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The foreign spillovers of hybrid trade-based climate governance

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Countries often adopt climate mitigation policies that generate extraterritorial effects through trade. These measures can interact with existing private governance tools, such as voluntary sustainability standards (VSS). We call this hybrid trade-based climate governance. This article aims to examine how the EU designed the hybrid trade-based climate governance in the biofuels sector, and to begin evaluating its spillover effects in third countries. We do so by revisiting the political process behind the EU's renewable energy directive (EU RED) and by probing its impacts in Brazil through Bonsucro. Using process tracing, we indicate that the European Commission avoided including socioeconomic criteria in the assessment of its biofuels regulation. Quantitative analysis, in turn, suggests that the EU's orchestration of VSS is associated with mixed effects on the ground in Brazil. The EU biofuels governance may be ill-suited to help promote climate justice abroad due to its excessive focus on procedures rather than fair impacts. While this is an initial, tentative analysis, the results nonetheless reinforce the need for a more careful discussion of alternative approaches to VSS orchestration.

In recent years, there has been a growing debate about the rise of unilateral or autonomous climate policies adopted independently of multilateral or bilateral negotiations[1,2], as well as about their public acceptability[3–5]. Prominent examples include the EU's Renewable Energy Directive (RED), the Carbon Border Adjustment Mechanism (CBAM), and the EU Deforestation Regulation (EUDR). Despite differences in scope, these measures share a core feature: international trade and global supply chains act as transmission mechanisms through which EU regulations generate effects in third countries. While such policies may bypass delays inherent in international negotiations, they have also been widely criticized abroad as unfair or neo-protectionist[6].

Can public–private interactions help mitigate these criticisms by helping deliver tangible and equitable outcomes in countries affected by unilateral, trade-based climate regulation? This article examines how the EU designs hybrid trade-based climate governance in the biofuels sector and evaluates its spillover effects in third countries. It assesses whether the EU's biofuels governance architecture is associated with outcomes across its main dimensions of climate justice, namely climate mitigation, recognition, distributive, and procedural outcomes. The analysis focuses on hybrid governance arrangements in which private actors, particularly voluntary sustainability standards (VSS), are mobilized to support monitoring and compliance with public climate regulations. We define hybrid climate governance as policy arrangements combining public authority and private rulemaking[7]. Within this broader category, orchestration refers to cases in which a public authority enlists intermediary actors to advance regulatory objectives[8,9]. Specifically, we examine governance tools implemented through international trade, including import regulations, market access conditions, and certification requirements applied across borders.

Public-private interactions are often promoted as a response to the limitations of both state-led and market-based governance[10,11]. Trade-linked labor and environmental provisions can contribute to stronger environmental regulation[12–14], yet state enforcement is frequently costly and uneven[15,16]. Private and voluntary governance, by contrast, is typically cheaper but often fails to produce measurable improvements on the ground[17]. Orchestration is frequently presented as a solution capable of increasing capacity, accountability, and legitimacy while reducing the risk of regulatory capture[18]. Empirically, however, orchestration is associated with uneven results. Orchestrated carbon footprint schemes have failed[9], orchestration under the EU biofuels policy has faced design constraints[19–22], and orchestration within the UNFCCC has been criticized for weak democratic accountability and limited capacity building[23,24]. Although orchestration presumes learning over time[25], its agendas are politically defined[10] and may reflect domestic preferences at the expense of affected actors abroad.

The empirical focus of the paper is the EU Renewable Energy Directive (RED), treated as a paradigmatic case[26], and its spillovers in Brazil. Under RED, economic operators may rely on voluntary sustainability standards to demonstrate compliance with the EU biofuels regulation and gain access to the European market. In Brazil, Bonsucro is the only VSS approved under RED, and producers may adopt the Bonsucro-RED standard, which combines Bonsucro's core criteria with additional EU-specific requirements.

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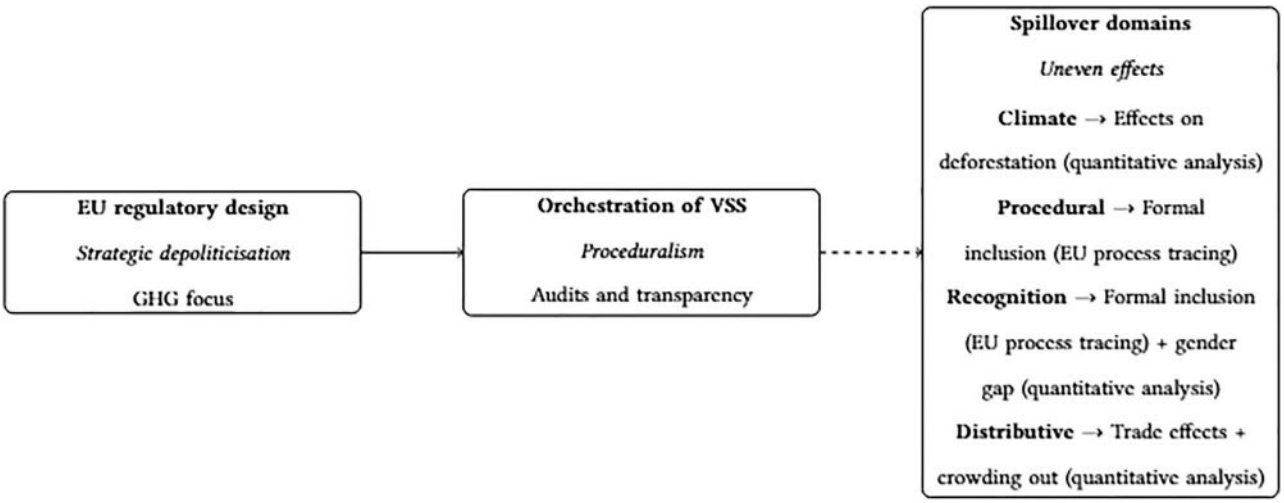

Fig. 1 | Conceptual framework. Framework linking EU orchestration of voluntary sustainability standards to climate justice spillovers in foreign countries.

Methodologically, we combine process tracing of RED political debates between 2008 and 2022 with a staggered difference-in-differences design[27], comparing Brazilian municipalities with and without firms certified under Bonsucro-RED. We preliminarily assess effects/spillovers across five domains: (1) sugar and ethanol exports, (2) the share of family farms, (3) labor allocation, (4) gender inequality, and (5) deforestation. While the qualitative analysis examines how the EU addressed the procedural dimension of climate justice, the econometric analysis captures distributive, recognition, and environmental dimensions. Climate justice is here understood as concerns with the unequal impacts of climate policies on vulnerable communities and future generations[28]. Specifically, we examine whether the Bonsucro-RED certification corresponds with changes in exports to the EU; whether it relates to the prevalence of smallholder and family farms as defined under Brazil's Law 11.326/2006; how it is associated with shifts in farm size distribution and gender disparities in land ownership; and whether it corresponds with variations in deforestation rates, which serve as a proxy for local environmental and climate mitigation outcomes.

We derive expectations about RED's foreign spillovers from the political dynamics that shaped its successive revisions within the EU (Fig. 1). Process tracing indicates that these revisions placed greater emphasis on emissions, on procedural quality and participatory processes than on substantive on-the-ground effects in terms of climate justice. As a result, distributive conflicts were sidelined, and the focus became technical compliance. Critics of proceduralism and throughput legitimacy suggest that strengthened transparency and governance requirements do not necessarily translate into substantive socio-economic change[29,30]. When regulatory legitimacy relies heavily on procedural quality, distributive consequences may remain contingent on pre-existing structural conditions rather than systematically addressed through policy design[31]. Under such a configuration, we do not expect certification under Bonsucro-RED to be systematically associated with positive effects across distributive, recognition, and environmental dimensions of climate justice. We do not mean to say that RED is the culprit behind inequalities in rural Brazil, but rather that its design and implementation did not contribute in a consistent and systematic way to measurable improvements in a context marked by entrenched inequalities and distributive challenges.

Consistent with our expectations, the empirical effects of Bonsucro-RED in Brazil are heterogeneous. Certification is associated with increased exports among municipalities with already high export volumes, while lower-decile exporters experience negative associations. Effects on smallholders are sensitive to specification, and gender-related outcomes are not statistically robust[32]. Finally, we find no statistically significant association between certification and deforestation. Robustness checks using anticipation tests confirm the fragility and unevenness of these patterns. These findings should be interpreted as suggestive associations rather than definitive causal effects, given limited pre-treatment observations for some outcomes and the non-random adoption of certification. Taken together, these results raise questions about whether a governance architecture centered primarily on procedural compliance is equipped at all to help deliver broader distributive and environmental outcomes abroad. To put it differently, procedural strengthening—including via process participation—may not automatically translate into equitable spillovers abroad.

The article contributes to the literature in three ways. First, it links debates on unilateral climate policy to empirical evidence on foreign spillovers. Second, it advances the study of orchestration by moving beyond compliance and procedural assessments to examine distributive outcomes on the ground. Third, it outlines cautious and differentiated avenues for strengthening the external monitoring of hybrid climate governance, while remaining attentive to political and legal constraints. The remainder of the article introduces RED and Bonsucro, traces the political process behind RED, presents the empirical analysis of Bonsucro-RED in Brazil, and concludes by detailing the methods used.

Results

Strategic depoliticization by the EU RED

As part of its strategy to reduce greenhouse gas emissions, the European Union launched the Renewable Energy Directive (RED) in 2009 to promote renewable energy use, including biofuels. RED establishes sustainability criteria that economic operators must meet in order to access the EU market, particularly with respect to greenhouse gas performance, land-use change, and supply-chain traceability. Rather than relying exclusively on state enforcement, the Directive allows the European Commission to recognize VSS as instruments for verifying compliance with these criteria.

Within this framework, producers seeking to align with EU regulatory requirements and broader international expectations regarding environmental and social responsibility may rely on third-party certification schemes[33]. One such scheme is Bonsucro, which defines sustainability benchmarks for sugarcane production and its byproducts, including ethanol. To obtain certification, producers must comply with environmental requirements (e.g., limits on greenhouse gas emissions, water return rates, biodiversity protection), labor and human rights obligations (e.g., occupational safety, wages, and the prohibition of child and forced labor), and economic performance metrics (e.g., efficiency and monitoring of resource use). Certification involves a self-assessment phase, on-site audits conducted by independent verifiers, and mandatory

record-keeping, with periodic recertification required to maintain validity and market access[34].

Bonsucro certification is structured around six core principles:

- Legal compliance;
- Respect for labor rights and human dignity;
- Efficient management of inputs and processes;
- Preservation of biodiversity and ecosystems;
- Commitment to continuous improvement;
- Compliance with EU RED-specific sustainability requirements for biofuels (for producers exporting to the EU).

The sixth principle constitutes the direct interface between Bonsucro and EU regulation. Under RED, the Commission may recognize schemes such as Bonsucro as valid mechanisms to demonstrate compliance with EU sustainability criteria for biofuels. These criteria focus on three core dimensions: land use (preventing conversion of high-carbon or high-biodiversity areas after 2008 and ensuring traceability), greenhouse gas emissions (accounting for emissions from production and land-use change along the supply chain), and chain-of-custody requirements (documenting product identity and volumes to guarantee traceability).

Although the EU recognizes several certification schemes under RED, such as ISCC EU, RSB, REDcert, and RTRS EU RED, Bonsucro is the only one with an operational presence in Brazil. As a result, it functions as a de facto gatekeeper for Brazilian ethanol producers seeking access to the European market under RED sustainability requirements. Importantly, Bonsucro offers two certification tracks: its core standard and a RED-compliant version. The latter incorporates all baseline Bonsucro requirements while adding EU-specific criteria. While certification remains formally voluntary, European market access conditions and regulatory expectations often steer producers toward RED-aligned certification, consistent with broader analyses of EU regulatory influence in global trade[35].

Why did the EU decide to orchestrate VSS under EU-RED? The most common justification for the EU's meta-regulation of VSS is the need to reduce administrative burden. This reflects the functionalist logic behind orchestration. Schleifer[19] suggests that the main motivation behind RED's engagement with VSS was efficiency: avoiding duplication and saving time and resources. The Commission viewed private schemes as a way to reduce implementation costs for Member States and to enable extraterritorial reach through third-party verification[20]. However, this efficiency logic may obscure the political contestation behind RED. We aim to uncover this political process in order to clarify the intended and unintended outcomes of RED.

During the discussions preceding RED (Directive 2009/28), the EU biofuel and sugar industries defended protectionist measures to shelter an "infant" ethanol industry[36] and demanded a transition period[37] before full trade opening to foreign biofuels. When the Commission was deciding whether to engage with VSS in RED's monitoring framework, EU farmers sometimes opposed the idea, arguing that the Common Agricultural Policy (CAP) already addressed biofuel sustainability and should serve as a model for third countries[38,39]. Some biofuel producers supported minimum social safeguards while opposing excessive regulatory burdens[40,41]. By contrast, EU producers dependent on cheap imports opposed stricter criteria, fearing cost increases[42]. Similar concerns were raised by foreign producers[43]. NGOs, concerned about unintended land conversions caused by shifts in agricultural production due to biofuel crop expansion, demanded the inclusion of indirect land-use change (ILUC) references in EU legislation and called for stronger social safeguards[44,45].

Faced with competing interests, the Commission strategically depoliticized the RED agenda by framing it around greenhouse gas (GHG) emissions and technical measurement[46], rather than redistribution or political trade-offs. For instance, Directive 2009/28/EC does not refer directly to climate justice and, with regard to social issues, states that it "is therefore appropriate to encourage the development of multilateral and bilateral agreements and voluntary international or national schemes that cover key environmental and social considerations." In June 2010, the Commission issued the non-binding communication "Communication from the Commission on voluntary schemes and default values in the EU biofuels and bioliquids sustainability scheme" (OJ C 160, 19.6.2010), outlining procedures for recognizing voluntary schemes. The document clarifies how voluntary certification schemes may be recognized and how default greenhouse gas values should be applied for compliance purposes. Its focus is on procedural guidance, reporting requirements, and verification mechanisms, while it does not engage with distributive trade-offs, land tenure conflicts, or broader socioeconomic effects in producer countries. By treating implementation as a matter of technical calibration rather than political contestation, the Communication reinforces a governance logic in which distributive questions remain largely external to the regulatory framework.

The debate on ILUC was similarly recast as a technical issue of "unforeseen emissions," distancing it from land rights or justice concerns[47,48]. Although modelers acknowledged that many ILUC scenarios rely on stochastic assumptions[49], environmental NGOs reinforced the perception that adequate monitoring tools existed, and the Commission aligned with this framing. Coordinated lobbying by EU farmers, biofuel producers, and foreign exporters led the Commission to postpone formal discussion of ILUC[50], but the issue resurfaced years later and was incorporated into RED II, the 2018 amendment to the Directive. The 2018 revision of RED mandated the Commission to define implementing rules, and Regulation 2022/996 subsequently formalized stricter, yet predominantly procedural, criteria for VSS recognition, with a strong emphasis on scheme governance. The Regulation focuses extensively on audit procedures, traceability systems, mass-balance requirements, and reporting obligations for recognized voluntary schemes. While it refines the technical architecture of compliance, it does not introduce explicit references to distributive justice, land tenure equity, or broader socioeconomic impacts in third countries.

Attempts to broaden the EU RED's framework to include economic and social impacts on the ground were largely driven by the European Parliament but ultimately abandoned. These included proposals requiring the Commission to produce regular reports on the social and economic sustainability impacts of biofuel demand in the EU and third countries[51]. The Council rejected these proposals, arguing that such reporting was neither necessary nor appropriate to fulfill the Directive's objectives, instead reaffirming priorities related to greenhouse gas performance and administrative efficiency.

This depoliticization granted the Commission greater autonomy to repackage domestic preferences while avoiding international backlash[52,53]. Crucially, the EU's approach helped avoid scrutiny at the World Trade Organization (WTO)[21,54]. The reforms reinforced RED's technical framing by emphasizing good governance metrics for VSS. According to the World Bank[55], "good governance is epitomized by predictable, open, and enlightened policymaking (that is, transparent processes); a bureaucracy imbued with a professional ethos; an executive arm of government accountable for its actions; and a strong civil society participating in public affairs; all operating under the rule of law." The issue, however, lies not in the adoption of good governance principles per se, but in their selective operationalization within RED. Rather than using good governance as a substantive yardstick to assess distributive outcomes, power asymmetries, or material impacts in third countries, the Commission translated it into procedural and managerial metrics applicable to VSS and GHG emissions. These metrics prioritize formal transparency, auditability, and organizational capacity, while sidelining questions of whose interests are served, who bears adjustment costs, and how benefits and burdens are distributed across affected communities abroad. In doing so, RED embedded a narrow, compliance-oriented interpretation of good governance that facilitated technical evaluation and regulatory delegation, while depoliticizing underlying conflicts over land use, labor, and development pathways. Table 1 compares the evolution of EU RED requirements over time. The table was constructed deductively based on a systematic analysis of the relevant EU legal texts.

Table 1 | Comparison of Renewable Energy Directive voluntary sustainability standard governance criteria in 2010 and 2022

Governance function	2010	2022
Recognition by the commission	General process; approved schemes listed in the official journal.	Formal procedure requiring documentation on governance, methodology, auditing, training, etc.
Scope of application	Applies to RED and FQD (2009); covers biofuels and bioliquids.	Applies to RED II (2018); broader scope including biomass fuels and low ILUC-risk certification.
Mass balance system	Recommended with basic documentation.	Technically detailed; includes traceability, mixing rules, and timeframes.
Auditing	Periodic third-party audits required; limited detail.	Initial and periodic audits are mandatory; auditors must meet ISO 17065; sampling and scope are defined.
Certification bodies	Must be independent.	Must be accredited, competent, and impartial; the Commission may audit or suspend schemes.
Scheme governance	Required to be "transparent and reliable."	Must have legal personality, documented procedures, grievance mechanisms, independent governance, formal inclusion of indigenous representatives, and safeguards against over-representation of interests.
Transparency obligations	Encouraged to publish methodologies and audit approaches.	Annual reporting to the commission is required; disclosure of volumes, auditors, complaints, etc.
Complaints handling	Not addressed.	Mandatory internal procedure; complaints must be logged and addressed.
GHG emissions accounting	May propose default values (Annex V).	Must follow strict methodology (Annex IV); includes allocation, emission factors, and residues.
Waste and residues	Briefly mentioned.	Verification and documentation requirements introduced.
Low ILUC-risk certification	Not included.	New provisions with requirements on additionality, monitoring, and traceability.
Monitoring and updates	General recommendation.	Mandatory notification of changes; the commission may suspend recognition.

Bearing all the above in mind, did RED help deliver positive on-the-ground climate justice effects in Brazil? The EU successfully built an unprecedented certification regime centered on limiting GHG accounting, but there is limited evidence that this approach delivers positive spillovers or advances climate justice abroad[19,21]. Existing critiques, such as Stattman et al.[22], analyze RED's design, arguing that it contributed to the proliferation of relatively lax, industry-driven sustainability standards. But what are the actual impacts on the ground?

Although procedural safeguards can improve the internal functioning of VSS, they do not guarantee equitable outcomes on the ground. Voluntary schemes may generate both negative and positive spillovers[56], and an emphasis on procedural quality can obscure the political conflicts that shape regulatory effects[29]. Empirical research suggests that stakeholder participation may reinforce business dominance within certification schemes[57,58], while the absence of systematic socioeconomic indicators leaves distributive consequences insufficiently monitored and can create unintended effects, such as increased food insecurity[59]. Consistent with these critiques, we expect mixed outcomes across municipalities and producer groups in Brazil. The EU largely delegated responsibility for socioeconomic impacts to private schemes and did not establish robust mechanisms to assess effects on the ground. Under such a governance architecture, procedural quality may coexist with persistent structural inequalities, and improvements in participation or transparency will not necessarily translate into broader gains across other dimensions of climate justice.

Did EU proceduralism deliver? Probing the spillovers of Bonsucro-RED in Brazil

The previous subsection showed that the European Commission strategically depoliticized the RED agenda, advancing a biofuels policy centered on GHG accounting and procedural notions of good governance while sidelining redistributive concerns. In Brazil, ethanol production has historically contributed to land concentration and has disproportionately benefited large producers and vertically integrated supply chains[60,61]. Biofuel policies have also reinforced social inequalities by crowding out smallholders and marginal producers[62]. This raises a central question: can the Bonsucro-RED certification mitigate these distributive distortions, despite the absence of an explicit focus on redistributive justice? Brazil provides a particularly relevant case to address this question. The country is a leading global producer of both sugar and ethanol[63]. While only a small share of Brazilian sugar exports was directed to the European Union in 2021, the EU absorbed a substantially larger share of Brazilian ethanol exports (9.43%), ranking as the third-largest destination after South Korea (36.25%) and the United States (35.58%)[64]. This export profile makes Brazil a critical testing ground for assessing whether EU-linked sustainability certification alters distributive outcomes on the ground. Given that Bonsucro is the only RED-accredited VSS in Brazil, its adoption allows researchers to construct a quasi-experiment comparing certified and non-certified municipalities (see "Methods" for details).

This section presents findings in five domains: (1) Brazil–EU trade in sugar and ethanol; (2) the share of family farms in a municipality; (3) the share of farms with few employees in a municipality; (4) rural gender inequality; and (5) deforestation. The results for family farming and gender disparities should be interpreted with particular caution, as they rely on only two data points and do not allow for testing the parallel trends assumption. A fuller discussion of limitations is provided at the end of the "Results" section.

We first examine the effects of Bonsucro-RED on Brazil's exports of sugar and ethanol to the European Union. Brazilian business elites frequently portray orchestrated voluntary sustainability standards, often described as "statized" schemes, as de facto trade barriers[65]. To assess whether these concerns are empirically warranted, we estimate heterogeneous effects of Bonsucro-RED across municipalities, grouping them into deciles based on pre-2010 export volumes to the EU. The staggered difference-in-difference (DiD) estimates yield an average treatment effect on the treated of 1.56 units (SE = 0.56, CI = [0.456, 2.6569]), with dynamic effects revealing that export gains materialize gradually and become statistically significant only several years after certification Fig. 2.

This aggregate effect, however, conceals substantial heterogeneity. Among municipalities already in the top deciles of EU exports prior to 2010, Bonsucro-RED further increases export volumes (Fig. 2), with staggered DiD estimates indicating a large and statistically significant average treatment effect on the treated of 3.73 units (SE = 1.29, CI = [1.2055, 6.2465]). Dynamic effects show that these gains materialize gradually and intensify over time, becoming consistently positive and statistically significant several years after certification. This pattern is consistent with scale-based advantages emphasized in new trade theory[66]. In contrast, municipalities in the lowest export deciles experience negative and statistically significant effects following Bonsucro-RED certification (Fig. 3). The staggered DiD estimates indicate an average treatment effect on the treated of −1.37 units (SE = 0.48,

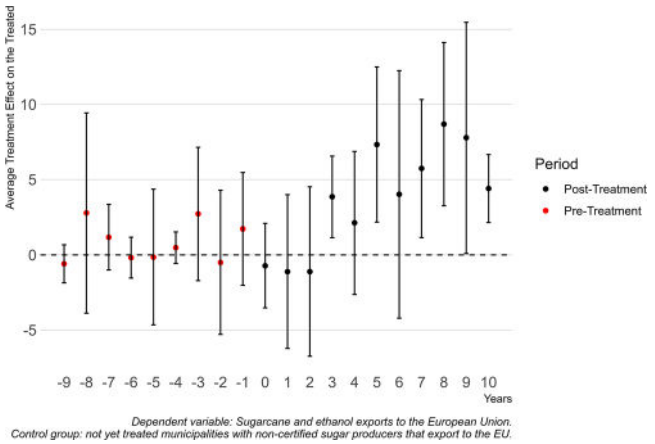

Fig. 2 | Staggered difference-in-differences estimates of post-certification effects on EU exports among high-export municipalities. This figure displays dynamic treatment effect estimates for municipalities in the upper deciles of pre-treatment export volumes. Estimates are obtained using a staggered difference-in-differences design with multiple treatment periods. The solid line represents the average treatment effect on the treated over time, while vertical lines indicate 95 percent confidence intervals. The horizontal reference line denotes zero effect. Positive post-treatment coefficients indicate increases in exports to the European Union following certification. Pre-treatment coefficients allow for visual inspection of parallel trends.

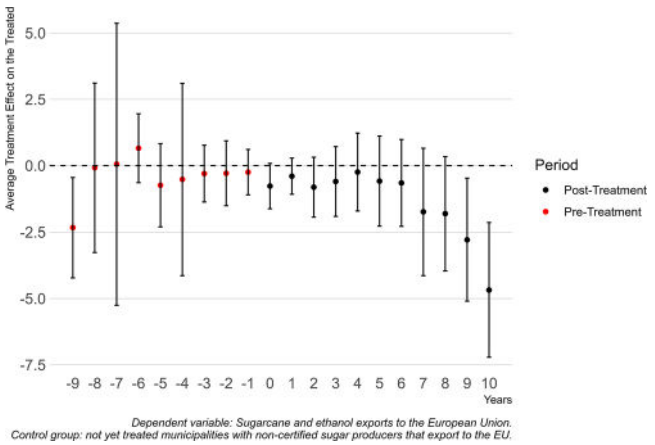

Fig. 3 | Staggered difference-in-differences estimates of post-certification effects on EU exports among low-export municipalities. This figure presents dynamic treatment effect estimates for municipalities in the lower deciles of pre-treatment export volumes. Estimates are obtained using a staggered difference-in-differences design with multiple treatment periods. The solid line represents the average treatment effect on the treated over time, while vertical lines denote 95 percent confidence intervals. The horizontal reference line indicates zero effect. Negative post-treatment coefficients indicate declines in exports to the European Union following Bonsucro-RED certification, suggesting adjustment costs and limited capacity among marginal exporters. Pre-treatment coefficients allow for visual assessment of parallel trends.

CI = [−2.3065, −0.4337]), with dynamic effects showing persistently negative coefficients that increase in magnitude several years after certification. Rather than facilitating export expansion among marginal exporters, certification appears to be associated with declining EU exports in these municipalities. Taken together, these findings suggest that pre-existing trade patterns disproportionately benefit municipalities with larger scales of production, while low-export municipalities are unable to translate certification into market access gains. This asymmetric adjustment deepens export concentration and echoes earlier distributional outcomes observed in Brazil's ethanol policy trajectory since the 1970s[67].

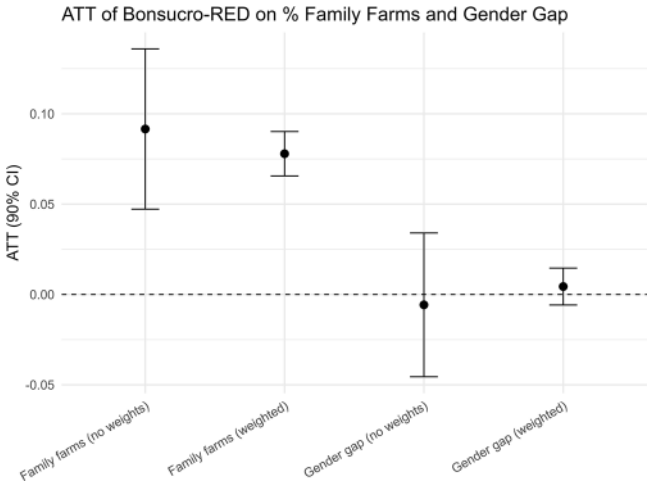

Fig. 4 | Staggered difference-in-differences estimates of post-certification effects on family farming and gender composition. This figure reports dynamic treatment effect estimates for two dependent variables: the share of family farms and the gender gap in agricultural management at the municipal level. Estimates are obtained using a difference-in-differences design. The solid line represents the average treatment effect on the treated over time, while vertical lines indicate 95 percent confidence intervals. The horizontal reference line denotes zero effect. Positive post-treatment coefficients for family farming indicate increases in the share of family-run agricultural establishments following Bonsucro-RED certification. Estimates for the gender gap, defined as the difference between the proportion of establishments managed by men and those managed by women, are small and statistically imprecise. Results should be interpreted with caution due to the limited number of pre and post-treatment time periods available.

Next, we examine the effects of Bonsucro-RED on family farming. Defined under Brazil's Law 11.326/2006, family farms are small rural properties primarily reliant on family labor and income. Using both unweighted and Kernel-weighted models to address selection bias on observable variables, we find that Bonsucro-RED certification is associated with a 7.8 percentage-point increase in the share of family farms between 2006 and 2017 (Fig. 4, weighted DiD with $R^2 = 0.2429$). At first glance, this finding contradicts crowding-out concerns[68] and raises the possibility that large producers may generate positive spillovers for smaller ones[69]. We cannot, however, verify the parallel trends assumption, as data are available for only two time points (2006 and 2017). By incorporating weights, we partially address selection bias on observables by improving balance on pre-treatment covariates. While this approach does not validate the parallel trends assumption, it serves as a second-best strategy: if treated and control municipalities are similar in relevant pre-treatment characteristics, it becomes more plausible, though not testable, that their outcome trajectories would have followed similar trends in the absence of certification.

The effect disappears when we use the share of properties with fewer than four employees as a proxy for small-scale farming. The staggered DiD estimates yield an average treatment effect on the treated of 0.17 (SE = 1.67, CI = [−3.106, 3.4396]), which is statistically indistinguishable from zero, with dynamic effects fluctuating around zero and showing no systematic post-treatment pattern. By contrast, the effect becomes negative and statistically significant when small-scale farming is proxied by the share of properties with fewer than nine employees. In this specification, the staggered DiD estimates indicate an average treatment effect on the treated of −3.95 (SE = 1.24, CI = [−6.381, −1.5116]), with dynamic effects turning increasingly negative several years after certification (Fig. 5). Taken together, these tentative results suggest that Bonsucro-RED is not associated with changes among the very smallest production units, but is instead linked to a contraction in medium-small establishments, consistent with processes of land concentration and labor reallocation toward larger production units.

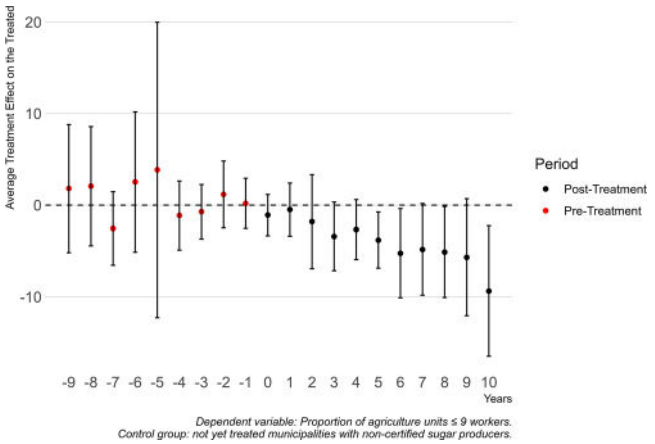

Fig. 5 | Staggered difference-in-differences estimates of post-certification effects on the share of agricultural units with nine or fewer workers. This figure displays dynamic treatment effect estimates for the proportion of agricultural units employing nine or fewer workers at the municipal level. Estimates are obtained using a staggered difference-in-differences design with multiple treatment periods. The solid line represents the average treatment effect on the treated over time, while vertical lines indicate 95 percent confidence intervals. The horizontal reference line denotes zero effect. Negative post-treatment coefficients indicate a decline in the share of small-sized agricultural units following Bonsucro-RED certification, consistent with unit reallocation toward larger production units. Pre-treatment coefficients allow for visual inspection of parallel trends.

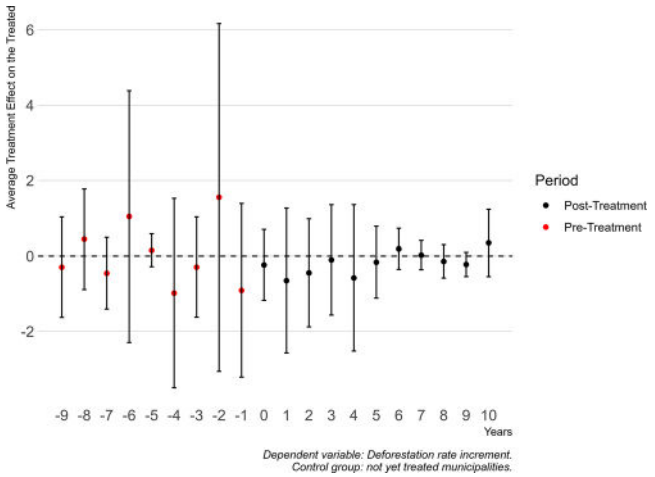

Fig. 6 | Staggered difference-in-differences estimates of post-certification effects on deforestation rates. This figure presents dynamic treatment effect estimates for annual deforestation rates at the municipal level. Estimates are obtained using a staggered difference-in-differences design with multiple treatment periods. The solid line represents the average treatment effect on the treated over time, while vertical lines indicate 95 percent confidence intervals. The horizontal reference line denotes zero effect. Post-treatment coefficients show no statistically significant changes in deforestation following Bonsucro-RED certification. Pre-treatment coefficients allow for visual assessment of parallel trends. Deforestation rates are measured as annual changes in forest loss.

In Brazil, gender disparities in land ownership and agricultural management are smaller within family farms[70]. Female participation in public procurement programs such as the Food Acquisition Program (PAA) reached 80% in some cases by 2019, supported by targeted regulations such as Ordinance 44/2011. Between 2006 and 2017, women's participation in family farming increased by 38%[71]. It is therefore plausible that Bonsucro, through its emphasis on community engagement, could indirectly support gender empowerment. When testing the effect of Bonsucro-RED certification on the share of women as owners or managers of rural properties, we find that Bonsucro-RED is associated with a 0.44 percentage-point increase in the gender gap when using Kernel weighting, but the estimated effect is not statistically significant. Cezar, Camargo, and Sun[70] likewise find no statistically significant effects, even with weighting. Moreover, matching techniques are sensitive to model specification[72]. As with family farming, the parallel trends assumption cannot be tested, rendering the 2×2 DiD estimates particularly fragile and calling for further investigation.

Finally, we assess whether Bonsucro-RED certification is associated with reductions in deforestation. Figure 6 reports the main results, with summary statistics provided in Supplementary Tables 1–3. Across the full sample of municipalities, we find no statistically significant effect (ATT = −0.181; SE = 0.376; 95% CI [−0.917, 0.556]). These findings cast doubt on the environmental additionality of RED when implemented through Bonsucro certification, at least with respect to deforestation outcomes.

As a robustness check for the staggered difference-in-differences analysis, we explicitly account for the possibility of anticipation. Anticipation arises when units adjust their behavior before the formal onset of treatment in response to credible expectations that the intervention will occur. Allowing for a two-year anticipation window, we find evidence that trade effects begin to emerge during the pre-treatment period, indicating that actors responded not only to the formal implementation of Bonsucro-RED but also to expectations surrounding its adoption (Fig. 7). In contrast, we find no evidence of anticipation effects for the share of agricultural units with up to nine workers, suggesting that labor allocation adjustments materialized only after certification was formally in place rather than in advance of it.

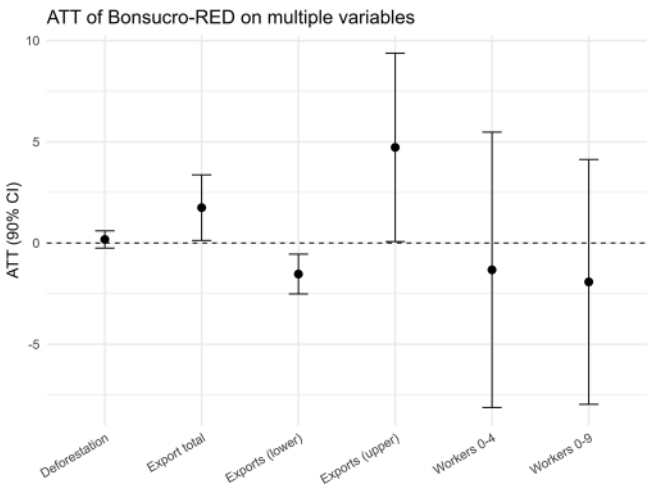

Fig. 7 | Average treatment effects across outcomes, allowing for a two-year anticipation window. This figure reports average treatment effects on the treated estimated using a staggered difference-in-differences design that allows for treatment anticipation up to two years prior to formal certification. Each point represents the estimated average post-treatment effect for a given outcome, while vertical lines denote 95 percent confidence intervals. Outcomes are grouped by domain, including exports to the European Union, labor allocation indicators, and environmental outcomes. Although the outcomes are measured on different scales and are not directly comparable in magnitude, presenting them side by side facilitates visual comparison of direction, statistical significance, and relative patterns across domains. Allowing for anticipation reveals early trade-related adjustments before certification among export outcomes, while labor and environmental effects either emerge only after treatment or remain statistically insignificant. ATT refers to the average treatment effect on the treated. The horizontal reference line indicates zero effect.

For further robustness, we also employ the Fixed Effects Counterfactual Estimator (FEct), which is well suited to settings with heterogeneous adoption and time-varying confounders[73], and does not suffer from the negative weighting concerns associated with conventional two-way fixed effects estimators[74,75]. The full results are reported in Supplementary Figs.

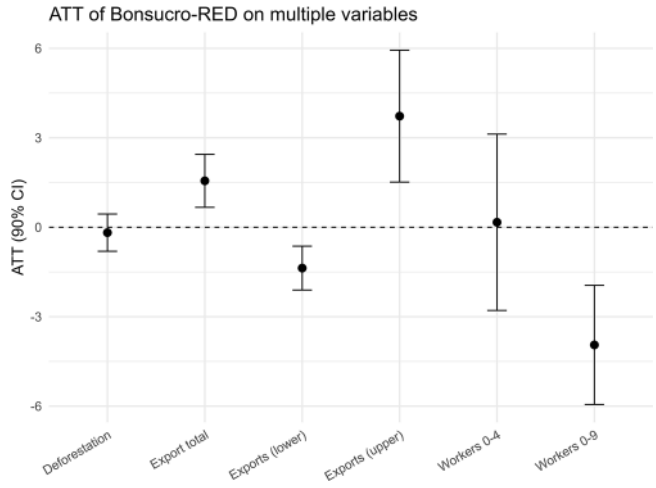

Fig. 8 | Comparison of average treatment effects across outcomes using staggered difference-in-differences estimates. This figure summarizes average treatment effects on the treated across some of the main outcomes analyzed in the paper. Each point represents the estimated average post-treatment effect for a given outcome, while vertical lines indicate 95 percent confidence intervals. Outcomes are grouped by domain, including exports to the European Union, labor allocation indicators, and environmental outcomes. Positive effects are concentrated in export outcomes, particularly among municipalities with high pre-treatment export intensity. Labor-related outcomes display negative or statistically imprecise effects, while environmental outcomes show no statistically robust post-certification changes. ATT refers to the average treatment effect on the treated. The horizontal reference line denotes zero effect.

6–9. The dynamic fixed effects counterfactual estimator (FEct) estimates closely mirror our main findings. For exports to the EU, post-treatment effects turn positive and increase over time, indicating sustained export gains among treated municipalities relative to their estimated counterfactual path, with no clear evidence of systematic pre-treatment divergence. By contrast, the labor allocation outcomes display smaller and less precisely estimated effects than the staggered DiD, with confidence intervals frequently overlapping zero, suggesting limited adjustments in workforce composition. For deforestation, the post-treatment coefficients also generally overlap zero, reinforcing the interpretation of mixed and domain-specific spillovers rather than uniform effects.

To summarize the main results, Fig. 8 reports the average treatment effects on the treated (ATT) estimates for each variable analyzed using staggered difference-in-differences. Overall, the available evidence suggests that Bonsucro-RED certification is associated with increased exports to the EU and a reduction in the share of farms with fewer employees in treated municipalities. Results for deforestation and gender gaps remain inconclusive, with point estimates near zero. Notably, even for exports and labor allocation, where treatment effects appear more pronounced, we observe some sensitivity to anticipation specifications. This suggests that while certification may generate tangible spillover effects in trade and labor markets, effects on environmental and social outcomes either operate through different channels than examined here or remain modest in magnitude.

On a final note, how did Brazilian producers and public authorities react to Bonsucro-RED? RED does not appear to be highly salient among most Brazilian producers or government officials. In November 2024, one of the authors delivered a course in Ribeirão Preto to representatives of approximately 100 Bonsucro-certified organizations. Most attendees were unaware that the certification requirements with which they comply originate in EU legislation and are enforced through Bonsucro's recognition under RED. We also find little evidence of organized resistance from smaller producers that could contest or mitigate the uneven outcomes documented in the empirical analysis. In practice, Bonsucro-RED is generally perceived as a pragmatic instrument adopted by large producers to secure access to the European market. Representatives reported that compliance does not impose significant additional burdens and that, therefore, RED is simply an add-on. At the federal level, Brazilian ministries formally criticize unilateral climate measures adopted by other jurisdictions; however, such reactions have focused primarily on the EUDR and CBAM[76], while RED has attracted comparatively limited political attention.

On a final note, despite robustness tests, this paper has multiple methodological caveats. First, our deforestation analysis includes only municipalities with available data and treated units, reducing the sample to 684 observations across 57 municipalities. This limits statistical power, increases uncertainty around dynamic effects, and constrains external validity relative to the export and labor analyses, which draw on much larger panels. It also implies that small to moderate effects may go undetected, so the null result should be interpreted as an absence of detectable effects given the available data rather than evidence of no effect. Second, our identification strategy relies primarily on staggered difference-in-differences, which presumes parallel trends in the absence of treatment and no anticipatory adjustment. While event-time coefficients do not display a uniform pattern of strong pre-trends, pre-treatment magnitudes vary between the baseline and anticipation-adjusted specifications, especially at longer horizons. Third, some outcomes have limited temporal variation: the family farming and gender analyses rely on only two Census time points (2006 and 2017), preventing direct assessment of parallel trends and rendering the corresponding 2 × 2 DiD estimates fragile. Weighting can improve balance on observables, but it cannot replace pre-trend diagnostics or rule out differential shocks over an eleven-year interval. In addition, proxies for "small-scale" production based on worker thresholds capture labor structure rather than land-holding size and may reflect mechanization, outsourcing, or reporting changes. Finally, results may still be affected by time-varying confounders not fully captured in our models, including commodity price cycles, exchange-rate movements, EU demand shifts, domestic biofuel policy changes, credit conditions, and region-specific shocks such as droughts or enforcement variation. Taken together, these limitations imply that our findings should be interpreted as suggestive patterns rather than definitive causal effects, and that stronger claims would require additional data, alternative identification strategies, and further robustness tests tailored to each outcome domain.

Discussion

This research constitutes an initial effort to examine the extraterritorial effects of trade-based climate action implemented through public–private interactions. As climate policies increasingly rely on unilateral instruments, they are likely to become more contested, politicized, and fragmented across jurisdictions[77]. In principle, public–private governance arrangements may enhance the legitimacy of such policies by improving implementation capacity and by generating fairer outcomes on the ground[18]. In the specific case of Bonsucro-RED, however, our findings point to limited and uneven effects across domains. Given data and methodological constraints, the econometric evidence should be interpreted as suggestive. Taken together with the qualitative analysis, the results indicate that the EU's orchestration of VSS under RED is associated with heterogeneous spillovers in Brazil, rather than broad-based positive externalities.

The role of the European Commission in the RED process is best understood as constrained and strategic rather than entrepreneurial or captured. The Commission neither acted as a fully autonomous agenda-setter[78,79] nor merely reflected interest group dominance[80,81]. Instead, it navigated competing domestic and international pressures by reframing politically contentious distributive issues as technical questions of greenhouse gas accounting and procedural governance[52]. This strategy proved partially successful. While RED has persisted despite external criticism and legal challenges[82], it continues to be perceived abroad as a form of disguised protectionism[65]. More importantly for our purposes, this reframing led to a

Table 2 | Empirical findings and policy recommendations

Domain	Tentative Finding	EU Recommendations
Trade	Bonsucro-RED is associated with export gains among already high-export municipalities, with negative effects for lower-decile exporters.	Future revisions of RED could place greater emphasis on monitoring how certification affects participation across producer sizes or regions, using context-sensitive benchmarks rather than uniform thresholds.
Family farming	Effects are heterogeneous and sensitive to specification, with limited ability to verify parallel trends.	Even greater transparency regarding land concentration and smallholder participation could improve the visibility of distributive dynamics without mandating specific redistributive outcomes.
Labor allocation	Bonsucro-RED is associated with a decline in the share of medium-small agricultural units, suggesting reallocation toward larger production units.	Monitoring frameworks could incorporate clearer concentration indicators to enhance transparency regarding structural adjustments.
Gender	No statistically robust association between certification and changes in the gender gap.	Monitoring frameworks might incorporate clearer gender-disaggregated indicators to enhance visibility of recognition outcomes where data permit.
Deforestation	No statistically significant association between certification and reductions in deforestation at the municipal level.	Complementary outcome-oriented environmental assessment tools could be considered alongside greenhouse gas accounting, where politically and legally feasible.

regulatory architecture centered on procedural compliance and administrative efficiency, with limited attention to distributive consequences in third countries. This emphasis aligns with the logic of throughput legitimacy[83], whereby policy acceptability derives from transparent procedures, auditability, and formal participation rather than from substantive outcomes[31]. As illustrated by Regulation 2022/996, RED II strengthened requirements related to governance, stakeholder inclusion, and internal accountability within VSS. While these reforms improved procedural safeguards, our tentative results suggest that procedural strengthening alone does not necessarily coincide with equitable outcomes on the ground. In line with existing critiques[29,30], greater participation may coexist with persistent business dominance[57], and may legitimize uneven distributive effects rather than correct them.

The preliminary empirical findings help clarify how these governance choices map onto different dimensions of climate justice. First, trade results show that Bonsucro-RED certification is associated with higher export volumes only among municipalities that were already major exporters to the EU, pointing to concentration effects rather than inclusive market access. Second, results on family farming and labor allocation are mixed and sensitive to measurement choices, suggesting that potential distributive benefits, where they exist, are fragile and context-dependent. Third, the absence of robust effects on gender outcomes and deforestation indicates that recognition and environmental dimensions of justice are not systematically advanced through certification under RED, despite enhanced procedural inclusion.

These findings have implications for policy design, but they do not support strong prescriptive conclusions. Although we strongly agree, in principle, with the limitations of proceduralism, we also advise against the top-down imposition of binding social criteria. Doing so could exacerbate existing controversies around indirect land-use change and intensify accusations of disguised protectionism[65]. Moreover, the strategic use of expertise in defining socioeconomic indicators risks reproducing technocratic biases[84] without resolving underlying distributive tensions. Instead, our results point to more targeted and differentiated avenues for reform. At the level of EU policy design, future revisions of RED could place greater emphasis on how distributive and recognition outcomes are monitored, without requiring direct reporting to the Commission. For example, given the observed concentration effects in trade, the EU could require that recognized VSS demonstrate how certification affects participation across producer sizes or regions, using context-sensitive benchmarks rather than uniform thresholds. The EU could encourage/mandate schemes to develop transparent, science-based impact assessment frameworks that are locally grounded and methodologically flexible. Such frameworks would not mandate specific outcomes, but would improve the visibility of distributive and recognition effects that currently remain unmeasured. Table 2 presents a set of targeted recommendations for the European Union.

Methods

Data sources and econometric estimation

Brazilian municipalities are the unit of analysis in this study. The variables for family farming and the gender gap were derived from the Brazilian Agricultural Census. The gender gap is calculated as the difference between the proportion of rural establishments managed by men and those managed by women. Family farms are defined as rural properties with up to four fiscal modules. The size of a fiscal module varies by municipality, depending on the predominant type of land use, associated income, and other relevant economic activities, as established by Special Instruction (July 29, 2022). The family farming indicator is expressed as the share of family agriculture units relative to the total number of agricultural units. Annual data on the share of agricultural units with up to four employees are sourced from IBGE. Deforestation is measured as the annual variation in deforestation rates, based on data from Brazil's National Institute for Space Research (INPE).

For export data, the article relies on municipality-level statistics on Brazil's sugarcane-based product exports, including sugar and ethanol, to all EU-26 countries. We selected all municipalities that exported to the EU and obtained data from Comexstat, the database of the Brazilian Ministry of Development, Industry, Commerce, and Services (MDIC). For each municipality, we retrieved Free-On-Board (FOB) export values for the following 4-digit Harmonized System (HS) categories, covering the period from 2009 to 2022:

- HS 2207: Undenatured ethyl alcohol of an alcoholic strength by volume of 80% or more; ethyl alcohol and other spirits, denatured, of any strength.
- HS 1701: Cane or beet sugar and chemically pure sucrose, in solid form.

Because Brazil's economic sector classification (CNAE) differs from the HS code system, the two are matched as follows:

- CNAE 19.31-4: Ethanol manufacturing (corresponding to HS 2207);
- CNAE 10.72-4: Refined sugar production (corresponding to HS 1701).

The treatment variable in our analysis indicates whether a municipality had at least one Bonsucro-RED certified company. Certification began in 2011, and municipalities were treated in different years depending on the timing of their first certified firm. Once treated, a municipality remains in the treated group in all subsequent years. Data on certified firms, including the year and location of first certification, were obtained from Bonsucro's Certification Holders Dashboard.

For the family farming and gender gap outcomes, we relied on data for two time points: 2006 (pre-treatment) and 2017 (post-treatment). Treated municipalities are those that had at least one certified firm by 2017, resulting in 61 Bonsucro-treated and 42 Bonsucro-RED-treated municipalities. For outcomes with annual data, including exports, deforestation, and labor

allocation, 4707 municipalities are covered from 2006 to 2021, yielding over 75,000 observations.

We first estimate a standard 2 × 2 DiD model:

$$Y_{m,t} = \alpha + \gamma_1 \,\text{Treatment}_m + \gamma_2 \,\text{Time}_t + \gamma_3 \,(\text{Treatment}_m \times \text{Time}_t) + \mathbf{Z}'_{m,t}\zeta + \varepsilon_{m,t} \quad (1)$$

where $Y_{m,t}$ denotes the outcome, either the gender gap or the family farming share, in municipality m and year t. The binary variable Treatment_m equals 1 if the municipality is treated and 0 otherwise. Time_t is a post-treatment indicator, equal to 1 for 2017 and 0 for 2006. The interaction term captures the average treatment effect. $\mathbf{Z}_{m,t}$ is a vector of control variables, and $\varepsilon_{m,t}$ is the error term.

For exports, labor outcomes, and deforestation, we implement a staggered difference-in-differences design using the estimator proposed by Callaway and Sant'Anna[27], which accounts for variation in treatment timing across municipalities. Treatment timing is defined by each municipality's first year of Bonsucro-RED certification (g), and event time is measured relative to g. The panel covers the period 2006–2021. Because certification began in 2011, municipalities contribute up to five pre-treatment years and up to ten post-treatment years, depending on cohort timing. Event-time estimates are therefore bounded by data availability, and later-treated municipalities contribute fewer post-treatment observations. Supplementary Fig. 1 shows the treatment status for the staggered DiD. We estimate group-time average treatment effects ATT(g, t) using not-yet-treated municipalities as the comparison group. As a robustness check, we allow for anticipatory behavior by specifying a two-year anticipation window, which treats the two years prior to first certification as potentially contaminated by pre-treatment adjustments and evaluates dynamic effects accordingly. The model is specified as follows:

$$Y = \alpha_1^{g,t} + \alpha_2^{g,t} G_g + \alpha_3^{g,t} \mathbf{1}\{T = t\} + \beta^{g,t}(G_g \times \mathbf{1}\{T = t\}) + \varepsilon^{g,t} \quad (2)$$

where $\beta^{g,t} = \text{ATT}(g,t)$ denotes the average treatment effect on the treated for group g at time t. The aggregated causal parameter is computed as:

$$\theta = \sum_{g \in G} \sum_{t=2}^{\tau} w(g,t) \cdot ATT(g,t) \quad (3)$$

Here, θ represents the overall effect of Bonsucro certification on exports, deforestation, and labor allocation, calculated as a weighted average of ATT(g, t) values across all groups and time periods. The weights $w(g,t)$ are based on group size and treatment timing.

When applicable, we included controls for the share of Workers' Party councilors and a dummy variable indicating whether the mayor belonged to the same party, as left-leaning governments may be more supportive of gender equality and smallholder-oriented initiatives. To enhance comparability between treated and control municipalities for the 2 × 2 DiD, we applied Kernel weights based on municipal GDP. These covariates account for structural production capacity and access to land, which shape the effects of certification[85]. To further capture the role of state support, we included the volume of subsidized agrarian credit, a key determinant of land access for smallholders and women[86]. This allows us to distinguish market-based effects from those driven by public policy interventions.

Supplementary Fig. 1 presents the treatment status under the staggered difference-in-differences design, illustrating the timing of certification across municipalities and the structure of cohort-specific adoption. Supplementary Figs. 2–5 report the number of municipalities in the treatment and control groups used in each analysis and document the distribution of treatment timing across cohorts, enabling assessment of sample composition and staggered exposure. Supplementary Tables 1–3 provide summary statistics for the main outcome variables used in the staggered specifications, including exports to the European Union and deforestation. Supplementary Tables 4 and 5 report descriptive statistics for family farming, gender, and deforestation variables derived from Census data, including means, standard deviations, and the number of observations for treated and control municipalities. Supplementary Tables 6–13 present the full set of econometric results. These tables report the numerical values of the ATT, associated standard errors, 95% confidence intervals, and R^2 statistics where applicable. They include baseline staggered difference-in-differences estimates, heterogeneous effects by export intensity (upper and lower deciles), anticipation-adjusted models allowing for a two-year pre-treatment window, 2 × 2 DiDs models for Census-based outcomes, and estimates obtained using the FEct, including dynamic treatment effects over event time.

Data availability

Replication data and code available at https://github.com/rfcezar/bonsucro.

Code availability

Replication code available at https://github.com/rfcezar/bonsucro.

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R.F.C. wrote the main manuscript, J.C, E.M and G.D.F performed and reported econometric estimations. Y.S. performed substantive revision of earlier drafts. All authors reviewed the final text before submission.

Competing interests

The authors declare no competing interests.

Additional information

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