Decentralized land use zoning reduces large-scale deforestation in a major agricultural frontier

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Abstract

Reducing large-scale deforestation is a key objective of global efforts to mitigate climate change. An important debate concerns the levels of governance at which deforestation can be reduced effectively. Political economic theory and evidence suggests that national governments are more likely than subnational governments in agricultural frontiers to adopt restrictive forest conservation policies, due to differences in political constituencies and capacity. Here we examine the validity of this claim using an impact study of provincial-level land use planning in Argentina's main deforestation frontier, the Dry Chaco. In 2007, Argentina's provinces were obliged to define land use zoning for their native forests, but had considerable leeway in its implementation. We use data from 30,126 properties in the provinces of Salta, Santiago del Estero, and Chaco, and a rigorous counterfactual estimation strategy to quantify the extent to which adopted zoning plans affected deforestation. We find evidence that provincial-level land use zoning reduced deforestation in all three provinces, but not in all zones and periods. Differences in impact are associated with differences in the location of zones and the timing of planning. Our findings suggest that subnational governments can make important contributions to reducing large-scale deforestation in agricultural frontiers.

Highlights

- Subnational governments might become key players in climate change mitigation.
- We study the impact of provincial land use zoning on deforestation in Argentina.
- Provinces allocated zones in ways that limited potential impacts on forest loss.
- However, provincial zoning plans also reduced forest loss over baseline.
- Our findings lend support to nested approaches to avoided deforestation policy.

Keywords

Argentina, Chaco, avoided deforestation, subnational, governance, matching

1. Introduction

Reducing emissions from large-scale deforestation constitutes a priority for global efforts to mitigate climate change. Tropical forest loss accounts for about 10% of anthropogenic greenhouse gas emissions (Baccini et al., 2012; Harris et al., 2012). Large-scale forest conversion in the tropics and subtropics in the 21st century was largely the result of agricultural expansion for the production of globally traded commodities such as soy, beef, palm oil, and timber (Gasparri et al., 2015; Newton et al., 2013; Rudel et al., 2009). To conserve global forests and associated ecosystem services, multilateral, bilateral, and private donors have begun to incentivize reductions in deforestation and forest degradation (REDD+) with billions of dollars in funding (Agrawal et al., 2013; Silva-Chávez et al., 2015). However, considerable academic and political debate surrounds the choice of strategies and policies that can effectively reduce deforestation at large spatial scales (Angelsen, 2010; Larson et al., 2013; Patel et al., 2013).

An important question for climate change mitigation scholars and policy makers concerns the level of governance at which large-scale deforestation can be addressed effectively (Angelsen et al., 2008). National governments have long held a privileged position among the actors involved in forest-based climate change mitigation, both as decision makers in international negotiations and as recipients of early funding flows. However, scholars have also proposed that an exclusive focus on national governments will not necessarily lead to effective and equitable avoided deforestation policy (Luttrell et al., 2013; Phelps et al., 2010). Strategies to engage other levels of government in the design of such policies have therefore become a major subject of inquiry, with authors examining the feasibility of "jurisdictional", "multiscale" or "nested" approaches (e.g. Agrawal et al., 2011; Cattaneo, 2011; Fishbein and Lee, 2015; Pedroni et al., 2009).

In practice, subnational governments are already actively involved in avoided deforestation efforts across the globe (Ravikumar et al., 2015; Sunderlin et al., 2014), and continue to position themselves as partners for forest conservation in international arenas. Thirty-five subnational governments from nine countries (including Brazil, Indonesia, and the USA) cooperate in the Governors' Climate and Forests Task Force (GCF) to advance jurisdictional programs for reducing emissions from deforestation and land use (GFC, 2016). In the New York Declaration on Forests, twenty subnational governments from tropical countries publicly committed to end deforestation by 2030 (UN Climate Summit, 2014). And in Brazil, the two Amazon states of Acre and Mato Grosso moved forward and signed jurisdictional REDD+ frameworks into law in 2010 and 2013 (Duchelle et al., 2014).

In spite of this rising interest in the role of subnational policies to reduce deforestation, the extent to which subnational governments are willing and able to inhibit agricultural expansion in active deforestation frontiers remains largely unexamined. Initial reflections on the motivation and capacity (Lambin, 2005) of different levels of governments lead us to assume that subnational governments are less likely than national governments to engage in large-scale forest protection. This is because the constituencies of national governments can be expected to be more urban, with higher incomes and educational levels, and lower dependence on agricultural expansion, than those of subnational governments in active deforestation frontiers. Such attributes are generally associated with a higher willingness to pay for forest protection (Vincent et al., 2014), and might translate into stronger political support and motivation for national governments to implement new effective forest conservation measures. National governments might also have a more diverse range of legal instruments, higher budgets, and better enforcement resources at their disposal (Lambin et al., 2014), which might convey them a higher overall capacity to implement strict forest conservation instruments.

Empirical evidence exists for multiple cases in which national governments were willing and able to implement effective forest protection policies at large spatial scales. For instance, recent substantial downturns in large-scale deforestation in Brazil, China, and Vietnam have been, in large part, ascribed to national forest conservation policies (Liu et al., 2008; Meyfroidt et al., 2009; Nepstad et al., 2014). Sweeping deforestation bans, such as those adopted in China and the Atlantic Forests of Brazil and Paraguay, were also driven by national governments. Examples of major conservation policies outside active deforestation frontiers, such as the U.S. Northwest Forest Plan (Thomas et al., 2006), protected area declarations in 1990 East Germany (Garrelts et al., 2005), and the European Union's Natura 2000 directive (Kati et al., 2015), provide further evidence for national (and supra-national) leadership in large-scale nature conservation – and for opposition of subnational actors against such policies.

Meanwhile, evidence on the impact of subnational policy on forest conservation in active deforestation frontiers remains scarce. A recent review finds that a majority of existing rigorous studies of the impacts of decentralized forest governance examine forest degradation, not deforestation (Miteva et al., 2012). Of the three rigorous studies studying deforestation outcomes, none finds decentralization to reduce forest loss (ibid.). In Indonesia, decentralization increased deforestation, especially before elections (Burgess et al., 2011); in the Brazilian Amazon, federally protected areas reduced deforestation, while state parks did not (Pfaff et al., 2012); and in Bolivia, better municipality-level forest governance was associated with reductions in unauthorized deforestation, but not total deforestation (Andersson and Gibson, 2007). These findings lend support to the hypothesis that subnational governments are more likely than national governments to prioritize local economic interests over the conservation of ecosystems. This phenomenon has also been observed and described as "zoning following the market" in the context of residential use (Pogodzinski and Sass, 1994; Wallace, 1988).

Here we provide empirical evidence that subnational approaches to forest conservation can significantly reduce large-scale deforestation in active subtropical agricultural frontiers. We base our finding on a rigorous impact analysis of provincial-level land use planning in the Argentinian Dry Chaco. In 2007, Argentina's federal government obliged provinces to implement land use zoning for their remaining native forests. Using data from 30,087 properties located in the three provinces with the highest historical rates of forest loss (Lende, 2015), we show that the provinces implemented land use plans in ways that significantly reduced property-level deforestation in the short term. As provinces had considerable leeway in the implementation of the law, we interpret these impacts as partial evidence for the motivation and ability of provincial governments to reduce deforestation.

2. Argentina's Dry Chaco and the 2007 Forest Law

Argentina's Dry Chaco is a vast semiarid plain located in the country's northwestern region. Its subtropical forest ecosystems are characterized by rich levels of biodiversity (Bucher and Huszar, 1999; Giménez et al., 2011) and globally significant carbon stocks (Baumann et al., 2016; Gasparri et al., 2008). Throughout the late 20th and early 21st centuries, the Dry Chaco witnessed some of the world's highest deforestation rates, mostly due to the expansion of large-scale soy and beef production by well-capitalized agribusinesses (Aide et al., 2013; Gasparri and Grau, 2009; Vallejos et al., 2015).

In Argentina, provinces are the constitutional original owners of natural resources, and entitled to manage land and forests within their territories (Article 124 of Argentina's 1994 National Constitution). Each province designs its own laws, directives, processes, and administrative structures to define, allocate, and enforce rights to land and its use. However, in order to guarantee all Argentinians the right to a healthy environment across provincial borders, the constitution also allows the federal government to define minimum standards for environmental protection (presupuestos mínimos, Article 41). If such standards are adopted, provinces are obliged to translate them into provincial law.

In the wake of rapid deforestation, catastrophic floods, and resulting societal pressure (Romero, 2012), the Argentinian federal government made use of this constitutional provision to define minimum standards for the protection of native forests. The Law #26.331 of 2007, hereinafter referred to as the Forest Law, obliged provinces to conduct a land use planning process with the goal to categorize all remaining native forests into three zones with different levels of protection (García Collazo et al., 2013; Gautreau et al., 2014):

- Category 1 (red): forests of high conservation value, which require permanent protection, but can be used by indigenous communities or for research.
- Category 2 (yellow): forests of medium conservation value, which can be used for sustainable resource use, tourism, gathering, or research.
- Category 3 (green): forests of low conservation value, which can be converted partially or completely.

The Forest Law defined several procedural criteria for the land use planning process, which the federal government proved willing to enforce. For instance, it required the planning process to be "participatory", and prohibited the issuance of deforestation permits until the process was concluded. Argentina's government rejected the land use plan of at least one province (Córdoba), because it allowed extractive activities in red zones and did not follow a participatory process (Silvetti et al., 2011). In another province (Salta), the Supreme Court of Justice revoked all deforestation permits and imposed a moratoria on deforestation in 2009, because the provincial government had not concluded its land use planning process (Di Paola et al., 2011).

However, within these procedural boundaries, Argentina's provinces appeared to enjoy considerable leeway in the allocation and implementation of the three zones across their jurisdiction. First, the Forest Law does not define a minimum percentage of native forests in each province that needs to be protected. Second, while the Forest Law lists ten socio-ecological criteria to characterize the conservation value of forests, it does not stipulate how these criteria are to be translated into zones. Third, the law remains ambiguous about the activities allowed under "sustainable resource use" in yellow zones. Specifically, it does not define guidelines for silvopastoral systems, an expanding land use in the Dry Chaco, in which understory is removed to grow grasses underneath a relatively sparse tree canopy (Grau et al., 2015; Mastrangelo and Gavin, 2012). Because silvopastoral systems can lead to a slow transition from forest cover to pasture, this regulatory absence constitutes a potential loophole for legal deforestation.

While the Forest Law did not dictate how to allocate protective zones, it offered some financial incentives for stricter protection through a "National Fund for the Enrichment and Conservation of Native Forests" (NFECNF), which indicated that funds would be allocated as a function of the size of stricter zones in each province. Similar policies exist in other deforestation frontiers, e.g. in Brazil (Ring, 2008; Sauquet et al., 2014). Although the NFECNF ended up chronically underfunded, receiving less than 10% of the envisaged budget between 2010 and 2015 (Ministerio de Ambiente y Desarrollo Sustentable de la Nación, 2016), it might have incentivized provinces to zone larger areas of forests under stricter categories. However, as deforestation risk is highly heterogeneous across the Argentinian Chaco (Piquer-Rodriguez et al., 2015), provinces were also in a position to allocate stricter protection to the most remote forests that were already protected by virtue of their location (Joppa and Pfaff, 2010, 2009).

Within two to five years after the promulgation of the Forest Law, most of Argentina's provinces had concluded their land use planning processes and signed the results into law. The resulting maps and regulations reveal substantial variation in the interpretation of the zoning criteria. For instance, among nineteen provinces, the percentage of forest allocated to the strictest category (red) varies between 2% and 80% (Gautreau et al., 2014). Zones frequently exhibit discontinuities at provincial boundaries, which do not appear to correspond to differences in forest condition or conservation value (García Collazo et al., 2013). Forests with particularly high ecological values (e.g. remnants of quebracho forests) were often assigned weak protection, probably due to their vicinity to valuable agricultural land (Piquer-Rodriguez et al., 2015). Provinces also differ widely in the percentage of deforestation that is allowed in different zones (Gobbi, 2015). Although no previous studies quantify how landscape factors influenced the allocation of zoning in Argentina's native forests, this existing evidence appears to corroborate the view that provincial governments had substantial leeway to shape the zoning plan in ways that served their interests.

Did these subnational land use planning processes reduce deforestation in Argentina's major deforestation frontier? Conventional wisdom suggests that provincial governments had little incentive to adopt zoning plans that would inhibit agricultural expansion. The economies of the four main provinces in the Dry Chaco – Salta, Santiago del Estero, Chaco, and Formosa – are strongly dependent on agriculture. In 2003, the primary sector contributed 22%, 21%, 16%, and 17% respectively, to their provincial gross domestic product (Ministerio de Economía y Finanzas Públicas, 2012). For comparison with other soy-and-beef frontiers in the area, these percentages are about twice as high as for Argentina as a whole, three times higher than for the country of Brazil, which reduced deforestation considerably, and of similar magnitude as in Paraguay and Bolivia, where deforestation is on the rise (Nolte et al., 2016). If provinces had the option to "follow the market" by allocating stricter zones to forests not exposed to the risk of deforestation, we would expect the impact of zoning on deforestation to be negligible, especially in the short term. In what follows, we examine empirically whether this was the case.

3. Data & Methods

3.1. Study Area

Our study area encompasses the Dry Chaco ecoregion of three provinces: Salta, Santiago del Estero, and Chaco, an area of approximately 276,000 km^2. In the years preceding the Forest Law, these three provinces were responsible for the largest share of forest loss in Argentina. Between 1996 and 2007, hand-digitized GIS datasets (Vallejos et al., 2015) recorded 28,934 km^2 of deforestation in our study region. This corresponds to 79% of the forest loss observed across Argentina's Dry Chaco over the same time period, with the remainder distributed across nine provinces. All three provinces also have significant remaining forest cover and are therefore key localities for avoiding future deforestation.

Salta, Santiago del Estero, and Chaco concluded their land use planning by 2009 with the adoption of legally binding zoning plans. However, implementation processes varied considerably. Santiago del Estero had been pressured by the federal government to adopt a provincial-level zoning plan since 2004; the province adopted a provincial plan in 2006, which was then translated into national categories by mid-2009 to comply with the Forest Law. Chaco did not feature a provincial plan, but had signaled an intention to conduct a planning process via a 2006 provincial decree, which suspended deforestation permits until a zoning plan was adopted. In Salta, in turn, the planning process was characterized by major controversies. In 2007, while the Forest Law was being discussed in the federal legislature, Salta tripled the number of issued deforestation permits as compared to previous years, prompting the national Supreme Court of Justice to declare a provincial moratorium on deforestation in 2009. Salta concluded its land use planning just a few months later (Gobbi, 2015).

3.2. Unit of Analysis

For each province, we obtained wall-to-wall data of rural property boundaries from provincial agencies and universities. Our analysis is based on all rural properties that:

1. are situated within the Dry Chaco ecoregion (Olson et al., 2001),
2. contained more than 20% forest cover at baseline (2007)
3. are larger than 10ha, as the Forest Law does not apply to smaller properties,
4. have an average slope of less than 2.5% (to exclude small patches of mountainous forests at the Andes foothills in Salta, whose land use dynamics differ from the Dry Chaco plain), and
5. have a ratio of edge length to area of less than $150m^{-1}$ (which excludes extremely elongated shapes that appear to be fill-in errors)

Our final dataset contains 30,126 properties, of which 3,169 are situated in Salta, 11,196 in Santiago del Estero, and 15,761 in the province of Chaco (Fig. 1)

3.3. Variables

We use the official land use zoning maps of the Forest Law of each province to categorize properties into three groups (red, yellow, or green), ascribing categories as a function of the zone that covers the majority of the property's remaining forest. This categorization of properties is relatively clear-cut: changing the coverage threshold by 10% in either direction results in only a small number of properties changing groups (0.08% – 1.6%, mean: 0.45%).

We measure deforestation as the percentage of a property's area that was deforested within any given time period, using a hand-digitized dataset of observed annual anthropogenic forest conversion in the Dry Chaco (Vallejos et al., 2015). The dataset is based on visual interpretation on LandSat imagery, and infers anthropogenic forest conversion to cropland and pasture from the spatial shapes of converted plots (e.g. regular shapes, hedgerows, etc.), with an overall classification accuracy of 97.8%. The data is also likely to record clearly timed transitions from forests to silvopasture, usually caused by the mechanical removal of tree cover, but unlikely to pick up slow and gradual degradation of forests caused by the mere presence of cattle. We compute annual averages of deforestation percentages for a six-year pre-treatment period (2001-

2006), a three-year implementation period (2007-2009) and a five-year post-treatment period (2010-2014).

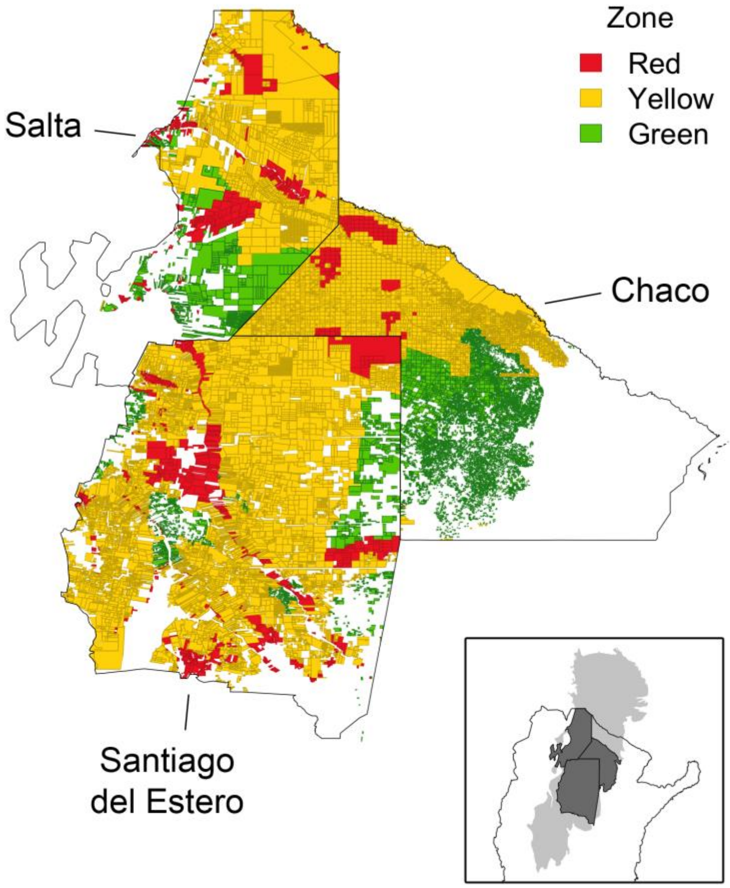


Fig. 1: Schematic map of the 30,126 properties included in this analysis, colored by the zone that covers most of the forests within each property. Inset shows study area (dark grey) within the Dry Chaco ecoregion (light grey) and Argentina (black outline).

We compile data for seven key covariates, i.e. variables that we expect to be associated with the likelihood of deforestation and the likelihood of stricter protection. These include indicators of agricultural productivity, accessibility, neighborhood effects, and property type. We use the following indicators and data sources:

1. Average annual precipitation (mm/yr), a pivotal determinant of agricultural suitability in the Dry Chaco, as estimated by the Tropical Rainfall Measuring Mission (TRMM)
2. Percentage of mollisols (%), an important indicator of the potential agricultural productivity of soils, estimated by the National Agricultural Technology Institute (INTA) (Volante et al., 2016)

3. Cost-distance to towns (in USD), an indicator of accessibility to commodity markets, computed on the basis of existing road networks and estimated average travel costs (unpublished data, María Piquer-Rodríguez)
4. Distance to rivers and wetlands (m, square root transformed), which affects access to water, drainage, and was an important variable in the allocation of protection, adapted from Instituto Geográfico Nacional (2012).
5. Percentage of deforestation that occurred prior to the adoption of the Forest Law (2001 – 2006) within a 50km radius around the center of each property, in order to account for local agglomeration economies and for unobserved factors influencing local variation in deforestation risk (Vallejos et al., 2015).
6. Percentage forest cover at baseline (2007), as shown in the official zoning maps of each province, which followed the methodology laid out in Argentina's official forest inventory (Secretaría de Ambiente y Desarrollo Sustentable, 2005).
7. Size of the property (ha, log transformed), to account for potential differences in the economics of scale at the property level.

We map all raster-based covariates (1-5) to properties as average values using Zonal Statistics 0.1 in QGIS 2.18.0.

3.4. Zone Allocation Models

To test whether our covariates influenced the allocation of zonation in the three provinces, we develop province-specific multinomial logit models that estimate the likelihood of zone allocation (green, yellow, and red) as a function of all seven covariates. In addition, we develop a pooled multinomial logit model with all covariates and interactions terms (each covariate interacted with each province) to test whether the allocation of zones differed between provinces.

3.5. Impact Estimation

We combine nearest-neighbor covariate matching with a differences-in-differences (DID) estimator to assess the impact of provincial-level land use zonation on property-level deforestation. Matching is a quasi-experimental method for causal inference that has witnessed a rapid uptake in the impact evaluation of land use policies over the past eight years (Andam et al., 2008; Joppa and Pfaff, 2011; Nelson and Chomitz, 2011; Nolte and Agrawal, 2013). Matching mimics an experimental setup by identifying groups of control units that are as similar as possible to the units that received a given treatment in terms of covariates, i.e. confounding factors that affect both the outcome and the likelihood of treatment (Ho et al., 2007; Joppa and Pfaff, 2010). However, matching eliminates bias only if confounders are observable and successfully controlled for (Ferraro and Hanauer, 2014). This assumption cannot be tested directly. We therefore use post-matching DID estimators to account for the possible influence of time-invariant unobservable confounders.

We define treated units as properties whose forests were predominantly situated in a stricter zone (red or yellow), and control units as properties whose forests were predominantly situated in a less strict zone (yellow or green). This results in three pairwise comparisons (red to yellow, yellow to green, red to green) for each province. We conduct matching without replacement (repeated draws of control units) and discard treatment units for which no suitable control parcel can be found within 1 SD of each covariate (calipers). Because matching without replacement is affected by the initial order of treatment units, we repeat our analysis 50 times with randomized order of observations and report average results.

We use three strategies to verify whether matching successfully reduced selection bias. First, we compute the absolute standardized differences in covariate means between treatment and control groups, averaged across seven covariates, before and after matching. Second, we test for significant differences in pre-treatment deforestation rates (2001-2006) between matched treatment and control groups. If matching successfully controlled for selection bias in zoning allocation, this “Placebo” test should reveal no significant differences in pre-treatment deforestation. Third, we test whether outcomes on matched treated and control units followed parallel time trends, a key assumption for the validity of DID estimation. To do so, we group pre-treatment years into two periods of equal length (2001-2003 vs. 2004-2006) and use a DID estimation to test for differences in time trends between groups.

To estimate the impact of stricter zones on deforestation, we use a DID estimator comparing deforestation rates between pre-treatment (2001-2006) and post-treatment (2010-2014) years on treated properties vs. matched controls. In addition, we test for the possible presence of pre-emptive clearing (higher deforestation triggered by the anticipation of regulation) by estimating group differences in deforestation rates in pre-treatment (2001-2006) vs. planning (2007-2009) years. As properties vary considerably in size and given our interest in the effect of zoning on aggregate deforestation, we weigh all tests and impact estimators by property size. All our DID estimators use robust standard errors (Rogers, 1993) and are specified as follows:

$$Deforestation = \beta_0 + \beta_1\ Treatment + \delta_0\ T2 + \delta_1\ Treatment \bullet T2$$

Where Deforestation is annual average deforestation within the respective time period, Treatment is a dummy variable for treatment units, T2 is a dummy variable for the second time period, and δ_1 is the DID coefficient of interest.

Spatial proximity between properties can lead to leakage of deforestation from more regulated to less regulated properties, leading to an overestimation of impact. To ensure our results are not impacted by this effect, we conduct a robustness check of our analysis, using as controls only properties whose average distance from treatment units is larger than 10km.

3.6. Supplementary Evidence

To identify plausible mechanisms for the impact of zonation on deforestation rates, we use evidence from documents review and key informant interviews. The first three authors conducted a total of 13 weeks of field research in the three provinces between 2013 and 2015, carrying out 122 interviews with government officials, researchers, advocacy groups, producers, and commodity traders. In addition, we revise implemented zoning plans and the corresponding legal documents.

4. Results

4.1. Aggregate Deforestation Trends

Fig. 2 shows aggregate deforestation trends on properties zoned red, yellow, and green in the adopted land use plans. Deforestation reached rates of > 150,000ha prior to the adoption of the Forest Law. In Salta and Chaco, green properties constituted the bulk of pre-treatment deforestation. Yellow properties accounted for the majority of forest loss in Santiago del Estero. In all three provinces, deforestation rates followed downward trends during planning and implementation of zoning.

4.2. Selection Bias in Zoning Allocation

We find strong evidence that Salta, Santiago del Estero and Chaco did not allocate zones randomly across the forests of the Dry Chaco. On average, stricter zones tend to be allocated to land that is less valuable for agricultural production, and thus less likely to be deforested than less strict zones (Fig. 3). In our province-specific multinomial models of zone allocation, 37 out of 42 coefficient estimates (88%) have the expected sign and are estimated to be significant (Table 1). This bias in the allocation of protection is most consistent in the province of Chaco. A pooled multinomial model of zone allocation with province interactions confirms that provinces differ significantly in the determinants of zoning allocation (Table S1). This observation appears to support our working assumption that provinces had leeway in the allocation of zoning.

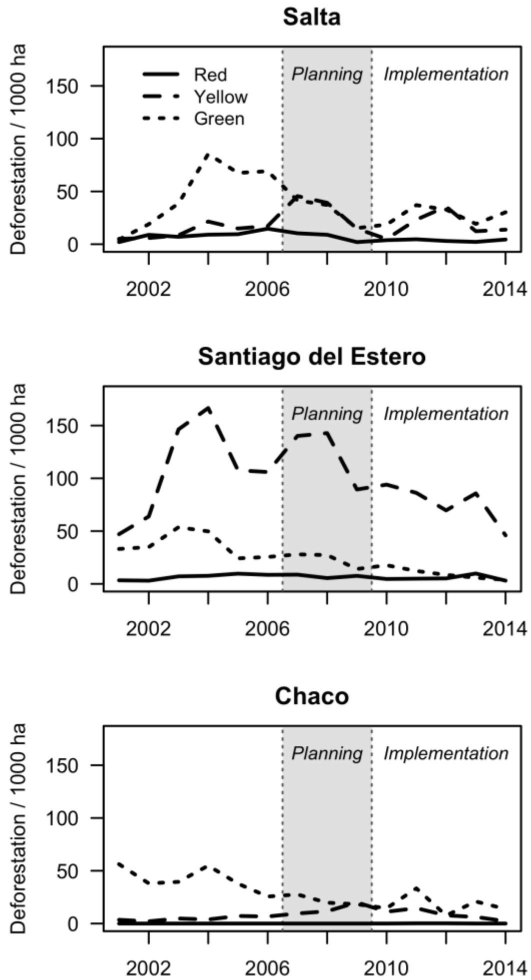


Fig. 2: Aggregate deforestation observed on properties situated in green, yellow, and red zones by province and year. This data includes properties that had less than 20% forest cover by 2007 (n = 40,388)

Differences in pre-treatment deforestation rates also confirm the presence of selection bias. In eight out of nine pairwise comparisons, properties located in stricter zones had significantly lower deforestation rates than properties located in less strict zones before the Forest Law was passed (Figs. 4-6, Panels C). An interesting exception is Salta, were properties later located in red zones exhibited, on average, higher deforestation rates before the adoption of the Forest Law than properties later located in yellow zones. Indeed, Salta's red-zoned properties are located closer to past deforestation, on average, than yellow-zoned properties (Fig. 3), and many are situated in direct adjacency to green properties (Fig. 1). As a result, red properties might have had a higher potential to reduce deforestation in Salta than in other provinces.

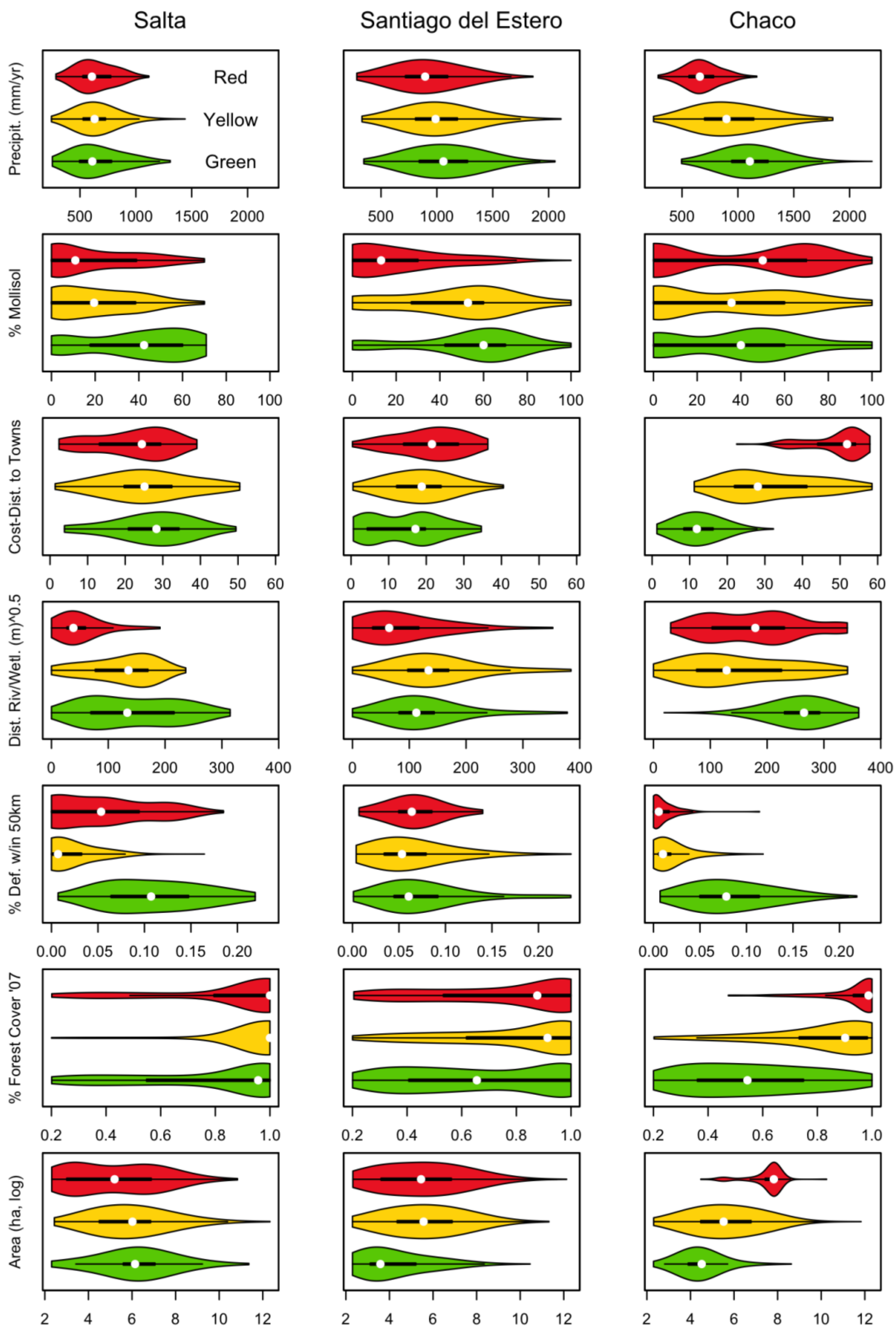


Fig. 3: Kernel density plots of covariate values of 30,126 properties in red (top), yellow (middle) and green (bottom) zones, by province.

Table 1: Coefficient estimates of multinomial logit models of zone allocation, by province. The reference zone is “green”. *** p<0.001 ** p<0.01 * p<0.05

	Expected	**Salta**		**Santiago del Estero**		**Chaco**	
	Sign	red	yellow	red	yellow	red	yellow
Intercept		5 ***	2.4 ***	-4 ***	-4.3 ***	-19.7 ***	-1.9 ***
Precipitation (mm/yr)	-	-0.00098 *	-0.00275 ***	-0.00099 ***	-0.00018	0.00024	-0.00088 ***
Percentage Mollisol (%)	-	-0.0322 ***	-0.0119 ***	-0.0303 ***	0.005 ***	-0.0287 ***	-0.0202 ***
Cost-Distance to Towns ($)	+	-0.017 *	-0.039 ***	0.168 ***	0.12 ***	0.309 ***	0.145 ***
Distance to Rivers and Wetlands (m) ^ 0.5	-	-0.02638 ***	-0.00084	-0.01139 ***	0.00405 ***	-0.00973 ***	-0.01722 ***
Deforestation 2001-2006 within 50km	-	-20.1 ***	-62.5 ***	-15.4 ***	-31.6 ***	-64.6 ***	-53.9 ***
Initial Forest Cover (%)	+	0.82 **	2.77 ***	1.89 ***	2.25 ***	4.26 ***	3.98 ***
Property Size (log ha)	+	0.037	0.474 ***	0.697 ***	0.729 ***	1.4 ***	0.607 ***

4.3. Mechanisms

Document reviews show that all provinces defined zone-specific legal limits for clear-cut deforestation and silvopastoral use on individual properties. Table 2 illustrates how these percentages vary between provinces. In addition, Salta allowed re-categorization (downgrading) of red zones between 2008 and 2014, possibly reducing the impact of its red zones within the time period of our analysis. All provinces enforced restrictions through a combination of remote detection, field visits, and sanctioning. During our field research, government authorities in all provinces reported increases in enforcement capacity after the adoption of the Forest Law, as exemplified by increased remote detection capabilities using satellite imagery, more frequent field visits, higher levels of sanctions, and an increase in numbers of sanctions issued. These changes did not occur abruptly but continuously throughout the planning and implementation period. While an in-depth analysis of enforcement patterns is beyond the scope of this paper, this evidence suggests that observed impacts of zonation are likely a result of increases in regulation and enforcement capacity.

Table 2: Percentage of property-level clear-cut deforestation permitted in each zone and province. Numbers in parentheses refer to permitted levels of silvopastoral use.

Zone	Salta	Santiago del Estero[a]	Chaco
Red	0%	Z6: 0%	0%
Yellow	0% (100%)	Z5: 0% (30%) Z4: 10% (50%) Z3: <1000ha: 20% (60%) >1000ha: 15% (55%)	20% (70%)
Green	<1000ha: 70%[b] >1000ha: 60%[b,c]	Z2: <1000ha: 70% >1000ha: 60% Z1: <500ha: 95% >500ha: 90%	<100ha: 90% (100%) >101ha: 80% (100%) >201ha: 70% (70%) or 60% (100%) >1000ha: 70% (70%) or 50% (100%)

[a] Z1 – Z6 refer to zones defined by Santiago del Estero's provincial zoning plan
[b] Percentages are stricter for properties with >5% slope (excluded in this analysis)
[c] At least 700 ha of deforestation is allowed for properties >1000 ha

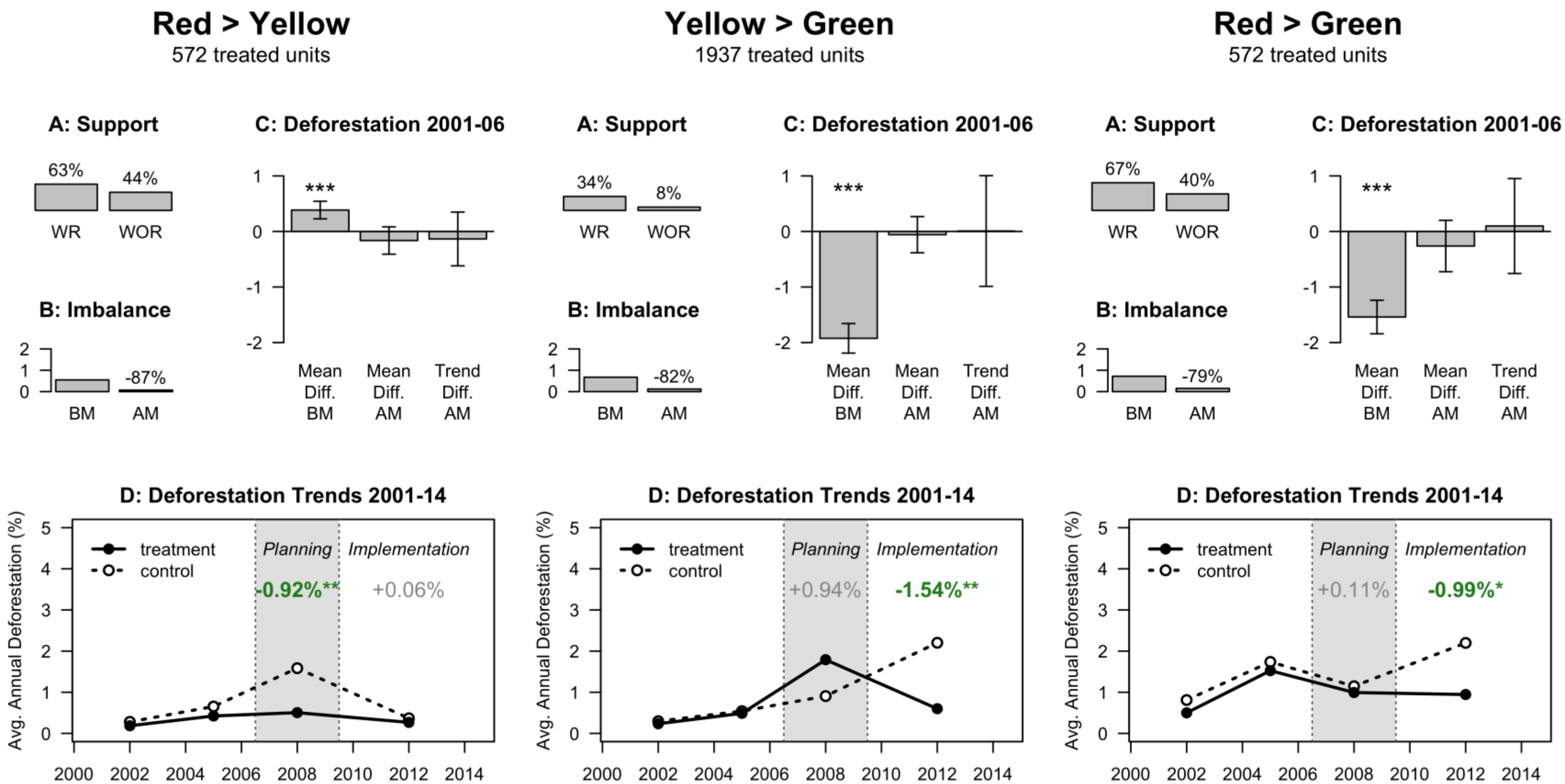
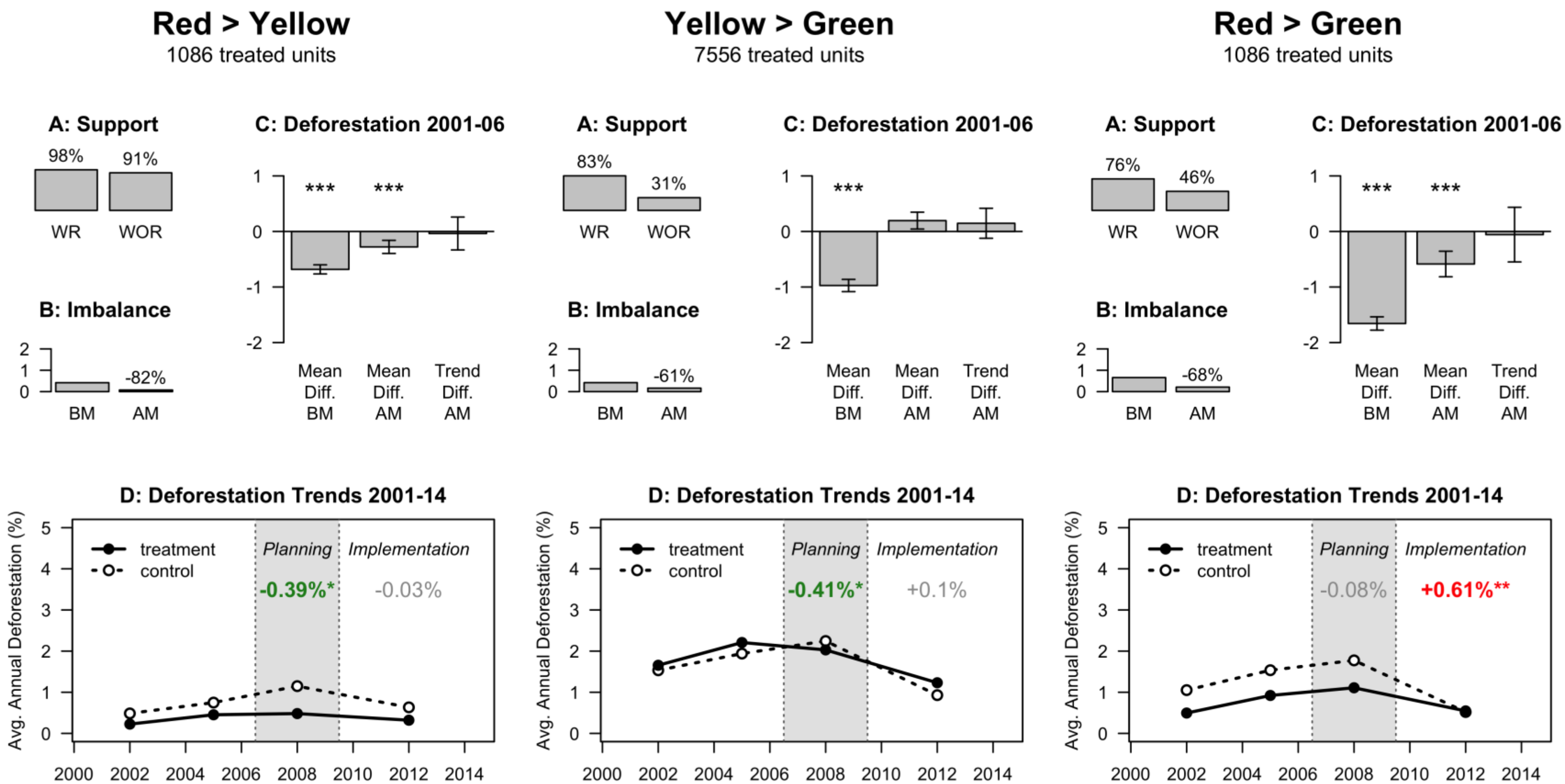


*Fig 4: Result summary for Salta. A: Percentage of matched treated units if matching is with (WR) and without (WOR) replacement. B: Average absolute standardized difference between groups in covariate means before (BM) and after (AM) matching. C: Differences in pre-treatment deforestation rates between groups before (BM) and after (AM) matching. "Trend Diff." refers to differences-in-differences (DID) between 2001-03 and 2004-06 (test of parallel time trend assumption). D: Average annual deforestation by period for treatment and control groups, with reported DID estimates for the planning (2007-2009) and implementation (2010-2014) period. Significant differences (p<0.05) are highlighted as bold. *** p<0.001 ** p<0.01 * p<0.05*



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549 *Fig 5: Result summary for Santiago del Estero. Legend as in Fig. 4*

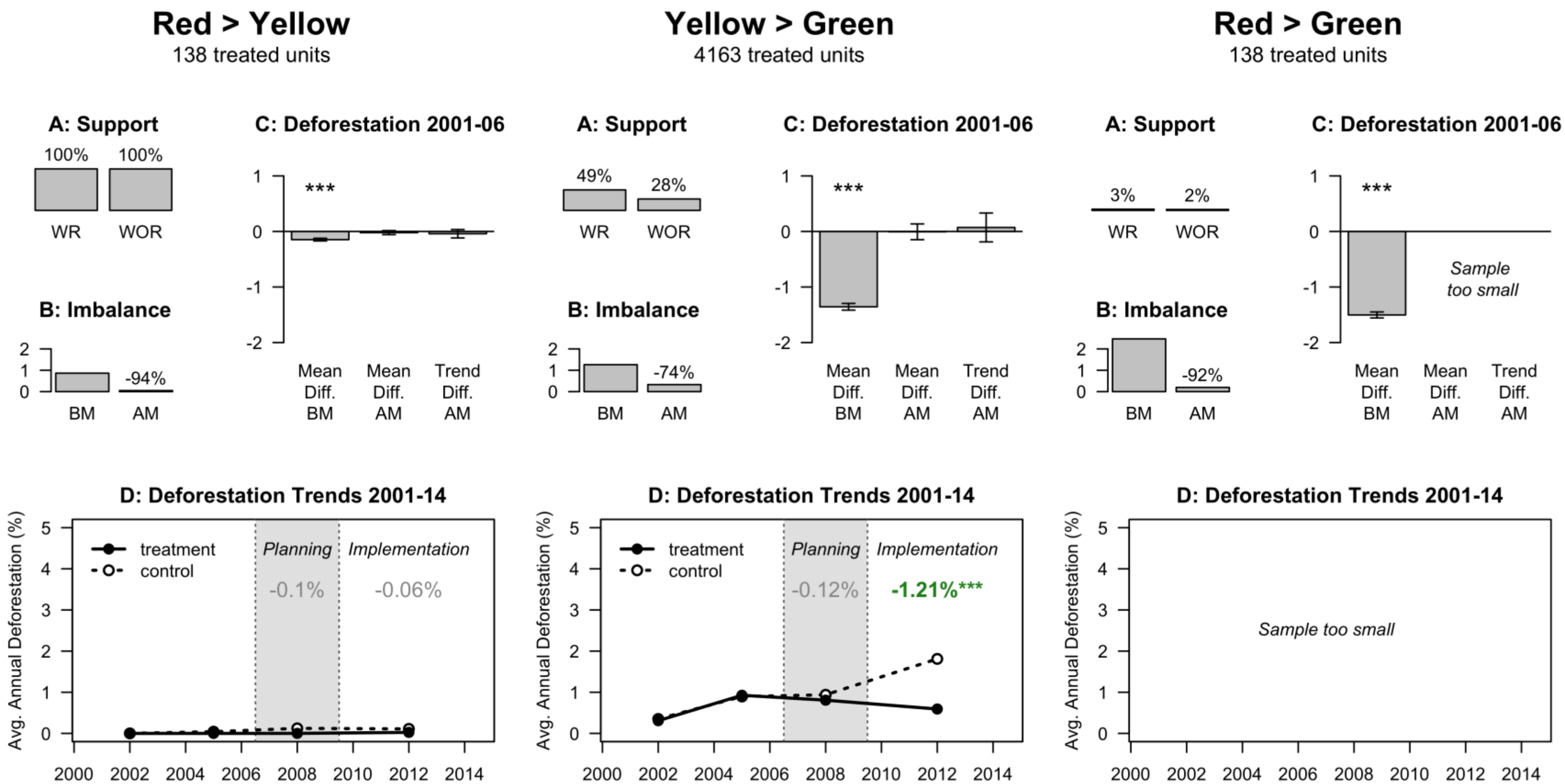

Fig. 6: Result summary for Chaco. Legend as in Fig. 4

4.4. Quality of Matching

Due to marked differences in covariate distributions of properties in different zones (cf. Fig 3), not all pairwise comparisons yield sufficiently large matched control groups for a confident assessment of policy impact. In three out of nine comparisons, comparable control units exist for only <50% of treated units (Figs. 4-6, Panels A). In the province of Chaco, were selection bias is strongest, only 3% out of 138 red properties could be matched to green controls. We therefore drop this comparison from the remaining analysis. For the remaining comparisons, suitable control units exist for an average of 71% of treated units. It is thus important to keep in mind that our impact estimates are based on comparable sections of the landscape and might not apply to the remainder.

Matching without replacement produces smaller sample sizes (Figs. 4-6, Panels A), because pools of suitable controls can become exhausted before all treatment units are matched. This effect is particularly strong when comparing yellow to green properties, as the former tend to cover larger and more heterogeneous parts of the landscape. It provides justification for our strategy to conduct multiple repetitions and report average results to ensure that findings are not specific to individual subsamples.

Matching successfully reduces bias in covariates between treatment and control groups. Across pairwise comparisons, covariate imbalance, measured as the absolute standardized difference in means between treatment and control groups, declines by 61-94% post-matching, with an average of 82% (Figs. 4-6, Panels B). Post-matching placebo tests confirm that matching successfully reduces, if not eliminates, selection bias in a majority of cases. While properties in different zones exhibit highly significant differences ($p<0.001$) in pre-treatment deforestation, these differences become non-significant ($p>0.01$) after matching in Salta and Chaco (Figs. 4-6, Panels C). In Santiago del Estero, significant differences in pre-treatment deforestation remain after matching. This observation points towards the presence of unobserved confounders and provides justification for the adoption of a DID design. The suitability of DID is further supported by test results for parallel time trends: None rejects the hypothesis that matched control and treatment properties followed similar deforestation trajectories before the Forest Law was adopted (Figs. 4-6, Panels C).

4.5. Impact Estimates: Planning Period

In two out of three provinces, deforestation trends diverged between treatment and control groups during the implementation process of the Forest Law (2007-2009). In Salta, DID estimates suggest that properties that were later assigned red zonation reduced deforestation in 2007-2009 vis-à-vis properties that were later assigned yellow zonation (Fig. 4, Red > Yellow, Panel D). This appears to be due to a sudden rise in deforestation on yellow properties in Salta, which is also noticeable in the comparison of yellow to green properties (Fig. 4, Yellow > Green, Panel D). In contrast, deforestation rates in red and yellow zones in Santiago del Estero appear to have declined vis-à-vis less strict zones during the implementation process of the Forest Law (Fig. 5, Panel D). This might reflect impacts of Santiago del Estero's early provincial-level zoning process, which concluded in 2006.

4.6. Impact Estimates: Post-Treatment Period

In Salta and Chaco, our estimates suggest that yellow zones significantly reduced deforestation if compared to green zones. In Salta, we find that red zones also significantly reduced deforestation as compared to green zones. Deforestation rates on matched green properties increased noticeably after the adoption of zoning plans (Fig. 4 and 6, Panels D). No significant impact estimates of red vs. yellow zones are found in either province, mostly because matched red properties and their yellow controls experienced low rates of deforestation both before and after the planning period.

In Santiago del Estero, we do not find significant effects of stricter zonation on deforestation after 2009 (Fig. 5). On the contrary, our DID estimates suggest that yellow zones <u>increased</u> deforestation if compared to green zones after the conclusion of the Forest Law planning process. This is true in spite of a noticeable over-time decrease in deforestation on yellow properties, as deforestation on green controls decreased even further.

4.7. Robustness

Excluding properties situated nearby treated units (< 10 km) from the pool of potential controls reduces the number of treatment unit with comparable controls by 1% to 40% across runs (average: -19%). This does not affect overall findings in Santiago del Estero or Chaco (Figs. S2 and S3). However, significance estimates change in Salta (Fig. S1), the province most affected by this reduction in the number of comparable treatment units (by an average of -24%, to values as low as 12%): After exclusion of neighbors, red zones in Salta are not estimated to have reduced deforestation if compared to green zones. However, diverging time trends in pre-treatment deforestation indicate that after exclusion of neighbors, treatment and control groups in Salta might not be sufficiently similar to estimate impacts robustly, at least when comparing red to green properties.

5. Discussion

Did provincial governments in Argentina's Dry Chaco implement land use plans that inhibited agricultural expansion and reduced deforestation? Our empirical answer is cautiously affirmative. On one hand, we find evidence that provincial governments "followed the market" in the allocation of zoning. In all three provinces, stricter zones were significantly more likely to be allocated to lands of lower agricultural value for beef and soy expansion, and thus faced lower deforestation risk than less protective zones.

This phenomenon caps the maximum inhibitory effect these zones can have. It also might put forests of high ecological values at risk, if these are situated on land valuable for agriculture, such as remnants of quebracho forests (Piquer-Rodriguez et al., 2015). We also find that provinces differed significantly in how landscape attributes influenced the allocation of zoning, supporting our initial assumption that provinces had some leeway in deciding where and how to allocate zones within their jurisdictions.

On the other hand, we find that land use plans adopted by Salta, Santiago del Estero, and Chaco effectively reduced deforestation over counterfactual scenarios, at least in some time periods. These restrictions were effective immediately, with measurable impacts within years after the approval of the land use plans. Across provinces, the inhibitory effect of yellow zones appears particularly consistent. Yellow zones are frequently adjacent to (and thus more comparable to) green zones, where deforestation pressures are higher and restrictions are lower; as a result, yellow zones face higher counterfactual deforestation pressure, and can thus have higher potential impact. It is noteworthy that this impact was observed in spite of the significant share of silvopastoral land use that each province permits in yellow zones (Table 2). In contrast, red zones are often located away from deforestation pressure, which attenuates their potential short-term impacts on forest loss. This finding is consistent with other studies that find stricter protection to be more likely allocated to remote areas (Nelson and Chomitz, 2011; Pfaff et al., 2014; but see Nolte et al., 2013b). In Salta, where many red properties are located close to green properties, estimated impacts on deforestation are higher, but might also be more vulnerable to the confounding effects of leakage. Inhibitory effects of red zones might become more important in the future as deforestation frontiers advance.

Our analysis reveals important dynamics of policy implementation over time. In Salta, we find deforestation on yellow properties to increase during land use planning before treatment was assigned. As noted in Section 3.1, Salta had shown little initiative to adopt land use plans prior to the adoption of the Forest Law, and its agencies sped up deforestation permits in anticipation of regulation. Elevated deforestation on yellow properties thus appears to be pre-emptive clearing, i.e. land use conversion to prevent stricter regulation (Seghezzo et al., 2011). In Santiago del Estero, we find stricter zones to have reduced deforestation after the provincial land use plan was adopted (2006), but not after its translation into the Forest Law (2009), when red zones are estimated to have increased deforestation if compared to green zones. This counterintuitive finding appears to be driven by a rapid decline in deforestation on green properties that we do not observe in other provinces. Provincial differences in deforestation trajectories and the impact of zoning might also have been influenced by factors that we could not explicitly consider in this analysis, including 1) the dynamics of silvopastoral land use, whose responses to zoning might differ from that of clear-cut deforestation (available data conflates both types of deforestation), and 2) differences in the presence of indigenous and other forest users and their success in resisting commercial agricultural expansion, for which comparable data was not available at the time of writing. Future research could elucidate these more complex relationships.

6. Conclusion

Subnational governments are increasingly important players in forest-based climate change mitigation, but their ability and willingness to reduce large-scale deforestation is rarely the subject of systematic empirical inquiry. For the Argentinian Dry Chaco, one of the planet's most active deforestation frontiers, we show that the three provinces with the highest historical levels of forest loss implemented zoning plans that reduced deforestation in a counterfactual scenario, at least in locations of the landscape that allow causal inference. While we also document a systematic bias in the allocation of protection to remote and unthreatened locations, this bias does not appear to void the forest conservation impacts of the adopted land use plans.

Can our findings serve as an indicator of the willingness and ability of subnational governments to reduce large-scale deforestation? As constitutional decision-making powers to land and forests rest with Argentina's provinces, we expect land use policies and resulting impacts in the Dry Chaco to be influenced by provincial priorities. Differences in the definition, allocation and implementation of zones in the Argentina's Dry Chaco corroborate our assumption that Salta, Santiago del Estero, and Chaco had considerable freedom to define and allocate zones in ways that served their interests. However, we also observe instances in which Argentina's federal government exercised power to ensure that provinces implemented land use zoning. We also cannot discard the possibility that the federal government influenced the allocation of zones towards stricter protection in ways we do not observe. Neither do we explicitly consider the role of indigenous and local forest users in resisting the expansion of commercial agriculture in the region. We therefore propose to interpret our results as what they are: rigorous empirical evidence that large-scale deforestation in major agricultural frontiers can be slowed down by subnational policy within a national framework that prescribes processes, but not outcomes.

Reducing global emissions from deforestation and forest degradation will require the combined efforts of actors at multiple governance levels, from the local to the international. Within international arenas, national governments will remain pivotal decision makers and drivers of forest conservation policies. Nonetheless, the engagement of subnational, local, and private actors in forest conservation warrants more attention. Our observation that provinces with high historical deforestation rates can effectively reduce forest loss if prompted to do so lends support to the proponents of jurisdictional, multilevel and nested approaches to avoided deforestation policy. We encourage further rigorous empirical research on the impacts of multilevel forest conservation efforts in the world's deforestation frontiers to build a stronger evidence base for effective and equitable climate governance.

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Supplementary Material

Table S1: Coefficient estimates of pooled multinomial logit models of zone allocation with province interactions. The reference zone is “green”. The reference province is Chaco. *** p<0.001 ** p<0.01 * p<0.05

	red			yellow		
		Interactions w/ Salta	Interactions w/ Santiago d. Est.		Interactions w/ Salta	Interactions w/ Santiago d. Est.
Intercept / Province Dummy	-19.7 ***	24.7 ***	15.7 ***	-1.9 ***	4.3 ***	-2.4 ***
Precipitation (mm/yr)	0.0002	-0.0012 *	-0.0012 *	-0.0009 ***	-0.0019 ***	0.0007 ***
Percentage Mollisol (%)	-0.0287 ***	-0.0035	-0.0015	-0.0202 ***	0.0083 *	0.0252 ***
Cost-Distance to Towns ($)	0.309 ***	-0.327 ***	-0.141 ***	0.145 ***	-0.184 ***	-0.025 ***
Distance to Rivers and Wetlands (m) ^ 0.5	-0.0097 ***	-0.0167 ***	-0.0017	-0.0172 ***	0.0164 ***	0.0213 ***
Deforestation 2001-2006 within 50km	-64.6 ***	44.4 ***	49.1 ***	-53.9 ***	-8.6 ***	22.3 ***
Initial Forest Cover (%)	4.3 ***	-3.4 ***	-2.4 ***	4 ***	-1.2 ***	-1.7 ***
Property Size (log ha)	1.4 ***	-1.36 ***	-0.7 ***	0.61 ***	-0.13 *	0.12 **

Table S2: Results of difference-in-difference estimations in Salta. Predicted variables are annual average deforestation rates observed on matched treatment and control properties in the time periods of interest. T1 and T2 indicate the first and second time period in each comparison, respectively. The reference time period is T1. All values are averaged across 50 repetitions (see main manuscript, section 3.5). Significance: *** p<0.001 ** p<0.01 * p<0.05

	Time Trend T1: 2001-03 T2: 2004-06		Planning T1: 2001-06 T2: 2007-09		Implementation T1: 2001-06 T2: 2010-14	
Red > Yellow						
Intercept	0.2815	*	0.4678	***	0.4678	***
T2	0.3728		1.1172	***	-0.0992	
Treatment	-0.095		-0.1626		-0.1626	
Treatment * T2	-0.1351		-0.917	**	0.0621	
R-Squared	0.008		0.031		0.003	
Observations	997		997		997	
Yellow > Green						
Intercept	0.2968		0.4193	*	0.4193	*
T2	0.2449		0.4871		1.7837	***
Treatment	-0.0616		-0.0578		-0.0578	
Treatment * T2	0.0076		0.9422		-1.5447	**
R-Squared	0.006		0.031		0.096	
Observations	609		609		609	
Red > Green						
Intercept	0.8105	***	1.2739	***	1.2739	***
T2	0.9269	**	-0.1279		0.9248	*
Treatment	-0.311		-0.2618		-0.2618	
Treatment * T2	0.0984		0.1093		-0.9921	*
R-Squared	0.023		0.002		0.028	
Observations	905		905		905	

Table S3: Results of difference-in-difference estimations in Santiago del Estero. Legend as in Table S2.

	Time Trend T1: 2001-03 T2: 2004-06		Planning T1: 2001-06 T2: 2007-09		Implementation T1: 2001-06 T2: 2010-14	
Red > Yellow						
Intercept	0.486	***	0.6178	***	0.6178	***
T2	0.2637	*	0.5314	***	0.0151	
Treatment	-0.2597	**	-0.2781	***	-0.2781	***
Treatment * T2	-0.0368		-0.3887	*	-0.0337	
R-Squared	0.013		0.022		0.013	
Observations	3933		3933		3933	
Yellow > Green						
Intercept	1.5338	***	1.7369	***	1.7369	***
T2	0.4064	***	0.5091	***	-0.8063	***
Treatment	0.122		0.1953		0.1953	
Treatment * T2	0.1467		-0.4109	*	0.1054	
R-Squared	0.007		0.003		0.026	
Observations	9235		9235		9235	
Red > Green						
Intercept	1.052	***	1.2941	***	1.2941	***
T2	0.4841	*	0.4804	*	-0.7738	***
Treatment	-0.557	***	-0.5856	***	-0.5856	***
Treatment * T2	-0.0572		-0.0799		0.6121	**
R-Squared	0.023		0.023		0.033	
Observations	1993		1993		1993	

Table S4: Results of difference-in-difference estimations in Chaco. Legend as in Table S2.

	Time Trend T1: 2001-03 T2: 2004-06		Planning T1: 2001-06 T2: 2007-09		Implementation T1: 2001-06 T2: 2010-14	
Red > Yellow						
Intercept	0.0005		0.0213		0.0213	
T2	0.0415		0.1007		0.0893	
Treatment	-0.0005		-0.0213		-0.0213	
Treatment * T2	-0.0415		-0.1002		-0.064	
R-Squared	0.008		0.016		0.024	
Observations	551		551		551	
Yellow > Green						
Intercept	0.3507	***	0.6236	***	0.6236	***
T2	0.5458	***	0.3155	**	1.187	***
Treatment	-0.0421		-0.006		-0.006	
Treatment * T2	0.0723		-0.1249		-1.2115	***
R-Squared	0.015		0.003		0.037	
Observations	4580		4580		4580	
Red > Green						
Not computed (sample too small)						

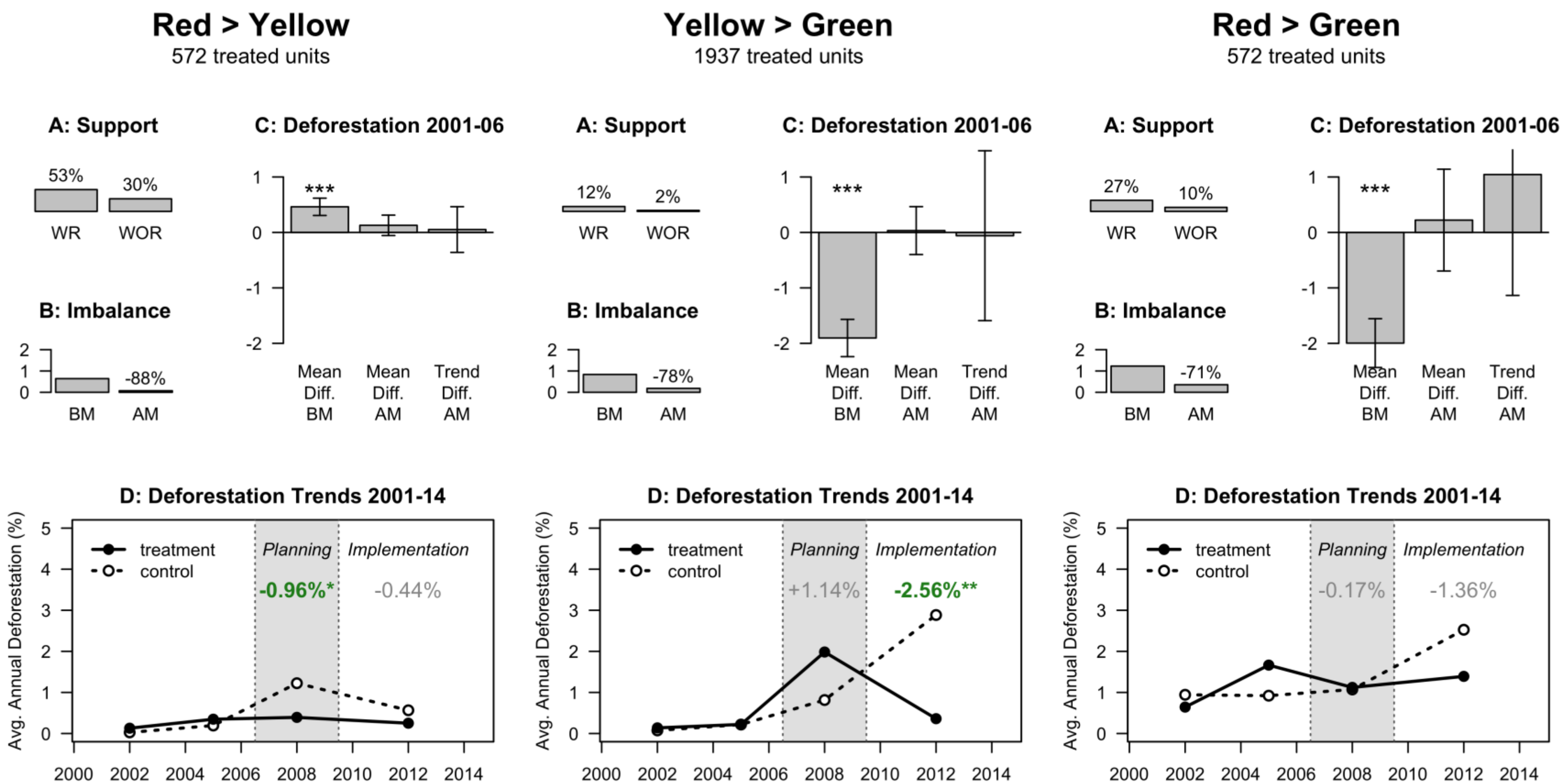

Fig. S1: Results summary for Salta, after exclusion of controls located nearby treatment units (<10km). Legend as in Fig. 4

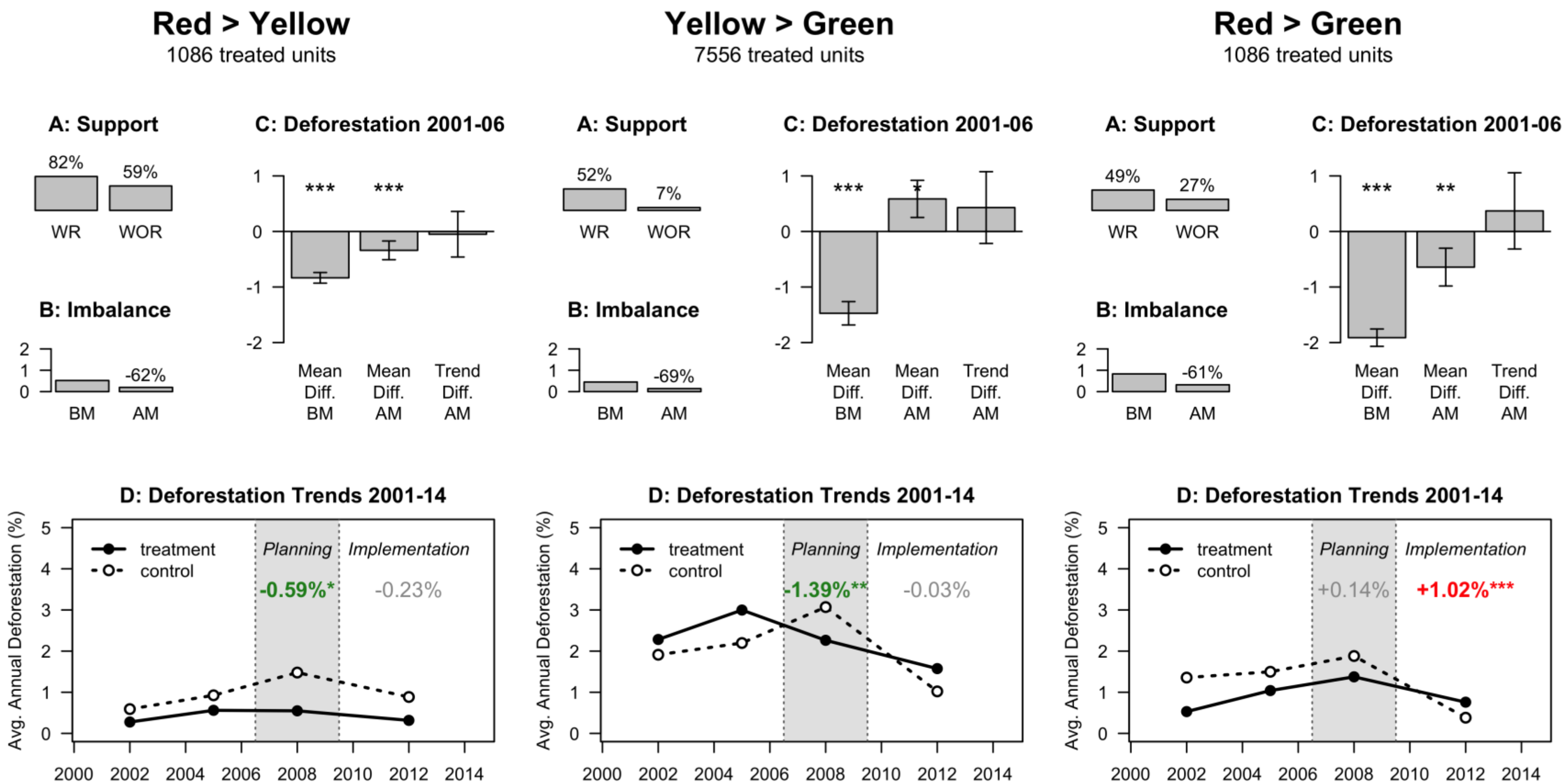

Fig. S2: Results summary for Santiago del Estero, after exclusion of controls located nearby treatment units (<10km). Legend as in Fig. 4

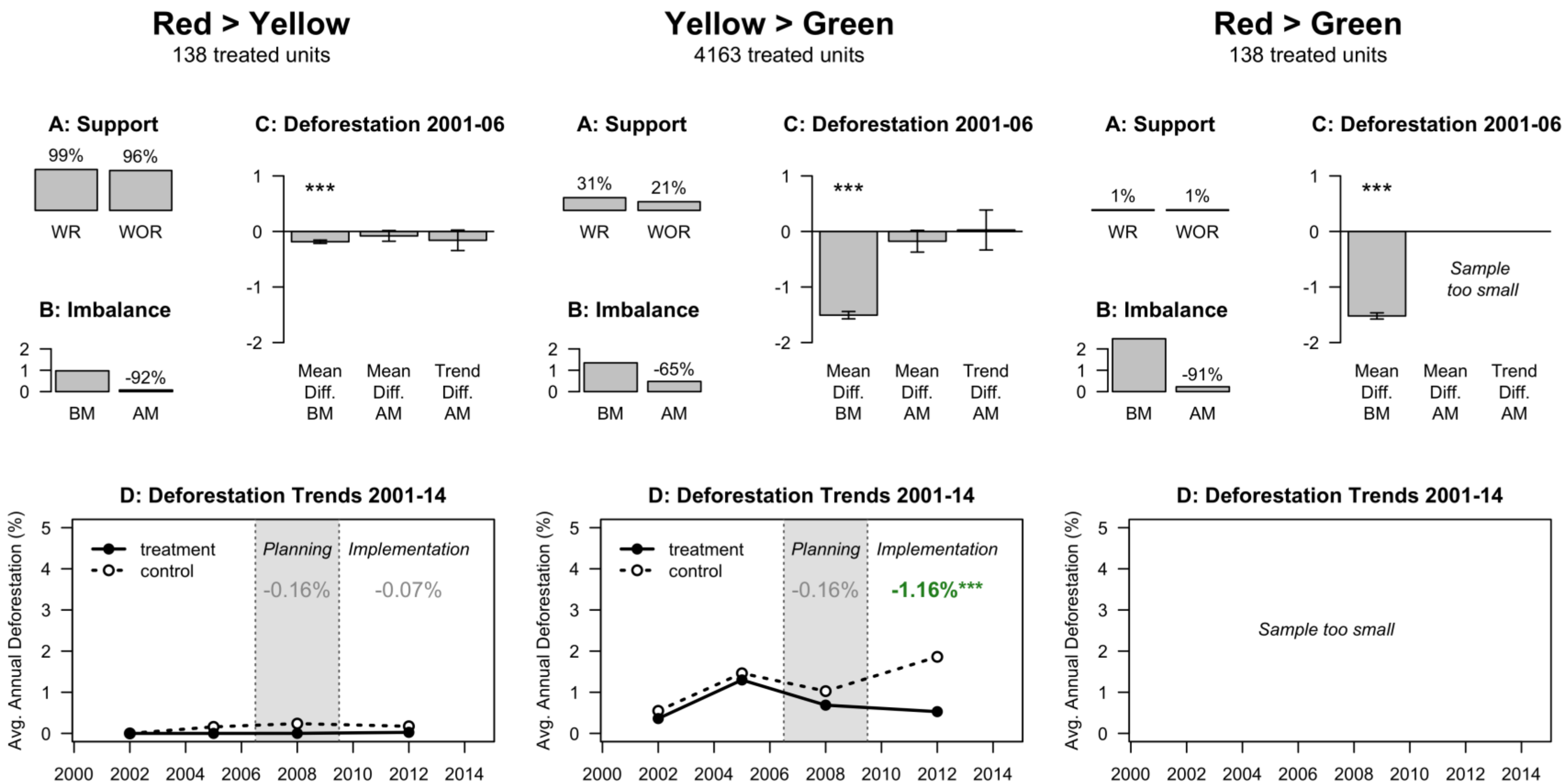

Fig. S3: Results summary for Chaco, after exclusion of controls located nearby treatment units (<10km). Legend as in Fig. 4