Are Geographical Indications contributing to environmental conservation? The case of *Café de Colombia*

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Abstract

Colombia has a rich history of coffee production spanning over 300 years. As one of the world's leading producers, the country dedicates a significant portion of its land to cultivating this vital crop. In the early 2000s, *Café de Colombia* received Geographical Indication (GI) certification, a milestone aimed at strengthening its reputation and competitiveness both nationally and internationally. This paper examines the impact of that recognition on land-use dynamics (*i.e.*, deforestation). Using the Synthetic Control Method on a country-level panel dataset from 1992 to 2020, it estimates the effect of the GI certification on Colombia's national deforestation rate. The findings reveal That

deforestation would have been about 0.2 percentage points lower on average without the acknowledgement. Based on these results, the paper proposes to adopt a territorial-based and community-led policy mix to convert local peculiarities in strategic assets for sustainable development.

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1 Introduction

Colombia, along with Brazil and Vietnam, is one of the world's top three countries for coffee production, consumption, and export. (FNC, 2011; FAO, 2022a). Although with a decreasing trend over the last decades, more than 800 thousand hectares of national land, mainly managed by artisanal and family farmers, are still dedicated to this crop that remains a cornerstone of the national economy and identity.

After the International Coffee Agreement ended in 1989, Colombia adopted a quality differentiation strategy to strengthen the reputation of its coffee both nationally and internationally. In this effort, coffee's place of origin became a key factor in defining quality (Marescotti and Belletti, 2016), making the protection of the origin name so important to certify the *Café de Colombia* as a Protected Geographical Indication (PGI) in December 2004 (Quiñones-Ruiz *et al*., 2015). Following the EU scheme, GI is a sign used on agri-food products that have a specific geographical origin and possess qualities and reputation that are essentially or exclusively due to a particular geographical environment, made of natural and human factors (Reg. (EU) 1442/2024).

The positive role of certifying a product within the GI scheme was stressed by economic literature that, among benefits, listed: premium pricing (Duvaleix *et al*., 2021), farmers' income (Hughes, 2009; Vaquero-Piñeiro *et al*., 2025), consumers' choices (Menapace *et al*., 2011), trade (Curzi and Huysmans, 2022; De Filippis *et al*., 2022; Giua *et al*, 2024), and local development (Takayama *et al*., 2021; Crescenzi *et al*., 2022). The presence of GI products in local economies, in fact, generates a set of direct and indirect spill-over effects that become drivers of socio-economic development. Consequently, the GI scheme is no longer an issue affecting only agrifood quality differentiation, but, conversely, has assumed a unique economic significance at the local level. More recently, the scheme has been enriched by a potential key role also in supporting the transaction towards more environmentally sustainable production processes (FAO and oriGIn, 2024). The new EU GI Law (Reg. EU No. 1443/2024) introduces, in fact, the possibility of including in the GIs' Product

Specifications sustainable criteria, encompassing environmental, social and economic objectives that go beyond mandatory standards (Art. 7), and reporting on them through sustainable reports (Art. 8). This reform marked a turning point in the GI market shaping its contribution on environmental sustainability: *"the environmental objectives should include [...] the conservation and sustainable use of soil, landscape, water and natural resources, the preservation of biodiversity, [...]* (Reg. EU No. 1443/2024). So far, in fact, the GI scheme does not include highly specific production rules or environmental constraints (Marescotti and Belletti 2016). In this respect, over the last years, the EU has put a lot of effort into financing research projects that will provide evidence-based recommendations to strengthen the contribution of GI to sustainability, while FAO proposed a Sustainability Strategy for GIs with specific intervention themes, topics and indicators (FAO and oriGIn, 2024) (Example of EU projects are: STRENGTH2FOOD and GISMART Horizon projects). Most of the existing studies attempting to evaluate the effects on a set of environmental indicators focused on European products (*e.g.*, water and carbon footprint, food miles (Caragliu *et al*., 2024), but some exceptions exist that also look at extra-EU GIs (Bagal *et al*., 2013; Marescotti and Belletti, 2016; Bellassen *et al*., 2022).

In this context, this paper aims to contribute to the literature on the environmental sustainability of extra-EU GIs by presenting a first reflection on the environmental consequences of the acknowledgement of the *Café de Colombia* on national deforestation patterns. The analysis was conducted on a country-level panel dataset over the 1992-2020 period by employing a Synthetic Control Method approach.

The effect on forest pattern represents a critical issue for sustainable socio-economic analysis, given that forests, from various perspectives, are recognised as a key ecosystem for sustainable development (Blackman *et al*., 2014). In developing countries, such as Latin America, they play an even more crucial role in determining societies' evolution and community well-being as a source of primary and non-primary goods (Ros-Tonen and Wiersum, 2003; Bakkegaard *et al*., 2017) and fighting climate change (Kramer *et al*., 1997; Lugo, 1997; Houghton *et al*., 2000; Cunningham *et al*., 2015; Wisniewski and Marker, 2019).

The acknowledgement of a GI may have a dual consequence, indeed. On the one hand, even if not automatically, but rather based on producers' and institutions' agreements, it may limit the deforestation practice by defining a production area that does not affect forest ecosystems and establishing higher environmental sustainability requirements. On the other hand, however, it could also be true that the economic benefits generated by GI may lead to expansion of agricultural land at the expense of forests, if not well designed and managed.

The empirical setting designed for the study is ideal for several reasons. Firstly, the study focuses on a pioneering case of extra-EU GI. The extension of the scheme to extra-EU products represents a strategic tool to accomplish trade agreements without making use of tariff measures (UNCTAD, 2019). Nowadays, extra-GIs are more than 360, and their role in trade agreements will become even more relevant in the future, given the extension of this scheme to manufacturing and craft products.

Second, the analysis investigates the effects of the GI policy since its inception in Colombia in 2005, rather than looking at a specific time subset, and looks at a strategic environmental outcome not only for climate adaptation, but also for the socio-economic development of local communities. Conversely to the existing studies, which conducted similar research by using qualitative approaches (Ingram *et al*., 2020), this paper estimates the effect by means of causal empirical methodologies, making the approach replicable. In this context, the paper provides a welcome basis for policy debate on the potential impact of such a policy scheme on the preservation of ecosystems and natural habitats (FAO and oriGIn, 2024).

The remainder of this paper is organised as follows. Section **Errore. L'origine riferimento non è stata trovata.** details the contextual framework guiding this paper, which includes the history of coffee production in Colombia, its link with forests and the institutional background of GIs. Section

3 introduces the empirical setting, Section 4 presents the results, together with some robustness checks, while Section 5 offers some policy implications and advice. Eventually, Section 6 concludes the manuscript.

2 Conceptual framework

In the EU, the GI quality scheme was established in 1992 to protect the name of local high-quality agri-food products whose characteristics are linked to the place where they are made, the so-called region of origin (Reg. EU No. 2024/1143). Even if preserving high-quality local productions and reducing information asymmetry between producers and consumers remain the main aims of this scheme, over the years, several socio-economic territorial externalities that literature demonstrated are associated with GIs. Among them, papers stressed the capacity of increasing agricultural added value (Cei *et al*., 2018), supporting local development (Crescenzi *et al*., 2022; De Simone *et al*., 2023; Vaquero-Piñeiro *et al*., 2025) and internationalisation (Giua *et al*., 2024). At the same time, scholars have demonstrated that GIs may support the transition towards more sustainable food systems and diets (Galli *et al*. 2020; Gocci and Luetge, 2020; Vaquero-Piñeiro and Curzi, 2024), with some positive evidence on the contributions to achieving environmental sustainability targets (Arfini *et al*., 2019). However, a contradictory picture about positive-negative implications of GIs remains for different components of environmental protection (Falasco *et al*., 2024).

The GI scheme is, in fact, not necessarily linked to preserving natural resources and several can be the transmission channels through which this scheme may affect, positively, negatively or both, environmental performances. The 2024 FAO Sustainability Strategy for GIs clearly highlighted the fact that GIs can be more sustainable than their conventional counterparts, but not automatically. The sustainability of a GI largely depends on how it is structured and on the extent to which local actors (e.g., producers, institutions, governments) collaborate to invest in sustainable practices. Farmers and producers acting collectively, for example, may have more powers than individual producers and take environmental responsibilities (Gori and Sottini, 2014). Environmental objectives could be introduced in the GI product specifications by limiting the region of origin with respect to pre-existing ecosystems or by making environmental production practices mandatory for all the GI producers. Among the key environmental challenges faced by GI systems, the FAO strategy explicitly highlights forest conservation and regeneration as a specific commitment for GI producers. By increasing the profitability of productions, and consequently the rent for producers and the value of land, the acknowledgement as a GI could constitute a risk for forest preservation. The economic benefits generated by agricultural activities (González-González *et al*., 2021; Armenteras *et al*., 2013) and GI reputation could enhance land-use changes from forest to agricultural land. To increase production without affecting the quality through the shift toward intensive production processes, producers can operate on the extensive margin by extending the production area at the expense of non-agricultural land, such as forest land.

In addition, land use changes may be induced by the free-riding behaviour of producers that offer similar non-certified goods, i.e., Colombian coffee without the GI certification. They indirectly benefit from the origin reputation induced by the GI without having any mandatory requirements to respect (Menapace and Moschini, 2024; Mao and Görg, 2025). For example, they can use the most recent coffee varieties that, conversely to the autochthonous coffee varieties that grew in the shade of natural forests (Beer, 1988), are sun-grown, do not need shade and can be planted instead of forest (FNC, 2008; Jha *et al*., 2011; Somarriba and Lopez-Sampson, 2018; González-González *et al*., 2021).

2.1 The Colombian case study

Coffee arrived in Colombia in the 18th century, introduced by Jesuits and over the decades has become the most widespread agricultural production of the country, accounting for 16% of the national agriculture gross domestic product (GDP) (Ciravegna *et al*., 2024). More than 500,000 people are employed in the coffee production, with a great number of small coffee growers (95% smaller than 5 hectares) and a few international corporations working as roasters, traders and distributors (Barjolle *et al*., 2017). From the 1930s, the Colombian coffee market was regulated by the National Federation of Coffee Growers, which, twenty years later, introduced a common strategy to differentiate its product and preserve its authenticity. Over the years, the claim "*Colombian coffee*" has become a guarantee of quality worldwide, and in the early 1980s, a specific trademark was registered (*i.e.*, Juan Valdez). In 2005, Colombia applied for certified *Café de Colombia* as a PGI under the EU GI scheme (Quiñones-Ruiz *et al*., 2015), becoming the first non-EU agri-food product recognised by the EU. With the GI acknowledgement, the reputation of *Café de Colombia* increased even more, becoming, on the one hand, a crucial production for the economic development, while, on the other hand, a potential risk to local ecosystems, such as the forest. The Colombian area is covered, in fact, for more than half (53.3%) of its surface by forest area and hosts 8% of the entire Amazon Rainforest (FAO, 2022a; Hansen *et al*., 2013). The mountain region where coffee plantations are primarily located (Armenteraas *et al*., 2011) was one of the regions that, over the last decades, experienced the largest share of deforestation (63 per cent) (GFW, 2023; González-González et al., 2021). As reported in the product specification: "*growing coffee exists in the Andean Mountain range and its foothills, which run the length of the country*". In this context, it is presumable, therefore, that forests, which are included in the region of origin, are potential targets of expansion for producers seeking to enlarge cultivation areas, generating a negative impact on deforestation, as seen in the case of *Cafè de Colombia*. In Colombia, in fact, the distance between agricultural areas and forest frontiers is mostly immediate, with a relatively small, if not absent, degraded area (Hyde, 2012).

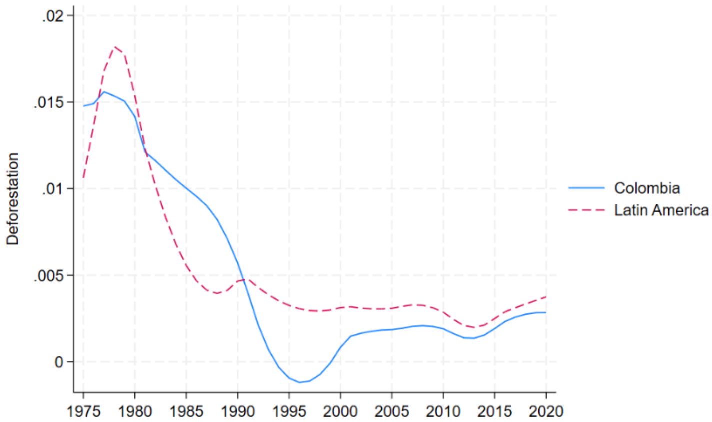
3. Data and methodology

To investigate what has happened in Colombia after the acknowledgement of the Café de Colombia in 2005, we use a novel dataset at the national level, exploit the Synthetic Control Method over the 1992-2020 period and rely on Stata19 software (Athey and Imbens, 2017).

3.1 Data

Our analysis relies on a dataset arranged by considering different sources of data. Regarding forest cover, we considered as a primary source the FAO's 2020 Forest Resources Assessment (FAO, 2022b) that represents an official source of forest cover data where countries must follow common guidelines (Total Forest cover as the sum of natural and planted forest. Source: FAO, 2018). To have a better cross-country comparison (Hyde, 2012; Puyravaud, 2003), we use as outcome variable the yearly deforestation rate, whose trend for Colombia and the rest of the Latin America is depicted by Figure 1.

Figure 1 Deforestation trend, Colombia *vs* Latin America.



Notes: the group of Latin America is composed by: Argentina, Bolivia, Barbados, Belize, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay, and Venezuela.

The dataset embodies several other variables which identify both socio-economic country characteristics and potential drivers of forest cover change and operate as controls in our model (Table A1). First, we include the share of agricultural area, the index of agricultural trade openness calculated as the ratio between the value of agricultural exports and imports (Hyde, 2012) and cereal yield, generally identified as a proxy to capture agricultural intensification (Barbier and Burgess, 2001). The agricultural land variable includes hectares dedicated to both crop and livestock. This allows us to control for all possible competing agricultural expansions.

Second, we control for population density and the share of people living in rural areas, which are considered by the literature as proxies of pressure on natural resources (Geist and Lambin, 2002; Grau and Aide, 2008; Carr *et al*., 2009). The variable of GDP per capita represents the core index of economic development for a country, widely used within the forest economics literature, especially through the Environmental Kuznets Curve (EKC) hypothesis (Caravaggio, 2020). We retrieved this variable from the World Development Indicators (WDI) of the World Bank (WB, 2022), and it is expressed in constant 2015 US$. Trade openness is another core economic variable of a country which may affect in different ways the use of natural and planted forests both negatively (Angelsen and Kaimowitz, 2001; Libman and Obydenkova, 2013; Lankina *et al*., 2016; Leblois *et al*., 2017) and positively (Meyer *et al*., 2003; Niklitschek, 2007; Hyde, 2012). We proxied this variable by using the sum of import and export as share of total GDP as proposed from the WB (2022) from which data has been retrieved. To identify the role of institutions we relied on data provided by Freedom House (2022) where the two variables of civil liberties and political rights have been merged within a unique proxy variable which identify the quality of institutions.[1] Good institutions are generally associated with better forest management, hence less deforestation (Bhattarai and Hammig, 2001, Murtazashvili *et al*., 2019, Cary and Bekun, 2021). Eventually, to account for the role played by climate change, we considered the variable of temperature change provided by FAO (2022a) which aggregates at country level monthly data of mean temperature anomalies with respect of a baseline climatology corresponding to the period 1951-1980.

2.2 Synthetic Control Method

The Synthetic Control Method is a counterfactual approach to estimate the impact of a policy on a single unit in panel data settings (Abadie *et al*., 2010). It creates a synthetic control unit for the treated observation (Colombia in our case) to simulate via a data-driven approach what its outcome path would be if it did not undergo the policy under analysis. The synthetic unit is obtained by combining and weighting the characteristics of a control group (*i.e*., donor pool) to construct an artificial control

[1] The two variables of the Freedom House (2022) both span from 1 to 7 where 1 is the highest level (*i.e*., high civil liberties and/or high political rights) while 7 the lowest. The variable used in our analysis is a rescaled sum of these two variables which spans from 1 to 10 (where 1 is the lowest institutional quality level and 10 the highest).

(not treated) unit that follows similar outcome's pre-trends of the treated one, but that has not experienced the policy. Some studies already exist that used Synthetic Control Method to estimate the effects of different events on forest projections. Sills *et al.* (2015) studied the impacts of local initiatives on the gross deforestation in Brazil (*i.e.*, loss of mature forest), Rana and Sills (2018) the effects of forest management certifications on tropical deforestation, while Amador-Jimenez *et al*. (2020) the impact of Covid-19 lockdown on forest fires in Colombia. Furthermore, Cappelli *et al*. (2022) used the Synthetic Control Method to estimate whether the implementation in the national constitution of the *Buen Vivir* principles has proved effective in reducing forest losses in Bolivia. In this paper, the treated unit is Colombia, the policy is the acknowledgment of the GI scheme in 2005, while the pre-period is from 1992 to 2005 and the post-period from 2005 to 2020. The first pre-treatment year is 1992 because it was when the EU food GI quality scheme came into force and extra-EU countries started to replicate and adopt the same scheme nationally.

The control group has been selected based on a set of socio-economic, cultural and environmental factors measured at the country level (Table A1) that literature has identified as forest cover change determinants, and the value of the outcome variable averaged over the pre-trend years to help that the synthetic control unit adequately mirrors the treated unit's deforestation trajectory before treatment (Kaul *et al*., 2015; Ferman *et al*., 2020). We need, in fact, a list of countries that are comparable to Colombia, but that have never implemented a GI certification for coffee.

The treatment variable has been reconstructed from the Product Specification downloadable from the eAmbrosia website and it is a dummy variable that takes the value one for Colombia, and zero otherwise.

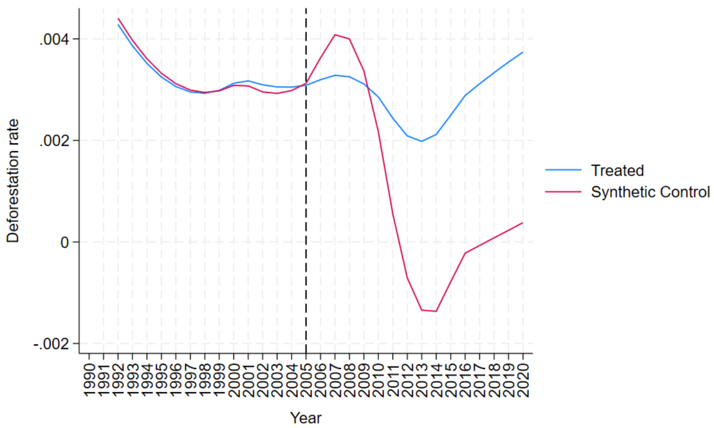
To select it, we started from the entire list of 25 Latin American countries and we discard: (i) small islands and tax heaven' countries because in these areas forest cover might have benefitted or lost from their characteristics unrelated to forest issues (*e.g.*, remote locations or economic conditions); (ii) countries for which relevant data are missing; (iii) Dominican Republic since in this country there is a similar policy, the *Cafè of Valdesia*, which has been acknowledged as a GI in 2016. We are conscious that there are other Latin American countries with GIs, but in selecting our control group, we do not discard because: (i) they do not regard coffee industry, and therefore we cannot consider them the same policy; (ii) the GI acknowledgment arrived at the end/after the period of analysis and we do not have enough post period treatment; (iii) the GI refers to wine or spirits and therefore follows a different regulation (see Table S7 in the Supplementary Materials – SM).

According to the Synthetic Control Method assumptions, to guarantee for the validity of the final control group (16 countries), we checked that the trends of the outcome variable in the treated country and in the donor pool were similar and that the values of pre-treatment predictors in the treated unit was neither the largest or the smallest of the sample (Table A2). From the donor pool, the Synthetic Control Method algorithm weighted all the observables for the synthetic control of Colombia (Table A3).

3 Results

Errore. L'origine riferimento non è stata trovata. depicts the trajectories of treated and synthetic counterparts (Figure A1 for p-values [Galiani and Quistorff, 2017]).

Figure 2 Deforestation trend, Colombia *vs* synthetic Colombia.



Note: The Yearly deforestation rate is expressed in hectares. See Table A4 for the weights donated by each country of the donor pool.

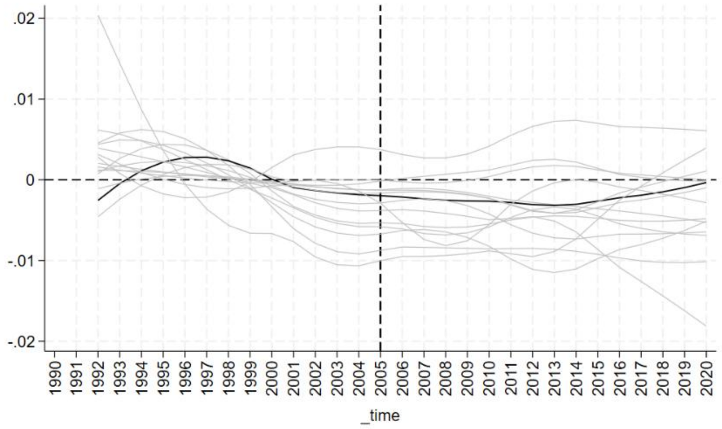
The red line shows the outcome for synthetic Colombia estimated as a counterfactual of what would have been observed for the affected unit in the absence of the intervention. Before the policy began in 2005, the pre-treatment trends in deforestation were similar for the real and the synthetic Colombia. Since 2005, a gap has emerged, with Colombia showing lower deforestation yearly rates. This suggests that, all else being equal, without the acknowledgement of *Café de Colombia* as a GI, the country would have overall experienced a lower deforestation rate. The estimated overall effect is approximately 0.2 percentage points, indicating a higher average deforestation rate over the entire post-treatment period. To quantify the impact of the treatment, we refer to the difference after treatment between the treated and the untreated cohort. It is calculated as the difference between the 2020-2005 difference in Colombia and the 2020-2005 difference of synthetic Colombia.

3.1 Robustness analysis

In order to verify the validity of our results, we conduct several robustness checks.

First of all, we run a placebo test, commonly used in Synthetic Control Method literature, by iteratively replicating the Synthetic Control Method for every other state that did not certify coffee production as a GI during the sample period (Abadie and Gardeazabal, 2003; Bertrand *et al*., 2004; Abadie *et al*., 2010). Figure 3 shows that the synthetic method provides a good fit for the deforestation trend in Colombia before the GI quality scheme. Overall, the gap between deforestation in Colombia and in its synthetic counterpart during the pretreatment period is smaller than for the states in the donor pool, but it becomes relatively higher after the treatment (Figure 3).

Figure 3 Trends in deforestation in Colombia (treated country) and placebo gaps.

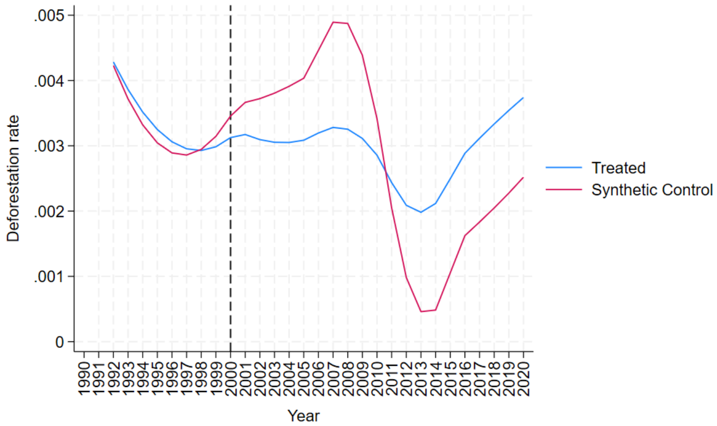


Notes: the grey lines represent the difference in deforestation between the respective synthetic control and the state in the donor pool (*synthetic – treated*); the bold black line represents the gap between Colombia and its synthetic country (*synthetic – treated*).

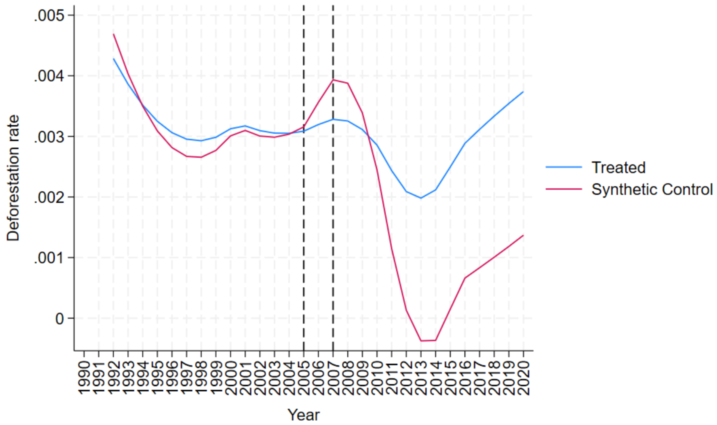
Thereafter, we conduct two placebo tests simulating an artificial (placebo) timing of the policy (Abadie et al. 2015, Heckman and Hotz, 1989): (i) we anticipate the treatment year to 2000; (ii) we postpone the treatment year to 2007, when the *Café de Colombia* was included in the EU GI list. The first test confirms the impact of the policy on the forest cover in Colombia, given that there is no significant effect of the artificial 2000 policy (Figure 4 – panel a; Figure S1, Table S1 in SM) (Abadie et al., 2021). The second test validates our results highlighting a similar significant trend of the baseline estimations (Figure 4 – panel b; Figure S2, Table S2 in SM): what influences the deforestation trend is, therefore, the moment when the *Cafè de Colombia* began to be discussed as a GI and introduced at the policy level, rather than the exact date of its official inclusion in the EU register, since producers already anticipated that recognition would eventually happen.

Figure 4 Deforestation trend, Colombia *vs* synthetic Colombia (placebo timing of the policy).

Placebo timing of the policy (2000)
Panel a



Placebo timing of the policy (2007)
Panel b



Note: Yearly deforestation rate is expressed in hectares. See Table S1 and Table S2 in SM for the weights donated by each country of the donor pool.

Thereafter, we replicate the analysis by excluding Brazil from the donor pool, which is the first Latin American agriculture and coffee producer. Neighbour countries, like Colombia, may be affected by Brazilian informal cross-border displacement of agri-food productions and exports (Meyfroidt *et al.*, 2010). Results show that our main results are robust (Figure S3, Figure S4, and Table S3 in SM). Findings are mainly coherent and slightly significant, also when we use a different source of data for forest land: Climate Change Initiative land cover (CCI-LC) data (ESA, 2017; FAO, 2022a) (Figure S5, Figure S6, and Table S4 in SM).[2] Even with this different source of forest cover data, the impact

[2] According to the land cover reclassification (UN, 2014), we combined tree-covered areas and mangroves. The former category comprises geographical areas dominated by natural tree plants with a coverage of at least 10%, hence both

of GI has a detrimental effect on deforestation rates in the first years after the introduction of the policy, while inverts in the long run.

We also conduct two other robustness checks by considering (Kaul *et al*., 2015): (i) the value of the outcome $t-1$ lag averaged over the pre-trend years as a predictor, rather than the outcome at t; (ii) all the lagged values of the outcome, but without other covariates (Ferman *et al*., 2020). While in the former case, results are in line with the baseline estimations (Figure S7 and S8, Table S5 in SM for weights donated), in the latter case, some differences in terms of significance emerge (Figure S9 and S10, Table S6 in SM for weights donated). In the case under analysis, and in line with Abadie and Gardeazabal (2003) and Abadie *et al*. (2010), covariates are deemed important and should be considered. Excluding them is not a first-best solution to simply optimise the pre-treatment fit by using all pre-treatment values of the outcome as separate economic predictors.

5. Discussion

5.1 Policy implications

We found that the GI scheme might have an overall negative impact on deforestation. These results can help policymakers to design policy interventions capable of addressing the characteristics, in terms of the local production system, that have generated this effect. Overall, policy interventions should aim at preserving forest ecosystems while guaranteeing the higher income generated by GIs (Mourao and Martinho, 2020).

First, our study confirms that more coordinated governance is needed to reduce deforestation (Furumo and Lambin, 2021). In particular, policy interventions that constrain deforestation should be implemented in parallel with those aimed at enhancing economic revenues.

natural and management forests. The latter category includes areas with a woody vegetation with 10% coverage of more but regularly flooded by salt and/or brackish water. Data, aggregated at national level, has been retrieved from FAO (2022a).

A concrete example for the Colombian government and institutions to consider is the new EU Forest Strategy for 2030 (EC, 2021). It sets concrete actions to improve the quantity and quality of EU forests, while supporting the production of sustainable food through different policy interventions, such as a new approach to finance ecosystems restoration and environmental services (Cantillon et al., 2025).

Second, the paper highlighted the need to set shared norms to guarantee that the GI scheme might contribute to enhancing environmental sustainability, given that it is not one of its primary objectives (EC, 2025). The acknowledgement as a GI, increasing the profitability of productions and, consequently, the rent producers and the value of land, might, in fact, constitute a risk for forest preservation. Common lines of interventions should be set at the national level for the entire supply chain and all the actors involved, regardless of their business form and economic dimensions (Meyfroidt and Lambin, 2011). In the case under analysis, the adoption of sustainability strategies is obstructed by the high fragmentation of the supply chain, which is primarily managed by small-scale rural people and family farms (Gibson *et al*., 2011; Matricardi *et al*., 2020). A higher level of power concentration in the upward part of the supply chain may help them to achieve fairer remuneration, increase their market power and avoid the rising costs for marketing and distribution, especially in importing countries, which will decrease the farmers' share in the coffee retail price. Policy makers and practitioners should investigate which production model may be most suitable to strengthen the position of small local producers and promote a reorganisation of local production systems. New entrepreneurial opportunities based on coordination and cooperation among actors along the supply chain (Arias and Fromm, 2019; ICO, 2022; EC, 2024; Belso-Martinez *et al*., 2024; Vaquero-Piñeiro and Pierucci, 2025; Quiñones-Ruiz *et al.*, 2016) and public-private partnerships are, in fact, considered as effective policy mechanisms to scale up impacts (Furumo and Lambin, 2020). As declared by the 2025 EU Vision for agriculture and food, "*encouraging* [farmers] *to join cooperatives and/or associations to reduce costs, increase efficiency and improve prices for the market* (EC, 2025:

p. 7). In this context, the GI system is, *per se,* a first step toward cooperation, given its peculiar combination of competition and cooperation among geographically close firms (Vaquero-Pineiro et al., 2025). However, a governance regime with greater collaboration between environmental and industry stakeholders achieved better environmental outcomes (Heilmayr and Lambin, 2016). Lastly, it should be appropriate for policy interventions managing the GI scheme in tandem with the increasing diffusion of eco-friendly private certifications, such as the Rainforest Alliance, that pose environmental sustainability as their prime objective (Vanderhaegen *et al*., 2018; Oberlack *et al*., 2023). In this context, the GI might consider the specific standards and requirements established by such certification as a welcome basis and integrate them into the product specification. The information system proposed in the product specification to monitor coffee growers could, for example, record the adoption of private schemes, thereby helping to identify which forest preservation requirements could be most easily incorporated into the specification.

5.2 Limitations

The study proposed has some limitations that should be discussed.

First, the national level could appear too much aggregated and not capable of accounting for regional deforestation patterns. The national level is, however, the only suitable one, given that in the product specification, there are no specific administrative boundaries defining the region of origin. Geo-referenced data on forest and coffee plantations could potentially be downloadable from satellite databases, even with some limitations in terms of time span (Hansen et al., 2013; Sulla-Menashe et al., 2011; Buchhorn et al., 2020) and spatial resolution (Liu et al., 2020). However, it will not be sufficient, given that causal impact estimations necessitate a set of socio-economic and demographic contextual information that does not exist at the gridded level.

Second, the study is limited by the fact that, based on the available data, it is not possible to distinguish between GI and non-GI coffee production. However, given the free-riding effects mentioned before, in this study, we can assume that, at least partially, the effect on land-use change (from forest to coffee plantations) deforestation is, directly and indirectly, driven by the presence of the scheme.

Third, the model does not isolate the potential presence of other simultaneous events that may have impacted the Colombian deforestation patterns in the post-treatment period. An example could be the long-lasting conflict within the Revolutionary Armed Forces of Colombia movement and the Colombian government, which could represent an obstacle to forest preservation. However, given that it has lasted for almost the entire period under analysis (MADR-UPRA, 2014), it can be considered a sort of contextual condition for the whole country (see Sánchez-Cuervo et al., 2012; Murillo-Sandoval et al., 2019; Negret et al., 2019; Clerici et al., 2020).

Fourth, the Synthetic Control Method is sensitive to the donor pool selection, which we tested by changing the donor pool in the robustness checks and the assumption of non-spillover effects. The registration of a GI may incentivise the reallocation of non-GI productions in the neighbouring regions that have not been included in the region of origin, generating a new demand for agricultural area, also in those regions that have not been directly targeted by the intervention. Territorial spill-over effects are, however, more plausible across sub-national areas within the same country than at the national level (Cortinovis and van Oort, 2018; Caragliu and Landoni, 2024).

6 Conclusions and takeaways

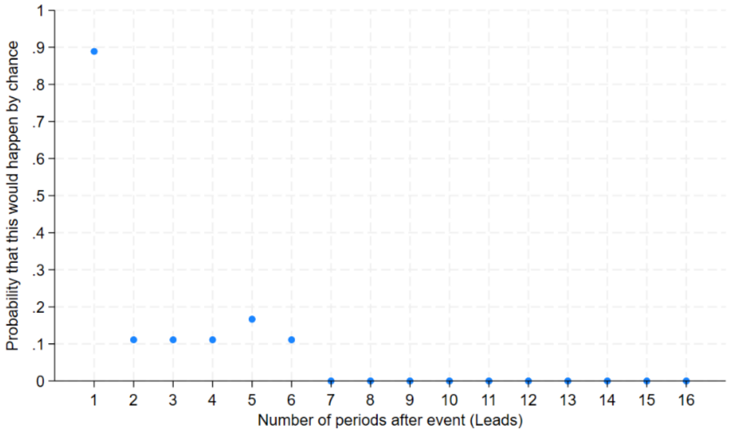
Does the GI scheme pose risks to the diversity of the ecosystem? By looking at the case of coffee production in Colombia, , this paper highlights that for forest ecosystems, such a risk exists. Without Café de Colombia's GI recognition, deforestation would have been about 0.2 percentage points lower on average, indeed. To preserve local ecosystem services (i.e., forest), while enhancing economic performance, a pre-assessment of the effects of policy intervention is, therefore, required. In the case of GIs, in fact, the acknowledgement of a product will enhance product reputation and competitiveness, but it could be at the expense of local ecosystems. Policy strategies belonging to different policy areas of interventions (i.e., agrifood, forest management and economic development) should be evaluated complementarily to obtain a comprehensive framework of the effects and

design a policy mix capable of supporting sustainable development. In the case of Colombia, the socio-economic development of rural and indigenous communities should be promoted through a sustainable forest management approach capable of guaranteeing the preservation of primary and old-growth forests. Territorial-based interventions, such as the GI scheme, should be integrated into a local development strategy that can blend economic performance with natural resources conservation. This synergy may enhance local expertise, converting into a strategic asset for sustainable development.

Our analysis needs, however, to be hedged with some caveats, especially due to data limitations. A better harmonised database at the sub-national level for all the regions of the South American countries could help to improve the level of detail of the analysis. At the same time, more exhaustive outcomes accounting for environmental sustainability (e.g., emissions and water use for coffee production) could help to provide a more comprehensive assessment of the scheme. Despite these limitations, our analysis offers new evidence to properly assess the environmental sustainability of the GI scheme. To our future agenda, we left investigating the linkages explored in this study in the case of other GI Cafès (*i.e.*, *Café de Valdesia* in the Dominican Republic or *Café Antigua* in Guatemala).

Appendix

Figure A 1 P-values – post-treatment period.



Note: P-values on the y-axis.

Table A 1 Variables' definitions.

Variable name	Definition	Source
Agricultural area	Share of agricultural (farming and livestock) area over total land area.	FAOSTAT
Population density	Total population over land area.	FAOSTAT
People leaving in rural areas	Share of rural people over total population.	FAOSTAT
Trade openness	Sum of import and export as share of total GDP.	WDI
Cereal yield	Kilograms per hectare of harvested land.	FAOSTAT
Temperature change	Mean monthly temperature anomalies with respect of a baseline climatology corresponding to the period 1951-1980.	FAOSTAT
GDP per capita	Gross domestic product per capita at 2015 constant US$.	WDI
House of freedom index	Sum of the two variables of civil liberties and political rights rescaled from 1 to 10 (where 1 is the lowest institutional quality level and 10 the highest).	Authors' elaboration on Freedom House data
Agricultural trade openness	Ratio between the value of agricultural exports and imports.	Authors' elaboration on FAOSTAT data
Deforestation	Deforestation rate, calculated on total forest (natural and planted forest) for the reconstructed data and on the sum of tree and mangroves cover for CCI-LC data.	Authors' elaboration on FAOSTAT data

Note: FAOSTAT (source: FAO, 2022a); Freedom House (source: Freedom House, 2022); WDI (source: WB, 2022).

Table A 2 Forest predictors' means, Colombia *vs* donor pool.

	Agricultural area	Population density	People leaving in rural areas	Trade openness	Cereal yield	Temperature change	GDP per capita	House of freedom index	Agricultural trade openess
Argentina	0,45	0,14	0,1	28,67	3873,65	0,47	11722,31	7,99	13,82
Bolivia	0,34	0,09	0,35	58,42	1682	0,6	2115,75	7,1	1,94
Brazil	0,28	0,22	0,17	21,41	2829,03	0,95	7109,65	7,56	6,06
Chile	0,21	0,22	0,13	60,55	4586,62	0,35	7806,03	9,34	2,13
Colombia	**0,4**	**0,38**	**0,24**	**33,48**	**2950,3**	**0,6**	**3974,18**	**5,86**	**1,85**
Costa Rica	0,36	0,85	0,33	79,48	3144,67	0,37	7101,63	9,68	3,17
Cuba	0.61	1.05	0.24	49.69	2472.74	0.80	4552.82	0.37	0.77
Ecuador	0,28	0,56	0,38	42,15	1918,29	0,66	4322,66	6,81	3,21
El Salvador	0.62	2.90	0.37	58.44	1879.78	0.80	2748.35	7.29	0.73
Guatemala	0,4	1,25	0,53	43,41	1721,85	0,79	2956,13	5,26	2,12
Guyana	0,06	0,04	0,72	166,51	3154,61	0,88	3114,65	7,79	2,13
Honduras	0,3	0,69	0,49	76,08	1279,29	0,76	1678,16	6,03	1,6
Jamaica	0.43	2.46	0.48	91.11	1515.45	0.81	4478.37	7.70	0.53
Mexico	0,53	0,55	0,24	27,68	2128,62	0,77	6992,36	6,87	0,87
Nicaragua	0,41	0,46	0,43	59,03	1424,42	0,71	1898,17	5,52	1,62
Paraguay	0,39	0,14	0,45	51,09	1532,24	0,52	2951,95	6,41	3,93
Peru	0,19	0,22	0,25	34,63	2034,98	0,8	3424,98	6,49	0,87
Uruguay	0,84	0,19	0,07	34,52	1426,39	0,64	7237,17	9,68	3,83
Venezuela	0,24	0,3	0,13	49,64	1658,7	0,66	12971,21	4,6	0,11

Notes: variables are averaged on the pre-treatment period, from 1992 to 2020.

Table A 3 Pre-treatment Forest predictors mean: Colombia, synthetic Colombia, and donor pool.

	Colombia		**Donor pool**
	Real	*Synthetic*	
Agricultural area	0.396	0.278	0.386
Population density	0.344	0.406	0.686
People leaving in rural areas	0.276	0.282	0.326
Trade openness	30.904	42.336	57.417
Cereal yield	2539.257	2537.35	2242.21
Temperature change	0.409	0.491	0.692
GDP per capita	3535.416	4569.47	5196.75
House of freedom index	5.476	6.998	6.805
Agricultural trade openness	2.356	2.371	2.747
Outcome variable averaged over the pre-trend years	0.003	0.003	0.002

Notes: variables are averaged from 1992 to 2005 (pre-treatment period). Pre-trend outcomes from 1992 to 2005. The table summarises the comparison between the pre-treatment average values of covariates used to create the synthetic counterfactual with the average of Colombia and the average of the donor pool.

Table A 4 Weights donated by each country of the donor pool, Colombia *vs* synthetic Colombia.

Country	**Synthetic Colombia weight**
Argentina	0
Bolivia	0
Brazil	0.161
Chile	0.420
Costa Rica	0
Cuba	0
Ecuador	0
El Salvador	0
Guatemala	0.230
Guyana	0
Honduras	0
Jamaica	0
Mexico	0
Nicaragua	0.040
Perù	0.126
Paraguay	0.023
Uruguay	0
Venezuela	0

Notes: Countries with positive weights are used as donors.

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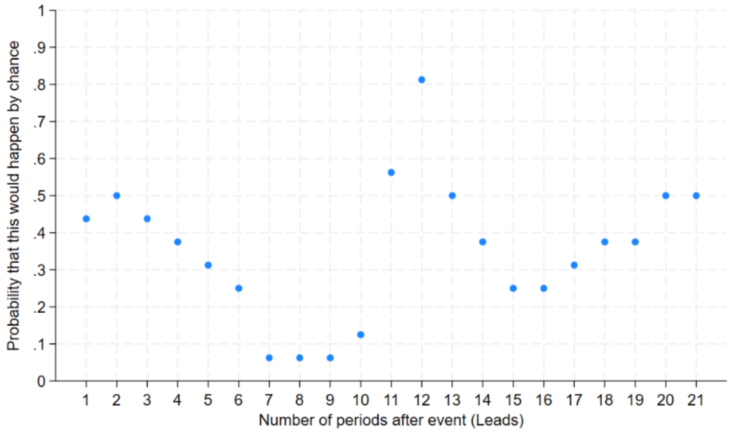
Supplementary Materials

Figure S 1 P-values – post-treatment period, placebo timing of the policy (2000).

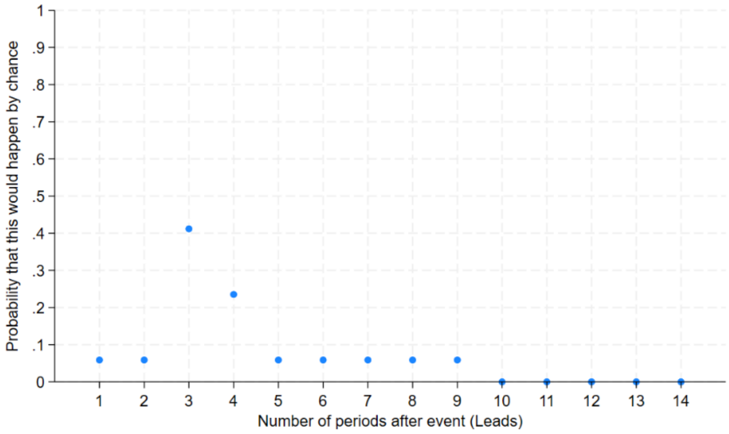


Note: P-values on the y-axis.

Table S 1 Weights donated by each country of the donor pool, placebo timing of the policy (2000).

Country	Synthetic Colombia weight
Argentina	0.186
Bolivia	0
Brazil	0
Chile	0.298
Costa Rica	0
Cuba	0
Ecuador	0
El Salvador	0
Guatemala	0.068
Guyana	0
Honduras	0
Jamaica	0
Mexico	0.349
Nicaragua	0.085
Paraguay	0.015
Perù	0
Uruguay	0
Venezuela	0

Figure S 2 P-values – post-treatment period, placebo timing of the policy (2007).



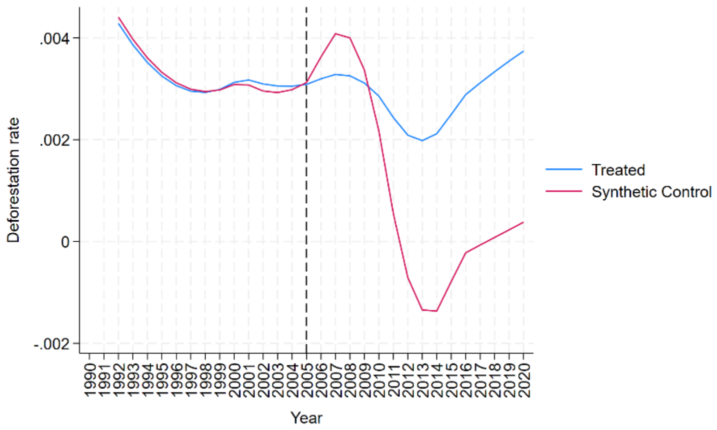
Note: P-values on the y-axis.

Table S 2 Weights donated by each country of the donor pool, placebo timing of the policy (2007).

Country	Synthetic Colombia weight
Argentina	0.060
Bolivia	0
Brazil	0.107
Chile	0.288
Costa Rica	0
Cuba	0
Ecuador	0
El Salvador	0
Guatemala	0.115
Guyana	0
Honduras	0
Jamaica	0
Mexico	0.378
Nicaragua	0.048
Perù	0
Paraguay	0.004
Uruguay	0
Venezuela	0

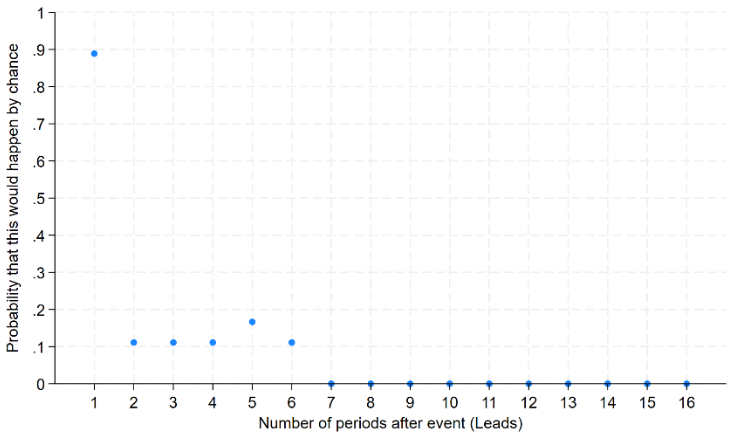
Notes: Countries with positive weights are used as donors.

Figure S 3 Deforestation trend, Colombia *vs* synthetic Colombia – excluding Brazil.



Note: Yearly deforestation rate is expressed in hectares.

Figure S 4 P-values – post-treatment period, excluding Brazil.



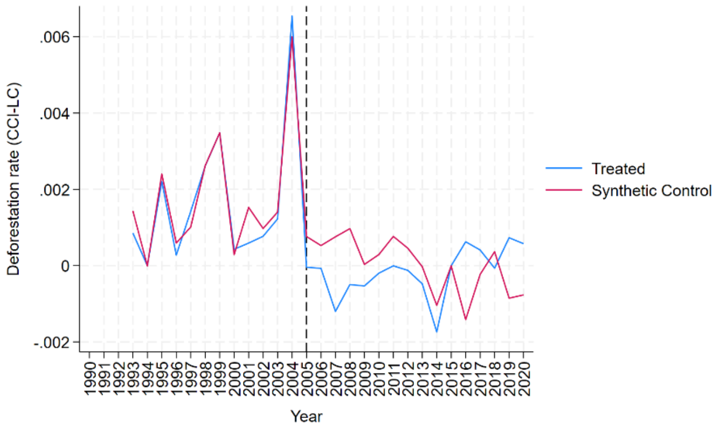
Note: P-values on the y-axis.

Table S 3 Weights donated by each country of the donor pool – excluding Brazil.

Country	Synthetic Colombia weight
Argentina	0.077
Bolivia	0.001
Chile	0.333
Costa Rica	0.021
Cuba	0.002
Ecuador	0.001
El Salvador	0.012
Guatemala	0.127
Guyana	0.001
Honduras	0.001
Jamaica	0.001
Mexico	0.326
Nicaragua	0.087
Paraguay	0.009
Perù	0
Uruguay	0.001
Venezuela	0

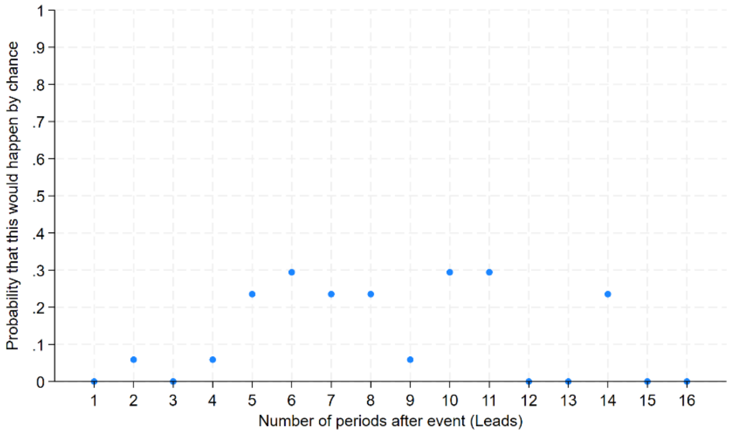
Notes: Countries with positive weights are used as donors.

Figure S 5 Deforestation trend, Colombia *vs* synthetic Colombia – Climate Change Initiative land cover (CCI-LC) data.



Note: Yearly deforestation rate is expressed in hectares.

Figure S 6 P-values – post-treatment period, Climate Change Initiative land cover (CCI-LC) data.

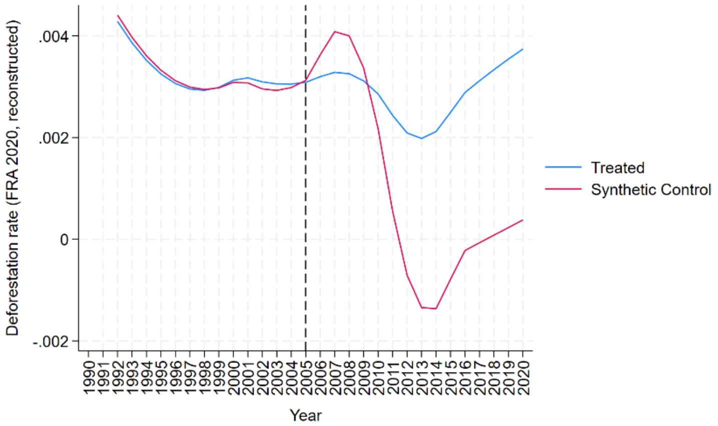


Note: P-values on the y-axis.

Table S 4 Weights donated by each country of the donor pool, Climate Change Initiative land cover (CCI-LC) data.

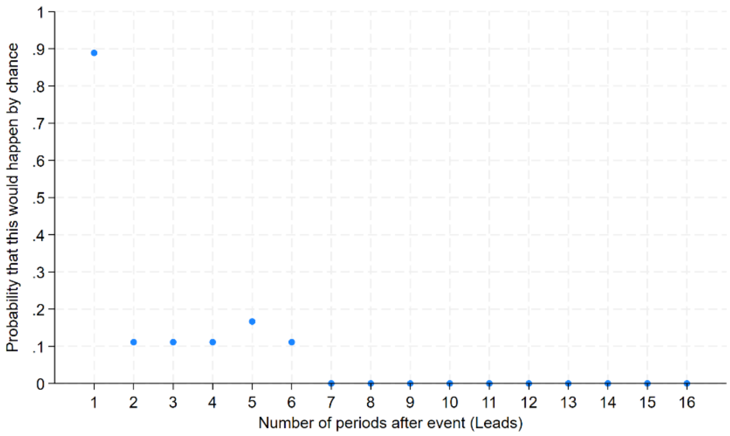
Country	**Synthetic Colombia weight**
Argentina	0.083
Bolivia	0
Brazil	0
Chile	0
Costa Rica	0
Cuba	0.113
Ecuador	0.113
El Salvador	0.025
Guatemala	0.021
Guyana	0
Honduras	0
Jamaica	0
Mexico	0.118
Nicaragua	0
Paraguay	0
Perù	0.639
Uruguay	0
Venezuela	0

Figure S 7 Deforestation trend, Colombia *vs* synthetic Colombia – average of t-1 outcome.



Note: Yearly deforestation rate is expressed in hectares.

Figure S 8 P-values – post-treatment period, average of t-1 outcome.

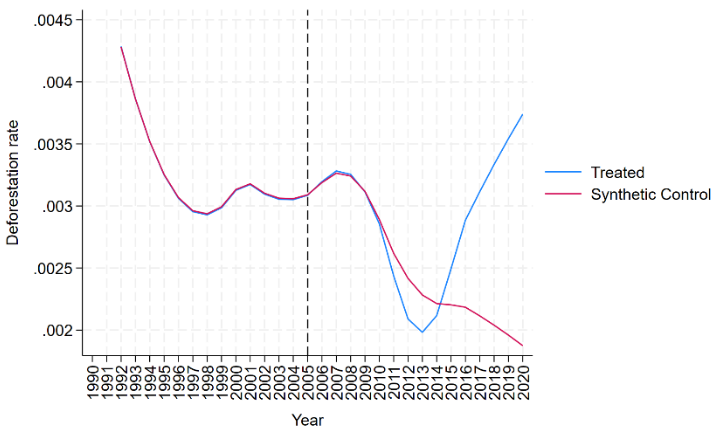


Note: P-values on the y-axis.

Table S 5 Weights donated by each country of the donor pool, average of t-1 outcome.

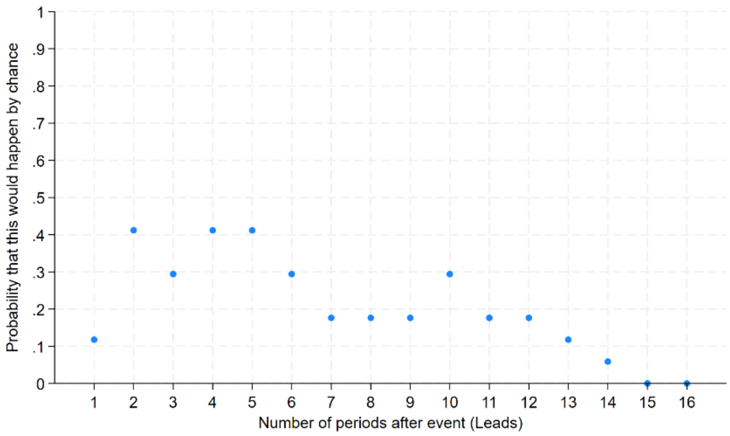
Country	Synthetic Colombia weight
Argentina	0
Bolivia	0
Brazil	00161
Chile	0.42
Costa Rica	0
Cuba	0
Ecuador	0
El Salvador	0
Guatemala	0.230
Guyana	0
Honduras	0
Jamaica	0
Mexico	0
Nicaragua	0.040
Paraguay	0.023
Perù	0.126
Uruguay	0
Venezuela	0

Figure S 9 Deforestation trend, Colombia *vs* synthetic Colombia – all the lagged values of the outcome.



Note: Yearly deforestation rate is expressed in hectares.

Figure S 10 P-values – post-treatment period, all the lagged values of the outcome.



Note: P-values on the y-axis.

Table S 6 Weights donated by each country of the donor pool, all the lagged values of the outcome.

Country	Synthetic Colombia weight
Argentina	0.006
Bolivia	0.0167
Brazil	0.013
Chile	0.002
Costa Rica	0.152
Cuba	0.001
Ecuador	0.017
El Salvador	0.010
Guatemala	0.086
Guyana	0.046
Honduras	0.006
Jamaica	0.003
Mexico	0.009
Nicaragua	0
Paraguay	0.028
Perù	0.433
Uruguay	0.001
Venezuela	0.019

Table S 7 Other Latin America GIs and reasons for not discarding countries in the donor pool.

GI name	Product category	Country	Year	GI type	Reasons why we do not discard the country from the donor pool
Ron de Guatemala	Spirit drinks	Guatemala	2014	PGI	Different Regulations for spirits.
Tequila	Spirit drinks	Mexico	2019	PGI	At the end/after the period under analysis - no sufficient post policy years.
Pisco	Fruit spirit	Perù	2013	PGI	Different Regulations for spirits.
Vale dos Vinhedos	Wine	Brazil	2007	PDO	Different Regulations for wines.
Demerara Rum	Spirit drinks	Guyana	2021	PGI	At the end/after the period under analysis - no sufficient post policy years.
Camarão da Costa Negra	Food	Brazil	Applied		Not registered yet.
Ron de Venezuela	Spirit drinks	Venezuela	Applied		Not registered yet.
Cuba	Spirit drinks	Cuba	2023	PGI	At the end/after the period under analysis - no sufficient post policy years.