Supplementary material for

International trade, and land use intensification and spatial reorganization explain Costa Rica’s forest transition

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1. Compilation of trade data

We combined the Faostat (http://faostat.fao.org/) and Comtrade (http://comtrade.un.org/db/) databases as sources for detailed trade quantities of the selected agricultural products, except for ‘Milk and cream’ and ‘Oil palm kernel’, for which we relied only on Comtrade (table S1). Detailed trade matrix is not available for ‘Oil palm kernel’ in Faostat, and the seven categories of dairy products in Comtrade do not correspond together to the aggregated ‘Milk equivalent’ Faostat category. We thus used the aggregated category of ‘Milk and cream’ provided by Comtrade. We also used Comtrade database as the only source for trade in wood-derived products as it is more detailed and comprehensive than Faostat for these products. We selected the main trading partners of Costa Rica independently for agricultural and wood products, based on Faostat and/or Comtrade detailed trade matrices. Together, they account for more than 90% of total imports of each product over the whole period (except for palm products (74%) and bovine products (85%)), and more than 86% of total exports of each product (except for coffee (67%) and sugarcane (82%)).

2. Estimation of pallets exports

We estimated the export of pallets associated with the export of the main agricultural products for each year of the study period by multiplying the exported quantities of bananas, pineapples, coffee, palm oil, and palm kernel oil with the average number of pallets used for these products between 2006 and 2013 from the Usos y aportes de la madera en Costa Rica of the Oficina Nacional Forestal (http://www.onfcr.org/) (table S1). We then converted the numbers of pallets into roundwood equivalent (RWE) volume based on the average quantity of wood required to produce one pallet over the period 2006-2013, as reported in the Usos y aportes de la madera en Costa Rica.

3. Estimation of land use displacement

We converted the traded weight of the different wood products into roundwood equivalent (RWE) volume based on [1], [2], [3] (table S1). We compiled data on production, harvested area, and yield of the selected products from Faostat, and national agricultural (http://www.infoagro.go.cr) and forestry (http://www.onfcr.org/) statistics. We calculated the land use displacement associated with trade of these products (excluding bovine products) by dividing annual imported and exported quantities by annual yields (ratio of production and harvested area) of exporting countries for agricultural products, and mean annual increment1 (MAI) for wood-derived products. We used the MAI of commercial species in exploitable forests by country from [4]. We attributed the annual residual quantities of each product that were traded with partners other than our countries' selection to a fictive country with the average yields and MAI of the selection.

1 The mean annual increment (MAI) is the average net annual increase in the yield (expressed in terms of volume per unit area) of living trees to a given age, and is calculated by dividing the yield of a stand of trees by its mean age.
We assigned the world average yields to the countries that have exported products in excess of their domestic production. The yields of palm fruits were used to calculate the land embodied in the four palm-derived products, the yields of soybeans were applied to soy oil, and the yields of pineapple were used for pineapples juice.

The displacement associated with trade of bovine products was computed using the same method as [5]. We derived the characteristics of animal production systems and the proportions of different crops composing the animal feed from [6,7] (table S1). We used the characteristics of the North American production system for the U.S. and Canada, those of the South and Central American production system for the corresponding partners and Costa Rica, and those of the West European production system for European partners. Unlike [5], we used the weight carcass specific to each country to convert the number of animals into meat equivalent weight, and the regional pasture area from Faostat to calculate the annual pasture yields. We specifically estimated the pasture yield of Costa Rica based on our reconstruction of the national pasture area over the study period (section 1.6). We did not consider waste in the estimation of grass and feed crops quantities required to produce the traded quantities of bovine products. We estimated the land use displacement associated with the imports of bovine products from countries not included in the selection as for crops and wood products, by using the average cropland and pastureland used per ton of product for our selection of trading partners. Note that we may have underestimated the land use embodied in Costa Rica’s exports of bovine products by using the regional parameters from Bouwman [7], which may not have fully captured the recent intensification of Costa Rican cattle ranching.

Land use embodied in imports was considered as positive displacement, while land use embodied in exports was taken as negative displacement (absorption) and subtracted from the first to compute net displacement. We calculated gross and net displacement separately for agricultural and wood products, and then combined them to estimate the total net displacement associated with trade in these two categories.

4. Statistical tests on trends in trade and land use displacement

We tested for increasing and decreasing trends in trade exchanges of the selected products over 1965-2013 by performing simple ordinary least squares (OLS) regressions with the lm package in R software. In each regression, the dependent variable was the volume traded and the explanatory variable was time. For most of the products, the residuals of the regression showed significant autocorrelation according to the Durbin-Watson test [8]. This was expected given the temporal nature of the dataset. We thus computed heteroscedasticity and autocorrelation consistent (HAC) estimators of covariance using the sandwich package in R, and Andrew’s (1991) method of estimating weights [9]. Using the Newey-West method to estimate weights led to very similar results. No pre-whitening was applied. The same tests were performed with the net land use displacement associated with agricultural and wood-derived products separately and with the total net displacement as dependent variables.

5. Reconstruction of wood and agricultural production

We obtained a time series of annual wood production (including pulpwood and particles, sawlogs and veneer logs, other industrial roundwood, and wood fuel) from Faostat for the whole study period (table S1). The sum of the first two categories (pulpwood and particles, and sawlogs and veneer logs) corresponded to the figures reported in the reports *Usos y aportes de la madera en Costa Rica* for the period 1998-2013, which provided the proportions of total processed wood coming from the three sources of wood in Costa Rica (natural forest, plantations, and agricultural land).
We applied these proportions also to the category of “other industrial roundwood”, to obtain the sources of wood for the total production (excluding fuelwood) compiled from Faostat. We excluded fuelwood from the analysis because it differs from the other categories in terms of both source and use, particularly regarding trade as it is not an internationally traded commodity.

We obtained times series of annual production and harvested area of the selected agricultural products from Faostat and corrected for outliers in the period 1989-2013 with data from the Boletines Estadísticos Agropecuarios of the Secretaría Ejecutiva de Planificacion Sectorial Agropecuaria (http://www.infoagro.go.cr) (table S1). Based on these data, we calculated the annual land yield for each product by dividing the production by the harvested area. We then computed the compound annual growth rate of agricultural expansion and intensification for the period preceding the forest transition with high deforestation rates (1965-1986), the transition period around the forest cover turning point in 1989 (1987-2000), and the period following it, with marked reforestation trend (2001-2013). Given inter-annual variations in harvested areas and yields, we considered the average of the first three and last three years of the period to compute each rate. For bovine products, we computed the annual number of producing animals as the sum of living animals exported by Costa Rica, slaughtered animals, and milk animals, and look at the annual change in this number compared to annual change in the total pastureland of the country. We obtained data on national pasture area from Faostat for the period 1965-1984 (matching with [10] for 1970, [11] for 1973 and [12] for 1982), 1992 (matching with [13]) and 2000, from [13] for 1988 and from [14] for 2012. Based on these sources, we linearly interpolated the area of pasture for the period 1985-1987, 1989-1992, 1993-1999, 2001-2011, and 2013 (table S2).

We tested for trends in agricultural yields and areas of the products whose production increased over the study period by estimating simple OLS regressions for the three periods 1965-1986, 1987-2000 and 2001-2013, and (HAC) estimators of covariance in case of significant autocorrelation. We then used the Chow test to test for difference in trends of successive periods [8]. We also performed a sensitivity analysis on the limits of the three periods, which confirmed that significance and trends are not sensitive to a change of one or two years.

6. Reconstruction of land use dynamics at national and provincial scales

Statistics on the national forest cover of Costa Rica have been largely reported in the literature and national reports, but only few are disaggregated at the sub-national scale. We found seven land cover studies whose published results included the forest area by province for the years 1960, 1979, 1986, 1997, 2000, 2005, 2010 and 2012 [12–25] (table S2). We focused on these years to reconstruct the land use evolution at the national scale. We derived the total area of pasture and cropland dedicated to the selected crops from the previous steps (see section 4).

At the sub-national scale, we compiled data on pastures and harvested areas from various sources for different years. For each product and pasture, we selected the closest dates to the seven years for which we had the provincial forest area (table S2). This allowed us to reconstruct the proportion of different land uses for each province at two time of the study period: 1982-1986 and 2012-2014. To be consistent with the national-scale analysis, we applied these proportions to the national figures previously used (section 4), to obtain areas of different land uses per province. For all the crops (except coffee), sub-national data related to the first period were reported by regions ² rather than by province. We thus distributed the data from regions to provinces based on the proportions of each province belonging to each region, which were computed in ArcGIS. We did the same for pasture area at the two dates.

² Costa Rica is divided into 6 regions, whose boundaries do not correspond to those of the 7 provinces.
7. **Evaluation of the relative agro-ecological suitability of provinces**

We assessed the agro-environmental suitability of the seven provinces based on data from the Global Agro-Ecological Zones (GAEZ) [http://www.gaez.iiasa.ac.at/] developed by the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO). We used the soil and terrain suitability for rainfed crops with high inputs, the reference length of growing period, the net primary production in rainfed conditions, and the crop suitability index for rainfed cultivation of banana and oil palm with intermediate level of inputs. All these indices resulted from agro-climatic analyzes based on mean climatic data for the period 1961-1990. We summarized the four indices by calculating the proportion of each province falling into different categories of each index.

8. **Evaluation of the relative ecological value of provinces**

First established in the 1950s, the protected areas system of Costa Rica has mostly expanded between the 1970s and the 1990s [26,27]. Given its objective of protecting biological resources and natural ecosystems, we assumed a generally positive correlation between ecological richness and the proportion of protected areas in each province, although the location of protected areas is known to be also affected by other factors [28,29]. The same assumption was made for indigenous reserves, whose forests cover 70% of the total territory, and which play an important role of buffer for the national parks and biological reserves they generally border [30,31]. We extracted the location of protected areas of Costa Rica as reported in [32] from the World Database on Protected Areas (WDPA) [http://www.protectedplanet.net/]. We combined the resulting shapefile with a shapefile including the indigenous territories legally-recognized in Costa Rica as of 2008, created by the Observatorio del Desarrollo within the Universidad de Costa Rica and obtained from the Global Forest Watch website [http://www.globalforestwatch.org/]. We then computed the proportion of the surface of each province covered by PAs and IRs.

We then used the average density of animal species belonging to the IUCN Red List of Threatened Species [http://www.iucnredlist.org/] – as indicators of biodiversity value – and the average density of carbon stored in forest biomass (below and above ground) as two major indicators of the relative ecological value of the seven provinces (table S3). We selected the IUCN Red List species of birds, amphibians, reptiles, and mammals classified in the following categories of conservation: extinct, extinct in the wild, critically endangered, endangered, vulnerable, and near threatened. We superimposed a grid of 5 kilometers side hexagons on the Costa Rican territory and extracted the number of threatened species of the different animals’ classes for each polygon based on shapefiles containing their worldwide distribution. We then computed the density of these species by hexagon and summarized the information by province. We assessed the average forest carbon stocks by extracting the density of carbon stored in tropical forests estimated by [33] from the forests of Costa Rica, based on the shapefile of forests resulting from the National Forest Inventory of Costa Rica 2013-2014 realized by the Sistema Nacional de Áreas de Conservación (SINAC) and obtained from the Sistema de Información de Recursos Forestales (SIREFOR) [http://www.sirefor.go.cr]. We also extracted the proportions of the different types of forest (mature, secondary, palm forest, plantations and mangroves) by province from this shapefile. Mature forests is defined as the result of a succession process that has occurred continuously since at least 75-100 years [34]. They consist of native tree species tree and their ecological processes have not been significantly affected by human activity. Secondary forests result from a process of secondary succession that occurred after the original vegetation had been eliminated by human activities or natural phenomenon. This class includes the deciduous forest, most of which is secondary forest. Plantations are artificial forest areas, which generally consist in trees of the same species with the same age and a homogenous distribution.
9. **Statistical tests for the 3rd hypothesis**

We used multiple OLS regressions to test the association between changes in the provincial forest area and (i) changes in the provincial area of pasture and export crops, (ii) agro-environmental suitability, and (iii) ecological value of each province. Given the small size of our sample (7 provinces), we limited the number of explicative variables to two in each regression. We tried all possible combinations of variables for each association and selected the most significant models according to the p-values of Fisher test applied to the regression and Student tests to the coefficients, and to the R-squared of the regression. Change in area of the different land uses (forest, pastures, and pineapple) was computed for each province as the difference of area between the second (2012/13/14) and first (1982/84/86) periods divided by the province area. The two selected variables associated with agro-environmental suitability were the proportions of the provinces with (i) a reference length of growing period larger than 300 days, and (ii) a moderate to high suitability index for rainfed cultivation of banana. The two selected variables related to ecological value were the densities of (i) extinct, endangered, and threatened species, and (ii) carbon stored in forests of each province.

10. **Estimation of the terms of Equation (1)**

For each term, we computed the accumulated number of hectares used or spared over each year between 1989 (year of the inflection point in our dataset of forest cover) and 2013 [5]. We assumed a linear increase of forest cover over 1989-2013. Since Equation (1) balances different processes leading to land use conversion between agriculture and forests, forest products that typically cause forest degradation rather than forest conversion were excluded from this calculation. Land released through the imports of agricultural commodities was estimated based on the Costa Rica’s yields. The two terms related to intensification and redistribution of land use were jointly estimated by comparing the actual area that has been required for domestic agricultural production with the area that would have been required to produce the same quantities with 1989 yields. The land demand for growing domestic consumption was estimated as the residual.
References

[1] Ollmann H 2001 *Holzbilanzen für die EU und ihre Mitgliedsländer* (Hamburg: Bundesforschungsanstalt für Forst und Holzwirtschaft)

[2] Reister M and Muryawan M 2009 *Quantity and Weight Data in UN Comtrade* (UN Department of Economic and Social Affairs)

[3] UNECE and FAO *Forest product conversion factors for the UNECE region* (Geneva: United Nations Economic Commission for Europe (UNECE), Food and Agriculture Organization of the United Nations (FAO))

[4] FAO 1988 *Global Fibre Supply Model* (Rome: Food and Agriculture Organization of the United Nations)

[5] Meyfroidt P, Rudel T K and Lambin E F 2010 Forest transitions, trade, and the global displacement of land use. *Proc. Natl. Acad. Sci. U. S. A.* 107 20917–22

[6] Wirsenius S 2000 *Human Use of Land and Organic materials: Modeling the Turnover of Biomass in the Global Food System* (Göteborg, Sweden: Chalmers University of Technology and Göteborg University)

[7] Bouwman A F, Van der Hock K, Eickhout B and Soenario I 2005 Exploring changes in world ruminant production systems *Agric. Syst.* 84 121–53

[8] Verbeek M 2004 *A Guide to Modern Econometrics - 2nd edition* (England: John Wiley and Sons Ltd.)

[9] Zeileis A 2004 Econometric Computing with HC and HAC Covariance Matrix Estimators *J. Stat. Softw.* 11 1–17

[10] Rodríguez S and Vargas E 1988 *El recurso forestal en Costa Rica: Políticas públicas y sociedad* (Heredia: Editorial Universidad Nacional (EUNA))

[11] MEIC and INEC 1973 *Censo Agropecuario 1973* (Ministerio de Economía, Industria y Comercio (MEIC) and Instituto Nacional de Estadística y Censos (INEC))

[12] Solera-Andara R and Weiss-Diaz F J 1983 *Encuesta Nacionál de Ganado Bovino* (San José: Secretaría Ejecutiva de Planificación Sectorial Agropecuaria (SEPSA))

[13] Montenegro J and Abarca S 1998 *La ganaderia en Costa Rica: Tendencias y proyecciones 1984-2005* (San José: Ministerio de Agricultura y Ganadería (MAG))

[14] SINAC and FONAFIFO 2015 *Inventario Forestal Nacional de Costa Rica* (San José: Sistema Nacional de Áreas de Conservación (SINAC) and Fondo de Financiaminet Forestal de Costa Rica (FONAFIFO))

[15] Sader S A and Joyce A T 1988 Deforestation Rates and Trends in Costa Rica, 1940 to 1983 *Biotropica* 20 11–9
16. SEPSA 1989 Informacion basica del Sector Agropecuario de Costa Rica.pdf (San José: Secretaria ejecutiva de planificacion sectorial agropecuaria y de recursos naturales renovables)

17. César-Calvo J, Watson V, Bolaños R, Quesada C, Sánchez A, González P and Ramírez M 1999 XI Congreso agronomico nacional y de recursos naturales Estudio de cobertura forestal de Costa Rica empleando imágenes Landsat 1986/87 y 1996/97 ed Ministerio de Agricultura y Ganadería (San José) pp 461–6

18. Sánchez A, Foley S, Hamilton S, César Calvo J, Arroyo P and Jiménez V 2002 Estudio de Cobertura Forestal de Costa Rica con imágenes Landsat TM 7 para al año 2000 (Laboratorio de Sistemas de Observación Terrestre (EOSL), Centro Científico Tropical (CCT) and Fondo de Financiamiento Forestal de Costa Rica (FONAFIFO))

19. Arroyo-Mora J P, Sánchez-Azoñéifa G A, Rivard B, Calvo J C and Janzen D H 2005 Dynamics in landscape structure and composition for the Chorotega region, Costa Rica from 1960 to 2000 Agric. Ecosyst. Environ. 106 27–39

20. Calvo-Alvarado J, McLennan B, Sánchez-Azoñéifa A and Garvin T 2009 Deforestation and forest restoration in Guanacaste, Costa Rica: Putting conservation policies in context For. Ecol. Manage. 258 931–40

21. MAET and FONAFIFO 2012 Estudio de cobertura forestal de Costa Rica 2009-2010 (San José: Ministerio de Ambiente, Energía y Telecomunicaciones (MAET) and Fondo Nacional de Financiamiento Forestal (FONAFIFO))

22. SEPSA 2013 Boletín Estadístico Agropecuario N°23 (San José: Secretaría Ejecutiva de Planificación Sectorial Agropecuaria)

23. INEC 2015 VI Censo Nacional Agropecuario. Resultados generales (San José: Instituto Nacional de Estadística y Censos)

24. Icafé Información de Mercado (Barva, Costa Rica: Instituto del Café de Costa Rica) (http://www.icafe.cr/)

25. FAO 2015 FAOSTAT (Rome: Food and Agriculture Organization) (http://faostat.fao.org/)

26. Kaimowitz D 1996 Livestock and deforestation in Central America in the 1980s and 1990s: a policy perspective (Jakarta: Center for International Forestry Research)

27. Kuper J and Fernández-Vega J 2014 The REDD desk: Costa Rica (Oxford, UK: Global Canopy Programme (GCP)) (http://theredddesk.org/countries/costa-rica)

28. Andam K S, Ferraro P J, Pfaff A, Sanchez-azofeifa G A and Robalino J A 2008 Measuring the effectiveness of protected area networks in reducing deforestation Proc. Natl. Acad. Sci. U. S. A. 105 16089–94

29. Joppa L N and Pfaff A 2009 High and Far: Biases in the Location of Protected Areas ed J Moen PLoS One 4 1–6

30. Vilma Obando A 2007 Biodiversidad de Costa Rica en cifras (Instituto Nacional de Biodiversidad (INBio) and Sistema Nacional de Áreas de Conservacion (SINAC))
[31] Molina Murillo S a., Pérez Castillo J P and Herrera Ugalde M E 2014 Assessment of environmental payments on indigenous territories: The case of Cabecar-Talamanca, Costa Rica *Ecosyst. Serv.* **8** 35–43

[32] INEC 2013 *Anuario Estadístico 2011* (San José: Instituto Nacional de Estadística y Censos)

[33] Saatchi S S, Harris N L, Brown S, Lefsky M, Mitchell E T a, Salas W, Zutta B R, Buermann W, Lewis S L, Hagen S, Petrova S, White L, Silman M and Morel A 2011 Benchmark map of forest carbon stocks in tropical regions across three continents. *Proc. Natl. Acad. Sci. U. S. A.* **108** 9899–904

[34] SINAC and REDD-CCAD-GIZ P 2015 *Cartografía base para el Inventario Forestal Nacional de Costa Rica 2013-2014* (San José: Sistema Nacional de Áreas de Conservación (SINAC))
### Table S1. Sources of data on wood and agricultural products.

| Selected categories of products | Products                        | Source of data                                                                 |
|---------------------------------|---------------------------------|-------------------------------------------------------------------------------|
|                                 |                                 | Trade                  Production harvested area Yield / Carcass weight of animals / GAI Rownwdwood conversion factors |
| Wood products                   |                                 | Comtrade              FAOSTAT, Usos y apotes de la madera en Costa Rica / /    Ollmann (2001), Reister & Muryawan (2009), UNICE & FAO (2010) |
| Paper, paperboard and manufactures thereof (Category SITC-Rev1: 64) |                                 | Comtrade              / / FAOSTAT (1998)                                  Ollmann (2001) |
|                                 | Pallets (Category SITC-Rev1: 64)| FAOSTAT, Comtrade, Usos y apotes de la madera en Costa Rica / / Usos y apotes de la madera en Costa Rica |
|                                 |                                 | FAOSTAT, Comtrade, Usos y apotes de la madera en Costa Rica / / Usos y apotes de la madera en Costa Rica |
|                                 | Wheat                           | FAOSTAT, Comtrade / /   FAOSTAT / /                                            |
|                                 | Maize                           | FAOSTAT, Comtrade       FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT / / |
|                                 | Soy products                    | Soybeans              FAOSTAT, Comtrade                                           |
|                                 |                                 | Soy oil                FAOSTAT, Comtrade                                           |
|                                 |                                 | Soybeans cake          FAOSTAT, Comtrade                                           |
|                                 | Rice                            | FAOSTAT, Comtrade       FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT / / |
|                                 | Bovine products                 | Bovine animals         FAOSTAT, Comtrade                                           |
|                                 |                                 | Bovine meat            FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT, Bouwman et al. (2005), Wirsenius (2000), and Meyfoit et al. (2010) / / |
|                                 |                                 | Milk and cream         Comtrade                                                |
|                                 | Coffee                          | FAOSTAT, Comtrade       FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT / / |
|                                 | Sugarcane                       | FAOSTAT, Comtrade       FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT / / |
|                                 | Bananas                         | FAOSTAT, Comtrade       FAOSTAT, Boletin Estadistico Agropecuario FAOSTAT / / |
|                                 | Pineapple products              | Pineapples             FAOSTAT, Comtrade                                           |
|                                 |                                 | Pineapple juice        FAOSTAT, Comtrade                                           |
|                                 | Oil palm products               | Palm oil               FAOSTAT, Comtrade                                           |
|                                 |                                 | Oil palm kernels       Comtrade                                                |
|                                 |                                 | Palm kernel oil        FAOSTAT, Comtrade                                           |
|                                 |                                 | Palm kernel cake       FAOSTAT, Comtrade                                           |
**Table S2. Sources of data on land cover/use.**

| Land use/cover | Year | Primary source | Source consulted | Comments |
|----------------|------|----------------|------------------|----------|
| Forest         | 1960 | Calvo-Alvarado et al. (2009) | | From map prepared by digitizing cartographic pages based on aerial photographs |
|                | 1979 | Calvo-Alvarado et al. (2009) | Arroyo-Mora et al. (2005) | From map prepared by reclassifying a Landsat MSS image used previously by Sader & Joyce (1988) |
|                | 1986 | Calvo-Alvarado et al. (2009) | César Calvo et al. (1999) | Outcome of a national study by César Calvo et al. (1999) based on Landsat images |
|                | 1997 | César Calvo et al. (1999) | | Outcome of a study based on 7 Landsat TM images from late-1996 and early-1997. Coverage of 91% of the country (because of clouds) |
|                | 2000 | | Sánchez et al. (2002) | Outcomes of a national study based on 7 Landsat TM from January 2000 to July 2001, and aerial photos from 1997. Coverage of 96% of the country (because of clouds and uninterpretable area) |
|                | 2005 | MAET & FONAFIFO (2012) | | Coverage of 96% of the country (because of clouds) |
|                | 2010 | MAET & FONAFIFO (2012) | | Outcome of a study based on Spot images of 2009 and 2010. Coverage of 99% of the country (because of clouds) |
|                | 2012 | SINAC & FONAFIFO (2015) | | Outcome of the National Forest Inventory based on RapidEye images from December 2011 to July 2012. Coverage of 91% of the country (because of clouds) |
| Pastures       | 1961 | FAOSTAT | | Correspondence with the figure reported in FAOSTAT |
|                | 1979 | FAOSTAT | | |
|                | 1982 | Extrapolated based on FAOSTAT and Montenegro & Abarca (1998) | Solera-Andara and Weiss-Diaz (1983) | Correspondance with the figure reported in FAOSTAT for 1992 |
|                | 1986 | Extrapolated based Montenegro & Abarca (1998) | | Official figure reported on FAO questionnaires from countries |
|                | 1997 | Extrapolated based Montenegro & Abarca (1998) | | |
|                | 2000 | FAOSTAT | | |
|                | 2005 | Extrapolated based on FAOSTAT and SINAC & FONAFIFO (2015) | | |
|                | 2010 | Extrapolated based on FAOSTAT and SINAC & FONAFIFO (2015) | | |
|                | 2012 | SINAC & FONAFIFO (2015) | | Outcome of the National Forest Inventory based on RapidEye images from December 2011 to July 2012. Coverage of 91% of the country (because of clouds) |
| Bananas        | 1984 | SEPSA (1989) and FAOSTAT | | Regional proportions from SEPSA (1989) applied to FAOSTAT total banana harvested area, and surfaces distributed from regions to provinces |
|                | 2013 | INEC (2015) and FAOSTAT | | Provincial proportions from INEC (2015) applied to FAOSTAT total banana harvested area of 2013 |
| Pineapples     | 1984 | SEPSA (1989) and FAOSTAT | | Regional proportions from SEPSA (1989) applied to FAOSTAT total pineapple harvested area, and surfaces distributed from regions to provinces |
|                | 2013 | INEC (2015) and FAOSTAT | | Provincial proportions from INEC (2015) applied to FAOSTAT total pineapple harvested area of 2013 |
| Oil palms      | 1984 | SEPSA (1989) and FAOSTAT | | Regional proportions from SEPSA (1989) applied to FAOSTAT total oil palm harvested area, and surfaces distributed from regions to provinces |
|                | 2013 | INEC (2015) and FAOSTAT | | Provincial proportions from INEC (2015) applied to FAOSTAT total oil palm harvested area of 2013 |
| Coffee         | 1984 | SEPSA (1989) | | Surfaces distributed from regions to provinces |
|                | 2012 | ICAFE | | http://www.icafe.go.cr/ |
| Sugarcane      | 1984 | SEPSA (1989) and FAOSTAT | INEC (2015) | Regional proportions from SEPSA (1989) applied to FAOSTAT total sugarcane harvested area, and surfaces distributed from regions to provinces |
| Maize          | 1984 | SEPSA (1989) and FAOSTAT | SEPSA (2013) | Regional proportions from SEPSA (1989) applied to FAOSTAT total maize harvested area, and surfaces distributed from regions to provinces |
| Rice           | 1984 | SEPSA (1989) and FAOSTAT | INEC (2015) | Regional proportions from SEPSA (1989) applied to FAOSTAT total rice harvested area, and surfaces distributed from regions to provinces |

*Data available/estimated and used at provincial level*
**Table S3. Sources of data on agro-environmental suitability and ecological value.**

| Indices                                      | Crops / animals | Year       | Source                      | Website link                |
|----------------------------------------------|-----------------|------------|-----------------------------|----------------------------|
| Proxies of agro-environmental suitability    |                 |            |                             |                            |
| Rain-fed soil and terrain suitability        |                 |            |                             |                            |
| (high inputs)                                |                 |            |                             |                            |
| Reference length of growing period           |                 |            |                             |                            |
| Net primary production (rainfed)             |                 |            |                             |                            |
| Crop suitability index (rainfed, intermediate level of inputs) | Bananas        | 1961-1990 | IISA & FAO (2010)           | http://www.gaez.iiasa.ac.at/|
|                                             | Oil palm        |            |                             |                            |
| Protected areas                              |                 |            | IUCN & UNEP, INEC (2011)    | http://www.protectedplanet.net/|
| (2011)                                       |                 |            |                             |                            |
| Protected areas                              |                 | 2008       | Global Forest Watch         | http://www.globalforestwatch.org/|
| (2008)                                       |                 |            |                             |                            |
| Protect areas                                |                 |            | IUCN Red List               | http://www.iucnredlist.org/|
|                                             |                 | 2015       |                             |                            |
| Exinct, endangered and threatened species    |                 |            | Birdlife International      | http://www.birdlife.org/    |
|                                             |                 |            |                             |                            |
| Total carbon stored in forest (above and below ground) | /              | Early 2000s| Saatchi et al. (2011)      |                            |

**Table S4. Results of the OLS regressions of trade exchanges on time.**

| Product                        | Imports Estimate and significance of the coefficient | F-statistic and significance of the regression | R² of the regression | Exports Estimate and significance of the coefficient | F-statistic and significance of the regression | R² of the regression |
|--------------------------------|-----------------------------------------------------|-----------------------------------------------|----------------------|-----------------------------------------------------|-----------------------------------------------|----------------------|
| Wood products                  |                                                     |                                               |                      |                                                     |                                               |                      |
| Roundwood                      | -                                                   | -                                             | -                    | 3396***                                             | 35.06***                                | 0.44                 |
| Paper, paperboard and manufactures thereof | 41734***                                        | 320***                                        | 0.88                 |                                                     |                                               |                      |
| Pallets                        | -                                                   | -                                             | -                    | 7132***                                             | 366.2***                                 | 0.89                 |
| Agricultural products          |                                                     |                                               |                      |                                                     |                                               |                      |
| Maize                          | 1605***                                             | 329.6***                                      | 0.88                 | -                                                   | -                                             | -                    |
| Wheat                          | 4432***                                             | 330.4***                                      | 0.88                 | -                                                   | -                                             | -                    |
| Soy products                   | 7304***                                             | 315.3***                                      | 0.88                 | -                                                   | -                                             | -                    |
| Rice                           | 2194***                                             | 103.7***                                      | 0.70                 | -                                                   | -                                             | -                    |
| Bovine products                | 264***                                              | 99.11***                                      | 0.69                 | 796***                                              | 65.5***                                 | 0.59                 |
| Coffee                         | -                                                   | -                                             | -                    | 913***                                              | 12.35***                                | 0.22                 |
| Sugarcane                      | -                                                   | -                                             | -                    | 2213***                                             | 47.36***                                | 0.51                 |
| Bananas                        | -                                                   | -                                             | -                    | 35048***                                            | 186.9***                                | 0.81                 |
| Pineapple products             | -                                                   | -                                             | -                    | 35249***                                            | 83.56***                                | 0.65                 |
| Oil plam products              | -                                                   | -                                             | -                    | 3929***                                             | 143.1***                                | 0.76                 |

***P < 0.0001; ** P < 0.001; - Imported/exported quantities not significant
### Table S5. Results of the OLS regressions of land use displacement on time.

| Net displacement associated with trade of | Estimate and significance of the coefficient | F-statistic and significance of the regression | R² of the regression |
|-----------------------------------------|---------------------------------------------|---------------------------------------------|---------------------|
| Wood-derived products                   | 5442***                                     | 109.9***                                   | 0.71                |
| Agricultural products                   | 19920***                                    | 85.35***                                   | 0.65                |
| Wood-derived and agricultural products  | 25361***                                    | 112.3***                                   | 0.71                |

***P < 0.0001; ** P < 0.001

### Table S6. Results of the OLS regressions of yield and area of agricultural products on time.

| Product           | Period          | Estimate and significance of the coefficient | Yield F-statistic and significance of the regression/ Chow test | R² of the regression | Area F-statistic and significance of the coefficient | R² of the regression |
|-------------------|-----------------|---------------------------------------------|---------------------------------------------------------------|---------------------|-----------------------------------------------------|---------------------|
| Sugarcane         | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | 14579*                                      | 8.467*                                                       | 0.41                | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | 14818***                                    | 137.1***                                                    | 0.87                | /                                                   | /                   |
|                   | 1987-2000       | -10230*                                     | 11.83*                                                       | 0.5                 | 2421**                                              | 32.51***            | 0.73                |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | 7649*                                       | 7.516*                                                       | 0.41                | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | 33564*                                      | 9.037*                                                       | 0.43                | 376**                                               | 25.46**             | 0.68                |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | -17964*                                     | 21.11**                                                      | 0.66                | 3084***                                             | 170***              | 0.94                |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | 2730*                                       | 9.362*                                                       | 0.46                | 2339***                                             | 95.64***            | 0.9                 |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | 2730*                                       | 9.362*                                                       | 0.46                | 2339***                                             | 95.64***            | 0.9                 |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | 61***                                       | 61***                                                       | 0.61                | 535.9***                                            | 0.96                |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | 1987-2000       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1965-1986  | > < 1987-2000                              | /                                                             | /                   | /                                                   | /                   |
|                   | 2001-2013       | /                                           | /                                                             | /                   | /                                                   | /                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | /                                                             | /                   | /                                                   | /                   |
|                   | 1965-1986       | 62776***                                    | 62776***                                                    | 0.99                | 2803***                                             | 0.99                |
|                   | 1987-2000       | 0.03***                                     | 0.03***                                                     | 0.97                | -83181***                                           | 94.11***            | 0.94                |
|                   | Chow 1965-1986  | > < 1987-2000                              | 418.8***                                                    | 0.97                | -83181***                                           | 94.11***            | 0.94                |
|                   | 2001-2013       | 0.03***                                     | 0.03***                                                     | 0.96                | -9838***                                            | 1.96e+11***         | 1                   |
|                   | Chow 1987-2000  | > < 2001-2013                              | 74.74***                                                    | 0.46                | 2339***                                             | 95.64***            | 0.9                 |
|                   | 1965-1986       | 16.18***                                    | 16.18***                                                   | 0.75                | 35.68***                                            | 0.75                |

***P < 0.0001; ** P < 0.001; *P < 0.01; ˜P < 0.05, /Not significant
Table S7. Results of the multiple OLS regressions of changes in forest area on changes in other land uses, agro-environmental suitability, and ecological value of provinces.

| Association between forest cover change and | Explanatory variable                                      | Estimate/F-statistic and significance | R² of the regression |
|------------------------------------------|----------------------------------------------------------|--------------------------------------|----------------------|
| Other land use change                    | Change in pasture area                                    | -1.5259*                             |                      |
|                                          | Change in pineapple area                                  | -7.113*                              |                      |
|                                          | F-statistic/R² of the regression                          | 14.02*                               | 0.88                 |
| Agro-environmental suitability           | % of the province with a growing period > 300 days        | -26.5*                               |                      |
|                                          | % of the province with moderate to high suitability for banana | -32.65*                             |                      |
|                                          | F-statistic/R² of the regression                          | 9.692*                               | 0.83                 |
| Ecological value                         | Density of extinct, endangered and threatened species    | 82.28*                               |                      |
|                                          | Density of carbon stored in forest                        | -0.32*                               |                      |
|                                          | F-statistic/R² of the regression                          | 23.84**                              | 0.93                 |

***P < 0.001; ** P < 0.01; *P < 0.05; ˜P < 0.1

Figures

Figure S1. Evolution of the area cultivated with the selected crops that have been produced in Costa Rica over the study period.