^a (0.103) | 0.712 ^a (0.116) | 0.846 ^a (0.177) |
| × Cover[D4] | | | | 0.953 ^a (0.102) | 1.017 ^a (0.118) | 1.138 ^a (0.174) |
| × Cover[D5] | | | | 1.102 ^a (0.102) | 1.095 ^a (0.120) | 1.357 ^a (0.183) |
| × Cover[D6] | | | | 1.176 ^a (0.097) | 1.151 ^a (0.113) | 1.313 ^a (0.169) |
| × Cover[D7] | | | | 1.447 ^a (0.101) | 1.443 ^a (0.118) | 1.556 ^a (0.173) |
| × Cover[D8] | | | | 1.645 ^a (0.098) | 1.590 ^a (0.117) | 1.750 ^a (0.167) |
| × Cover[D9] | | | | 2.052 ^a (0.095) | 1.769 ^a (0.111) | 1.950 ^a (0.159) |
| × Cover[D10] | | | | 2.505 ^a (0.101) | 1.980 ^a (0.125) | 2.142 ^a (0.170) |
| Cell FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 196506 | 146286 | 73782 | 196506 | 146286 | 73782 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. Standard errors clustered at the cell level in parentheses. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000. In columns (1) and (4), we dropped the top 10% of the countries with respect to their average market share in our sample's crops post-2000 (top 25% in columns (2) and (5) and top 50% in columns (3) and (6)). ln dist. port is the log of distance from the closest seaport. ln dist. cap. is the log of the distance from the country's capital city at the beginning of the period. night lights is the average amount of nighttime lights emitted in the cell in 2000.

Table 11: Sensitivity analysis of specifications with cell characteristics: Conley standard errors

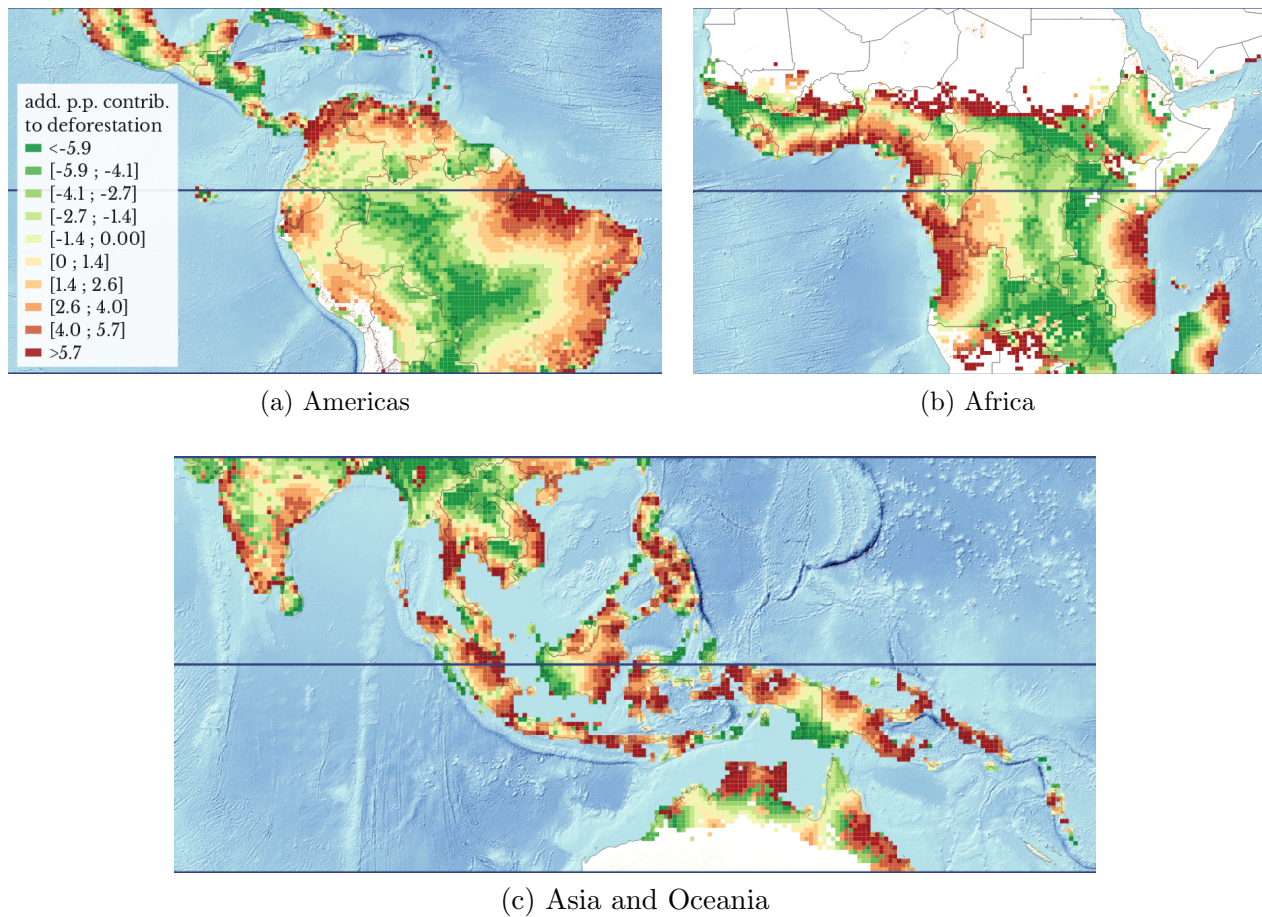
| | (1) | (2) | (3) | (4) |
|-------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| | Model 1 | Model 1 | Model 2 | Model 2 |
| Spatial threshold | 500 | 500 | 1000 | 1000 |
| Estimator | OLS | OLS | OLS | OLS |
| ln Price | 1.294 ^a (0.293) | | 1.294 ^a (0.362) | |
| × ln dist. port | -0.370 ^b (0.183) | -0.760 ^a (0.173) | -0.370 ^c (0.201) | -0.760 ^a (0.184) |
| × ln dist. cap. | 0.260 (0.174) | -0.040 (0.156) | 0.260 (0.197) | -0.040 (0.171) |
| × night lights | -0.037 ^a (0.010) | -0.023 ^b (0.009) | -0.037 ^a (0.011) | -0.023 ^b (0.010) |
| × Cover[D1] | | 0.186 (0.302) | | 0.186 (0.366) |
| × Cover[D2] | | 0.547 ^c (0.294) | | 0.547 (0.354) |
| × Cover[D3] | | 1.184 ^a (0.285) | | 1.184 ^a (0.335) |
| × Cover[D4] | | 1.357 ^a (0.285) | | 1.357 ^a (0.333) |
| × Cover[D5] | | 1.521 ^a (0.286) | | 1.521 ^a (0.337) |
| × Cover[D6] | | 1.583 ^a (0.289) | | 1.583 ^a (0.343) |
| × Cover[D7] | | 1.860 ^a (0.294) | | 1.860 ^a (0.348) |
| × Cover[D8] | | 2.039 ^a (0.296) | | 2.039 ^a (0.353) |
| × Cover[D9] | | 2.394 ^a (0.300) | | 2.394 ^a (0.366) |
| × Cover[D10] | | 2.764 ^a (0.311) | | 2.764 ^a (0.379) |
| Cell FE | Yes | Yes | Yes | Yes |
| Country × Year FE | Yes | Yes | Yes | Yes |
| Observations | 251982 | 251982 | 251982 | 251982 |

Note: Least square estimator. ^c significant at 10%; ^b significant at 5%; ^a significant at 1%. [36] standard errors allowing for infinite serial correlation and spatial correlation within a 500km or 1000km radius. The dependent variable is the hyperbolic inverse sine of the number of pixels deforested in the cell. ln Price is our crop price index, defined in equation (1). Cover[x] are bins for deciles of forest cover in 2000. ln dist. port is the log of distance from the closest seaport. ln dist. cap. is the log of the distance from the country's capital city at the beginning of the period. night lights is the average amount of nighttime lights emitted in the cell in 2000.

10.3 Full quantification with cell-level characteristics

Figure 8 provides the same quantification as in Figure 4, but over all the Tropics.

Figure 8: Additional contrib. of cell-level characteristics, full Tropics sample



Note: This figure displays the difference (in percentage point) in the contribution of crop prices to deforestation when interacting variables with cell characteristics (Model 2, Figure 3), compared to our baseline (Figure 2). For each model, the quantification is computed in the following way. First, we compute the predicted level of deforestation using observed prices, our benchmark). Then, we compute a counterfactual level of deforestation assuming fixing prices at their 2001 level. Finally, we sum these predictions by cell over the period, and compute for each cell the contribution of prices as the difference between the benchmark and the counterfactual predictions, divided by the counterfactual.

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