

# Commodity Prices and Robust Environmental Regulation: Evidence from Deforestation in Brazil

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## Abstract

Increasing international agricultural commodity prices create pressure on tropical forests. We study the effectiveness of three regulatory policies implemented by Brazil in reducing this pressure: *blacklisting* of municipalities, the *Soy Moratorium*, and *conservation zones*. We use a triple difference approach that combines international agricultural commodity prices with the policies across three million km<sup>2</sup> in the Brazilian Amazon. We find that the blacklisting program is effective, as it reduces deforestation related to the prices by 40%. The Soy Moratorium made deforestation in exposed municipalities more sensitive to non-soy prices, in line with crop substitution. Conservation zones amplify the effect of prices on deforestation on the remaining unprotected land, consistent with reduced land supply. Our results highlight that the effect of environmental regulation depends on the economic pressure to use natural resources.

**Keywords:** deforestation, commodity prices, protected areas, soy moratorium, priority municipalities, environmental regulation, climate change

**JEL-codes:** O13, Q15, Q17, Q28, Q54

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# 1 Introduction

Land-use change, largely due to tropical deforestation (Mitchard, 2018), is estimated to account for about 10-12% of anthropogenic CO<sub>2</sub> emissions in the years 2000-2015 (Le Quéré et al., 2016; Edenhofer et al., 2014). The backdrop of high deforestation rates has been strong global economic growth, high global energy prices, subsidies for biofuels and a doubling of the real price of agricultural commodities like grains (Mitchell, 2008; Alexandratos, 2008). Large scale agriculture accounted for about two-thirds of deforestation in Latin America and one-third in Africa and Asia in the period 2000-2012 (Kissinger et al., 2012). Around half of such deforestation can again be attributed to the cultivation of crops for export markets like the EU, China and North America (Lawson, 2014). In response, countries such as Brazil have committed to an array of command and control policies to reduce deforestation. The question addressed in this paper is whether such policies are effective in curbing deforestation related to higher commodity prices.

We evaluate the effectiveness of three central policy measures implemented in Brazil. The policies vary in terms of the deforestation they target. *Blacklisting of municipalities* (PM) targets municipalities with high deforestation rates by the means of increased monitoring and law enforcement as well as by more stringent conditions for subsidized rural credit.<sup>1</sup> This policy focuses on the total extent of deforestation at the municipality level. The *Soy Moratorium* (SM) is an industry-driven initiative that aims to keep the commodity supply chain clean of soybeans that come from recently deforested land. Hence it focuses on deforestation caused by soy cultivation. *Conservation zones* (CZ) impose regulation on certain geographic areas. In this paper, we include three broad categories of protected areas in what we call Conservation Zones, namely indigenous lands, sustainable use conservations zones and strictly protected conservations zones. We study the deforestation frontier in the Brazilian legal Amazon. This is the part of the Amazon, the largest forest left on earth, that is likely to have experienced the most intense deforestation pressure to date. Our main dataset is a balanced panel of 486 municipalities covering the years 2002-2013 and about three million km<sup>2</sup>. The main analysis focuses on deforestation outside of the protected areas.

We begin our analysis by estimating the direct effect of agricultural commodity prices on deforestation. We construct a municipality-level price index based on international real prices.

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<sup>1</sup>The blacklisted municipalities were also called “priority” municipalities. Throughout the paper, we use the terms “priority” list policy and “black-listed” policy interchangeably.

We use weights based on each municipality’s cultivated area of the different crops in 2002, the initial year of our sample. Consistent with the finding of [Hargrave and Kis-Katos \(2013\)](#), we find that higher agricultural commodity prices are associated with higher deforestation. We estimate that a 100% increase in the prices leads to an increase in deforestation of about 40%. The average 56% higher level of the price index over 2004-2013 compared to 2003 then contributes with 1,700 km<sup>2</sup> of additional deforestation each year. This adds up to about 19% of the total deforestation of 91,000 km<sup>2</sup> in our sample over the ten-year period 2004-2013.

Next, we estimate how the effect of international agricultural commodity prices varies with the policies, which represents the main contribution of the paper. We use the municipality-specific index of prices interacted with policy exposure in a triple difference model (DDD). This model essentially compares price effects in municipalities exposed to a given policy with price effects in municipalities not exposed to the policy. Exposure to a policy varies both across municipalities and over time. We cannot reject common trends in deforestation in the pre-policy period, suggesting that our design effectively nets out potentially confounding trends driving both deforestation and the policy-roll out.

We find that the policy of *blacklisting* municipalities reduced the impact of commodity prices on deforestation by about 40%, saving 35 km<sup>2</sup> forest per treated municipality per year. In our sample, the total saved forest due to this effect is 9,000 km<sup>2</sup>. This is consistent with the expected effect that the policy increases the costs of deforestation. Previous studies have also suggested that this policy reduced deforestation.<sup>2</sup>

For the *Soy Moratorium*, we do not find a robust statistically significant effect for the agricultural commodity price index. This overall ineffectiveness masks two effects working in opposite directions: the soy price has a lower effect on deforestation under the Soy Moratorium, while the prices of other crops have a higher effect. This is consistent with the Soy Moratorium reducing deforestation related to soy cultivation, while the production of alternative crops is moved to or expanded on newly deforested areas. Corn may be a case in point. We find

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<sup>2</sup>[Arima et al. \(2014\)](#) find that 10,653 km<sup>2</sup> of deforestation or 0.123 PgC of emissions were avoided over 2009–2011 in the targeted municipalities. [Andrade and Chagas \(2016\)](#) study spill overs of the blacklisting policy on non-targeted neighbouring municipalities and find a decrease of 15% to 36% in deforestation in the non-listed neighbours. [Koch et al. \(2018\)](#) also find reduced deforestation in priority municipalities, but no effect on dairy production or crop production. [Assunção et al. \(2019\)](#) find that the policy reduced deforestation by 40%, in period 2009-2010, and cut emissions by 39.5 million tons of carbon. PgC (petagrams of carbon) is the same as gigatonnes of carbon (GtC). The weight of CO<sub>2</sub> is equal to 3.67 times the weight of Carbon, assuming that all the carbon is emitted. For more information on details of conversion of emissions measured in terms of carbon dioxide equivalent into carbon, see section 7.

deforestation to be more sensitive to the price of corn due to the Soy Moratorium, potentially explaining some of the remarkable increase in corn production seen in the Brazilian Legal Amazon since 2006. We find that leakage to corn can explain about 20% of the leakage to non-soy crops. Our results suggest that studies of the Soy Moratorium that have not allowed for substitution across crops may have overestimated its effect on deforestation.<sup>3</sup>

Finally, we find that *conservation zones* amplify the effect of agricultural commodity prices. On average, the prices in the years after zone expansions were 40% higher compared to the years before zone expansions. This led to about 6,000 km<sup>2</sup> extra deforestation outside of the conservation zones compared to a situation without the zone expansions. One interpretation of our finding is that the deforestation could have continued into the new protected lands in the absence of the policy. The effects are similar if we include deforestation within the protected areas, which historically had low deforestation rates. Conservation zones take away land from the potential land supply and can thus increase the deforestation pressure on the remaining unprotected land. Our analysis, based on deforestation in non-conserved areas and explicit deforestation pressure, suggests that conservation zones have been less effective in reducing deforestation than existing studies have found.<sup>4</sup>

Is there a trade-off between local economic development and the global public good of carbon storage? We use data on crop production values and carbon data in a stylized cost-benefit calculation to address this question. The carbon data are based on initial spatial variation in biomass in combination with deforestation over time. Compared to 2003, we estimate that higher agricultural commodity prices over 2004-2013 lead to a gain in the present value of current and future crop production and an increase in the loss of carbon. Combining the two estimates, we find a carbon price of 15 USD/tCO<sub>2</sub>, based on the unrealistic assumption that all the carbon held in the cleared forest is emitted. In terms of the policies, we find support for a trade-off also in the context of the priority list, as it reduces both the local production

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<sup>3</sup>Gibbs et al. (2015) find that deforestation for soy dramatically decreased due to the Soy Moratorium, while Nepstad et al. (2014) find only a marginal effect of the Soy Moratorium. Svahn and Brunner (2018) find that the Soy Moratorium reduced deforestation in the Brazilian Amazon biome, but only after it was enforced with satellite monitoring since 2008.

<sup>4</sup>Assunção et al. 2015 find that about half of the avoided deforestation in the Brazilian Amazon over the period 2005-2009 was due to conservation policies. Soares-Filho et al. 2010 assign 37% of the reduction in deforestation in the Brazilian Amazon over the period 2004-2006 to expansion of protected areas. Also Nolte et al. 2013 find that protected areas have contributed to reducing deforestation rates. Anderson et al. (2016) find that conservation zones are mostly located in areas where agricultural production is likely to be unprofitable. They find that zones reduce deforestation if the incentives for municipalities to reduce deforestation are high.

values and the carbon loss. To replace the loss in production values, the municipalities would have to be compensated by about 42 USD per tonne avoided CO<sub>2</sub>. For conservation zones, we find a modest effect on production values compared to carbon, suggesting a carbon price of 4 USD/tCO<sub>2</sub>. For the Soy Moratorium, we find that it on average increases local production values due to the commodity prices, but we find no robust evidence that it changes the impact of prices on carbon loss. The Soy Moratorium therefore seems to be profitable for the treated municipalities. When we split crop production values into soy, corn and the rest, the results resemble crop substitution: the Soy Moratorium reduced the impact of commodity prices on soy production values and increased their impacts on corn and the rest.

This paper makes three contributions to the growing literature on the drivers of deforestation and the effectiveness of policies against deforestation.<sup>5</sup> First, we focus on the effectiveness of policies explicitly accounting for the pressure to deforest, as expressed through international agricultural commodity prices.<sup>6</sup> Our analysis thus tests the robustness of environmental regulation when the pressure on natural resource use is high. A positive price shock resembles a positive shift in the demand curve for agricultural land. The priority list policy and the Soy Moratorium are expected to make the supply curve for agricultural land steeper, i.e. they increase the marginal cost of expanding agricultural land into forested lands (deforestation). A given price increase would then lead to a smaller expansion of agricultural land with the policy in place, compared to a situation without the policy in place. The conservation zones, on the other hand, are expected to shut down parts of the land market. The residual demand for non-protected land then increases, i.e. a given international price increase imposes a higher pressure on the remaining unprotected land. This results in a larger land expansion into unprotected lands with than without the policy in place. Deforestation pressure is discussed in the literature that tests policy effectiveness, e.g. Pfaff et al. (2014) and Assunção et al. (2015), but we explicitly bring in demand shocks. Based on our estimates, we graphically demonstrate that the effectiveness of a given policy measure in saving forest, measured in km<sup>2</sup>, depends on

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<sup>5</sup>See Alix-Garcia et al. (2015), Alix-Garcia (2007), Assunção et al. (2015), Assunção et al. (2017), Assunção et al. (2019), Barbier and Burgess (2001), Burgess et al. (2012), Burgess et al. (2017), Chomitz and Thomas (2003), Foster and Rosenzweig (2003), Gibbs et al. (2015) Pfaff (1999), Lopez and Galinato (2005), Rodrigue and Soumonni (2014), Rudel et al. (2005) and Hargrave and Kis-Katos (2013), as well as references therein.

<sup>6</sup>There is large empirical literature which has analyzed various impacts of booming commodity prices on commodity-exporting economies, i.e. macroeconomic performance and fluctuations (Deaton et al., 1995; Fernández et al., 2017; Drechsel and Tenreyro, 2018), structural adjustment via Dutch disease mechanisms (Harding and Venables, 2016; Cust et al., 2014) and conflict (Dube and Vargas, 2013; Bazzi and Blattman, 2014).

the agricultural commodity prices.<sup>7</sup>

Second, this paper contributes to understanding the issue of policy ineffectiveness due to leakage (Aukland et al., 2003; Harstad and Mideksa, 2017). For the Soy Moratorium, we present evidence in support of substitution across crops, as the impact of non-soy prices increases under the moratorium. For conservation zones, we find increasing deforestation pressure due to prices when new areas are put under protection. In contrast, we find that the priority municipality policy is effective in reducing the impact of prices. Within municipality leakage thus reduces the effectiveness of the two policies that zoom in on specific sub-categories of deforestation, whereas the policy that targets deforestation irrespective of its source is effective at the municipality level. While the existing empirical literature has revealed leakage across space, e.g. Pfaff and Robalino (2017) on conservation zones and Gibbs et al. (2015) on the Soy Moratorium, we are not aware that the leakage due to substitution across crops has been documented previously.

Third, this paper provides a simple cost-benefit analysis of the three policies we study, whereas most of the literature on deforestation focuses on the environmental effects. We measure economic costs in terms of crop production value loss at the municipality level and benefits in terms of avoided loss of carbon at the municipality level. The paper thus has links to the literature on economic growth and the environment, e.g. Grossman and Krueger (1995), Jaffe et al. (1995) and the large related literature. Specifically, there are different views on to which extent economic growth will have to be reduced to limit climate change, as characterized by Acemoglu et al. (2012). In our context, there is some evidence of a trade-off between local economic development and the global public good of carbon storage.

The remainder of this paper is organized as follows. Section 2 presents the institutional context. Section 3 discusses the data, the identification strategy and tests of parallel pre-trends. Section 4 presents econometric estimates of price effects and how they vary with respect to policy

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<sup>7</sup>Focusing on the interaction between prices and policies also helps with econometric identification, i.e. separating out the effect of the price-policy-interaction from the effect of other factors potentially affecting land demand or land supply. Our specifications allow us to control for a large set of observable and unobservable characteristics, including rich heterogeneity in the effect of prices, and we present evidence that the effect of prices is similar across control and treatment municipalities in absence of the policies. Existing studies have used several approaches to deal with endogenous placement of policies. Assunção et al. (2015) use a measure of the tightness of municipal land constraints, which is defined as the share of land that is not legally available to farmers relative to total municipal land, in order to identify the effect of policies across municipalities. Their approach is based on the argument that policies are effective in places where land constraints for agricultural production are tight. Assunção et al. (2017) argue that satellite-based enforcement contributed to reductions in deforestation rates and use cloud cover as an instrument. Assunção et al. (2019) use a 2008-change in access to rural credit lines conditional on farmers' environmental compliance in order to show that this policy reduced deforestation rates in municipalities where cattle ranching is a dominant economic activity.

exposure. Section 5 investigates the impact of soy prices versus the prices of other crops under the Soy Moratorium. Section 6 presents robustness checks. Section 7 presents estimates for crop production value and carbon loss and a stylized cost-benefit analysis. Section 8 concludes.

## 2 Background: Key anti-deforestation policies in the Brazilian Legal Amazon

Our starting point is that agricultural profits are a major driver of deforestation.<sup>8</sup> Since 2004, Brazil has implemented a set of command-and-control policies to avoid the high deforestation rates it experienced in the 1990s and early 2000s, which to a large extent were related to expansion of commercial agriculture. Deforestation on private lands is governed by the Forest Code (FC), which establishes a percentage of rural properties that need to be preserved in the form of native vegetation. In the Brazilian Legal Amazon, this fraction has been 80 percent since 2001 (Soares-Filho et al., 2014). In 2004, the National Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) was first launched. The plan set out new procedures for monitoring and environmental control. The first phase covered 2004-2008, the second phase 2009-2011 and the third phase 2012-2015. Arima et al. (2014); Assunção et al. (2015) and others have recognized a significant role of the different policies in reducing deforestation.

**Blacklisting/priority municipalities policy (PM)** was the main component of the second phase of the PPCDAm, launched in 2008. The policy defined a list of 36 municipalities to be prioritized in monitoring and law enforcement due to their high deforestation rates. The priority municipalities were subject to more intense environmental monitoring and enforcement as well as to a number of other administrative measures, such as more stringent conditions applied to the approval of subsidized credit. These measures have increased forest conversion costs and thus reduced incentives to deforest.<sup>9</sup> This group of municipalities accounted for 45%

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<sup>8</sup>But commodity prices may carry not only information about current land use opportunities (forest vs pasture) and manifest through changes in *current* agricultural profits, but also through *expected revenues* from future land uses. The latter effect manifests itself through a speculative component of the value of the land. In this paper, we do not differentiate between the effects on deforestation caused by either current or future land opportunities.

<sup>9</sup>In addition to a more stringent system of monitoring and law enforcement, they also became subject to a series of other measures, not officially established through legislation, such as compromised political reputation of



of the deforestation in the Brazilian Amazon in the year before the policy was implemented. More municipalities were added to the list later. During 2011-2013, eleven municipalities were allowed to leave the list due to a remarkable decline in deforestation. In the data section below we describe in more detail the variation in our sample.

**The Soy Moratorium (SM)** reflects intensive campaigning by nongovernmental actors and private sector’s willingness to adopt sustainable land-use practices. Soy has been Brazil’s most profitable crop, with most of it going to exports; 33% in 1996 to 69% in 2004 and to 75% in 2013 ([Karstensen et al., 2013](#); [Lawson, 2014](#)). A rapid expansion of soybean plantations on forested lands combined with the strong link to downstream markets in the EU and North America raised international awareness and increased the pressure on soybean producers to reduce deforestation. This led to the announcement of the Soy Moratorium in 2006. Buyers who joined the Soy Moratorium banned the purchase of soybeans planted on farmlands cleared after June 2006. The SM was extended to remain in place indefinitely in May 2016. The Soy Moratorium increases the costs of producing soy on newly deforested lands and thus increases the relative attractiveness of alternative uses of deforested lands, which can lead to substitution from soy to other crops.

**Conservation zones (CZ)** expanded significantly in the Brazilian Legal Amazon in the early 2000s, especially during the first phase of PPCDAm. The areas that we name “conservation zones” in this paper include three types of protected areas: strictly protected areas (SP), sustainable use zones (SU), and indigenous lands (IL).<sup>10</sup> The policy of conservation zones takes away land from the potential land supply, and is thus expected to increase the value of, and the deforestation pressure on, the remaining unprotected areas.

**CAR** The government has made significant progress towards increasing enforcement of the Forest Code (FC) through mapping properties for environmental registration, first with a num-

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mayors ([Abman, 2014](#)), politicians pressuring farmers to comply with environmental legislation. Priority status is determined based on: (a) total deforested area; (b) total deforested area over the past three years; and (c) increase in the deforestation rate in at least three of the past five years. The upper map on the right-hand side of figure 1 shows that these municipalities are mainly located in the southern part of the Amazon region, along the arc of deforestation.

<sup>10</sup>In SP: harvesting of trees or settlements are prohibited completely. In SU zones, extraction of forest resources as well as logging are permitted subject to a sustainable management standard [Verissimo et al. \(2011\)](#). IL are federal territories which are in the permanent possession of indigenous populations, who have exclusive rights to use the natural resources.



ber of state-level systems in the Amazon, and more recently with a national “SiCAR” system.<sup>11</sup> The national system was finalized and became operational after 2013, when our sample period ends. However, CAR systems have been used in the zero-deforestation cattle agreements (Gibbs et al., 2016) and the Brazilian Central Bank’s (BCB) rural credit policy, mentioned below (Assunção et al., 2019). Two states, Mato Grosso and Pará, had the most developed state-level property registration systems preceding the SiCAR (INPE, 2015). To make sure that our results are not affected by factors correlated with the property registration, we take into account the area of properties registered in CAR in robustness checks.

**Credit** In February 2008, the Brazilian Central Bank published Resolution 3545, which conditioned the concession of rural credit for agricultural activities in the Amazon biome upon proof of borrowers’ compliance with legal titling requirements and environmental regulation. Resolution 3545 applied to all rural establishments within the Amazon biome. It was obligatory for all banks and credit cooperatives to implement the terms of the resolution as of July 1st, 2008. As 30% of the resources required to fund a typical harvest year in Brazil come from the rural credit, Resolution 3545 represented a potentially limiting mechanism for agricultural production in Brazil. Estimates by Assunção et al. (2019) indicate that the total observed deforested area from 2009 through 2011 was about 60% smaller than it would have been in the absence of credit restrictions. We thus control for credit in robustness checks.

**Fines** The real-time System for Detection of Deforestation (DETER), developed by the National Institute for Space Research (INPE), has been Central to the PPCDAm’s law enforcement. DETER is a satellite-based system that captures and processes georeferenced imagery on forest cover in 15-day intervals. This allows authorities to identify deforestation hot spots and enforce the law with a much shorter lag. In addition to the adoption of DETER, the PPCDAm promoted institutional changes that enhanced the monitoring and law enforcement capacity in the Amazon, e.g., through more and better qualified law enforcement personnel. Assunção et al. (2017) use the total number of fines issued by Ibama, the Brazilian regulator, in each municipality as a proxy for the intensity of law enforcement activity. They estimate that deforestation observed from 2007 through 2011 was 75% lower than it would have been in the

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<sup>11</sup>Sistema Nacional de Cadastro Ambiental Rural, SiCAR 2016.

absence of the fines. We control for fines in robustness checks.

### 3 Empirical Approach

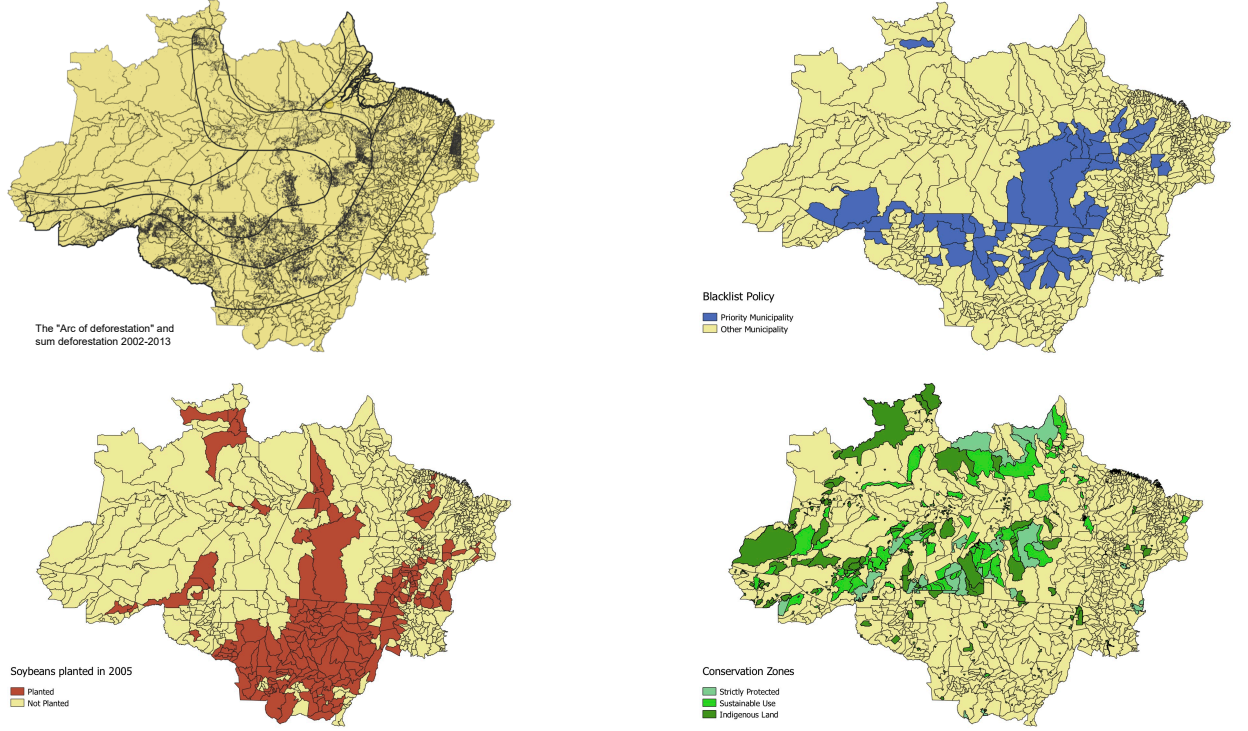
#### 3.1 Data

Our initial data set is a balanced panel of 771 municipalities in the Legal Brazilian Amazon from 2002 until 2013. We drop municipalities that on average have zero deforestation, zero remaining forest or a price index equal to zero. In addition, we drop municipalities with average forest cover below the 1st percentile and above 99th percentile. In our baseline sample, we focus on municipalities located within the forest frontier, the “arc of deforestation,” which are to a large extent located along the transition from the Amazon to the Cerrado (tropical savanna) biomes (Levy et al., 2018). Historically, the deforestation in Brazil started in the south east and has swung in the north-western direction over time. The smooth lines in the upper left map of Figure 1 show the “arc of deforestation”, which includes three areas based on different historical periods of deforestation. We include all municipalities that have some area that falls within either of the three areas. We end up with a balanced panel of 470 municipalities covering 11 years (2003-2013, with lagged variables for 2002-2012). For a complete overview of data sources and the relevant variables used in this paper, see tables A.1 - A.20. Below, we provide more information on the most central variables.

**Forest data** For annual data on deforestation and forest cover we use data based on NASA satellite images and processed by the Brazilian Space Research Agency, *Instituto Nacional de Pesquisas Espaciais (INPE)*. This processing includes filtering out forest plantations and the data provide the loss of primary forest. We have aggregated the high-resolution forest data (at 250m x 250m) to 1  $km^2$  grid cells covering the entire Brazilian Legal Amazon (BLA). For each municipality, we consider the sum of cells outside of conversation zones, the sum of cells inside of conversation zones, and the sum of cells both inside and outside of conversation zones. In our main analyses, we focus on areas outside of conversation zones. We measure deforestation and forest cover in  $km^2$ . The black dots in the upper left map of Figure 1 indicate the sum of deforestation over 2002-2013 at the 1  $km^2$  resolution. The upper left panel of Figure 2 presents the sum of deforestation over time in our sample and in the “entire” BLA, i.e. including also

municipalities outside of the forest frontier.

*Figure 1: Policy and Deforestation Maps*



Note: Maps show, clockwise from the upper left: 1) the forest frontier together with accumulated deforestation over 2002-2013; 2) the municipalities on the priority list; 3) municipalities exposed to the Soy Moratorium as they planted soy in 2005; and 4) the three types of protected lands included in this paper’s “conservation zones”.

**Carbon data** We use biomass data from [Baccini et al. \(2017\)](#) and obtain the carbon stock in the year 2000 at the 1 km<sup>2</sup> grid-cell level ( $C_{2000}$ ). For each grid cell, we calculate the carbon stock in year  $t$  as the remaining forest,  $F_t$ , times the carbon density of the forest in that grid cell in year 2000:  $C_t = F_t * C_{2000} / F_{2000}$ . Analogously, we calculate the carbon flow as deforestation,  $DF$ , times the carbon density in year 2000:  $DC_t = DF_t * C_{2000} / F_{2000}$ . We recalculate the carbon to CO<sub>2</sub>, i.e. multiply the carbon figures by 44/12. We thus assume, for simplicity, that all the carbon in the cleared forest is turned into omitted CO<sub>2</sub>, which is unrealistically high as, for example, some forest may be used as building materials. The upper right panel of Figure

2 presents the loss of CO<sub>2</sub> over time in the two samples. To further simplify the cost-benefit analysis, we value the CO<sub>2</sub> to 50 USD per tonne (2020-prices), which is a simple and seemingly not unreasonable estimate for the social cost of carbon in 2020 (see for example [Howard and Sylvan \(2015\)](#)). Based on the carbon stocks in the year 2000 and the total area of the included 1 km<sup>2</sup> cells, the lower panels of Figure 2 present the distributions of mean CO<sub>2</sub> values per hectare across municipalities in the two samples, outside and inside of conservation zones.

In the cost-benefit analysis, we also add a estimate for sequestration, i.e. the trees could have absorbed carbon continuously if they were kept standing. If the forest were allowed to grow back instead of the area being turned into non-forest permanently, however, regrowth of new forest could mean higher absorption of carbon than the previous forest. In our context, this is likely to be rare as we focus on the effect of agricultural commodity prices on deforestation. [Hubau et al. \(2020\)](#) estimate that “intact old-growth tropical forests” in Amazonia sinks about 0.4 ton Carbon per hectare per year, which corresponds to about 1.5 tonnes or USD 75 of CO<sub>2</sub> per hectare forest. This corresponds to a bit more than 0.5% of the value of the carbon stock per hectare of total land in our data.<sup>12</sup> Standing forests provide benefits beyond carbon capture and storage, e.g., biodiversity, that we do not pick up with our stylized carbon valuation.

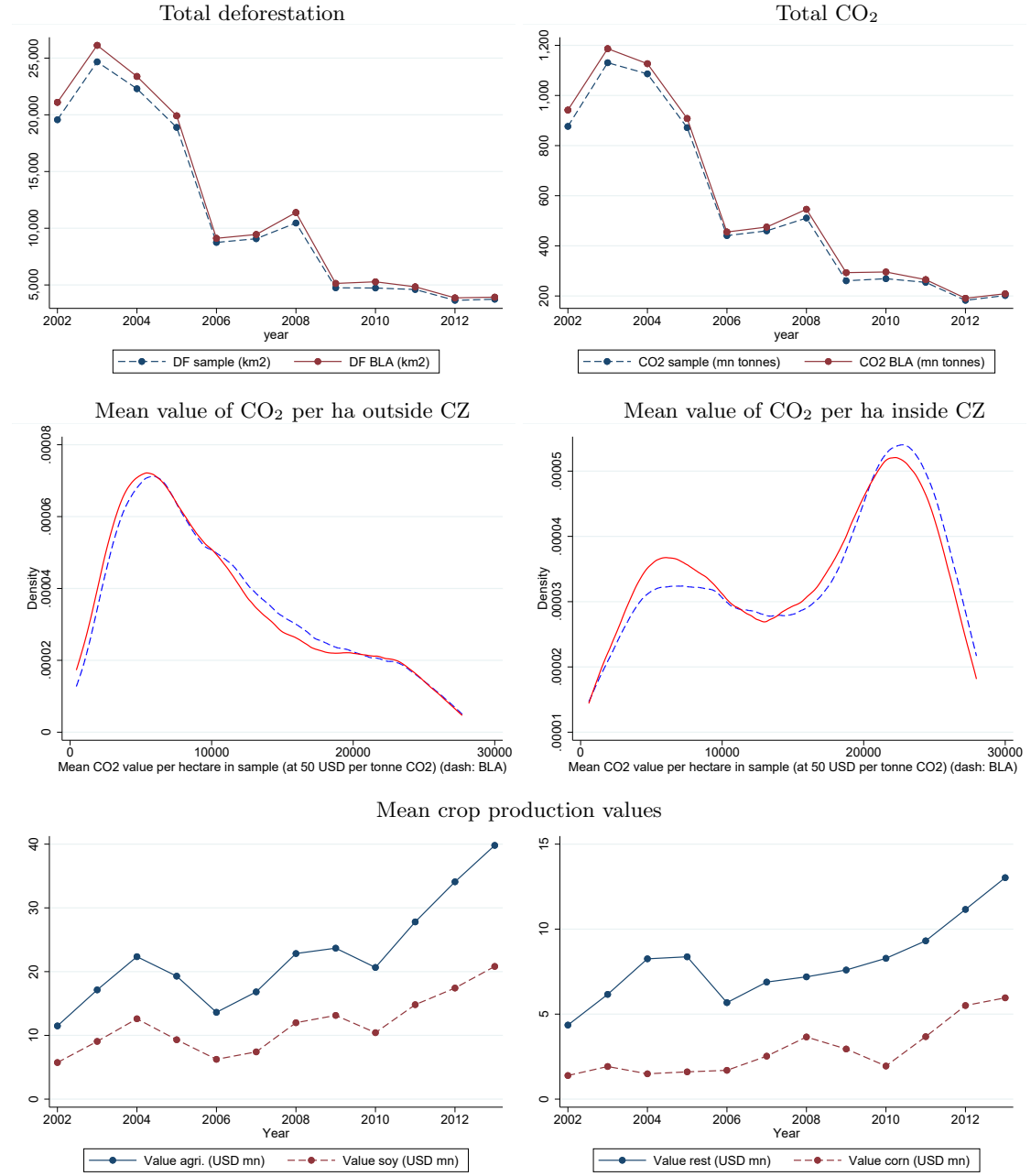
**Data on production values in agriculture** IBGE provides data on annual production value for each crop at the municipality-level. We deflate with the deflator used by the World Bank in their Pink Sheet, i.e. the same deflator that is used to deflate our agricultural commodity prices. We recalculate such that the figures are in 2020-USD. Clearly, there may be other economic benefits related to expanding the agricultural sector that are not captured by crop production values. We also ignore the sales of timber.

**Priority municipalities** The Brazilian Department of the Environment, *Ministério do Meio Ambiente*, MMA, publishes the list of municipalities with a “priority” status, including the date they entered the list. The upper right part of figure 1 shows the listed municipalities. In our sample, a total of 50 municipalities were blacklisted. 33 got on the list in 2008, 8 in 2009, 7 in 2011 and 2 in 2012. None of the municipalities in our sample got off the list during the period

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<sup>12</sup>Clearing a hectare of forest thus corresponds to the removal of a present value of about 750 USD per hectare in terms of lost carbon sequestration at a discount rate of 10%: 75/0.10. In effect, our assumption is about the difference between the forest sequestration and the sequestration of the cleared land. [Naclér and Enkvist \(2009\)](#) cites research suggesting that “biodiverse forests sequester more carbon than their monoculture equivalents”.

Figure 2: Deforestation, CO<sub>2</sub> and crop production values



Note: Upper panels: Total deforestation and lost CO<sub>2</sub> in our baseline sample (forest frontier) and in the wider Brazilian Legal Amazon (BLA). Middle panels: The mean value of CO<sub>2</sub> per hectare (of land) per municipality, based on carbon stock data in year 2000 at the 1 km<sup>2</sup> grid level: left panel is based on cells located outside of conservation zones in 2013 and right panel is based on conservation zones located inside of conservation zones in 2013. 1 tonne of carbon equals  $44/12 = 3.67$  tonnes of CO<sub>2</sub>. We set the value of a tonne of CO<sub>2</sub> to 50 USD. There are 100 hectares in 1 km<sup>2</sup>. The carbon data are based on [Baccini et al. \(2017\)](#). Lower panels: mean per municipality in the sample of the value of crop production (agri. refers to the ten crops included in this study). Values are measured in millions 2020 USD and deflated with the same deflator as the World Bank uses to go from nominal to real commodity prices ([Pink Sheet, World Bank](#)).

we study. The weighted mean length on the list is 5.5 years in our sample. For the empirical analysis, we generate an “Active” dummy (denoted  $A$ ) taking one for the years a municipality was on the list and an “Ever” dummy (denoted  $E$ ) indicating whether a municipality was blacklisted at any point in time during the sample period.

**Soy Moratorium** We classify the treatment group as those municipalities that produced soybeans in 2005, the year before the Soy Moratorium started. Data on the planted area and production volume of soy are published in the municipal agricultural report *Produção Agrícola Municipal* from IBGE (2017). The lower left part of figure 1 maps the 190 municipalities in the entire Brazilian Legal Amazon that planted soy in 2005 according to the IBGE data. For reference, 201 municipalities planted soy in 2013. In our sample, the IBGE data suggest that 147 municipalities planted soy in 2005. We now define the “Ever” variable  $E$  as the log of the area in  $\text{km}^2$  allocated to soy in 2005. The “Active” dummy  $A$  is now simply one for all years after 2005.

**Conservation zones** Data on implementation dates and locations of protected areas were obtained from the Brazilian Ministry of Environment MMA (2017). There are 258 protected areas implemented between 2003 and 2014: 48 strictly protected zones, 92 sustainable use zones and 118 indigenous lands. The lower right part of figure 1 illustrates how they are distributed over the Brazilian Legal Amazon. In our sample, there were 5 municipalities with at least one of the three types of protected areas in 2003, covering in total between 2.6% and 10.6% of the municipality areas. In 2013, 136 municipalities had such conservation zones, covering between 0.4% and 73.4% of the municipality areas. 0.25% of the 3.2 million  $\text{km}^2$  covered by our sample of 486 municipalities were covered by one of the three types of protected areas that we consider as conservation zones in 2003. In 2013, this number had increased to 17.2%. For the empirical estimation, the variable  $A$  is the log of the area in  $\text{km}^2$  located in a conservation zone in a municipality. The dummy variable  $E$  takes one if the municipality expanded the area covered by conservation zones in the sample period.

**International prices** We obtain international crop prices from the World Bank. Data on the land allocated to each crop in a municipality are provided by an annual survey of agricultural production across all Brazilian municipalities from the IBGE. In our price index, we include ten

internationally traded crops: banana, coffee, groundnut, maize, orange, rice, sorghum, soybean, sugar cane, and wheat. Together they account for over 80% of the agricultural area in the Amazon region.<sup>13</sup> Soy occupies the most crop-planted area in the Amazon. The area planted with soy increased from 41,965  $km^2$  in 2002 to 66,976  $km^2$  in 2006. It further increased to 93,504  $km^2$  in 2013, which corresponds to about 53% of all crop fields in the region. Corn, the second largest crop, increased its share from around 16% in 2002 to over 25% in 2013. Sugar cane is another important monocultural crop that is mainly produced in the south of Brazil, but is also increasingly being planted on recently deforested land in the legal Amazon (Martinelli and Filoso, 2008).

We construct our municipality-specific price index as follows:

$$P_{a,it} = \sum_j w_{ij,2002} P_{jt}, \quad w_{ij,2002} = \frac{area_{ij,2002}}{\sum_j area_{ij,2002}} \quad (1)$$

where  $P_{jt}$  is the international price measured in current \$US of crop  $j$  at time  $t$ , normalized to 1 in year 2000. The weights  $w_{ij,2002}$  are calculated based on the size of the planted area of crop  $j$  in municipality  $i$  in 2002, the initial year in our sample. We use these predetermined weights to avoid that the price index itself is affected by the farmers' behavior during the period we study. The weights sum to one. When we use the soy, non-soy and corn prices separately in the context of the Soy Moratorium, we apply Equation 1 with weights based on 2005, the year before the introduction of the Soy Moratorium. As the weights are then for a subset of crops, they do not sum to one. We provide robustness checks with alternative weights, as described in section 6. Figure 3 presents the price indexes we use.

**Controls.** We account for: (i) rural credit policy, by including the normalized total value of credit concessions in a given municipality in a given year; (ii) for overall level of stringency of monitoring and law enforcement, by using the log of the annual number of environmental fines applied at the municipality level in the previous year.<sup>14</sup> In addition, we perform a large number of robustness checks in section 6, where we also run robustness with respect to the CAR policy.

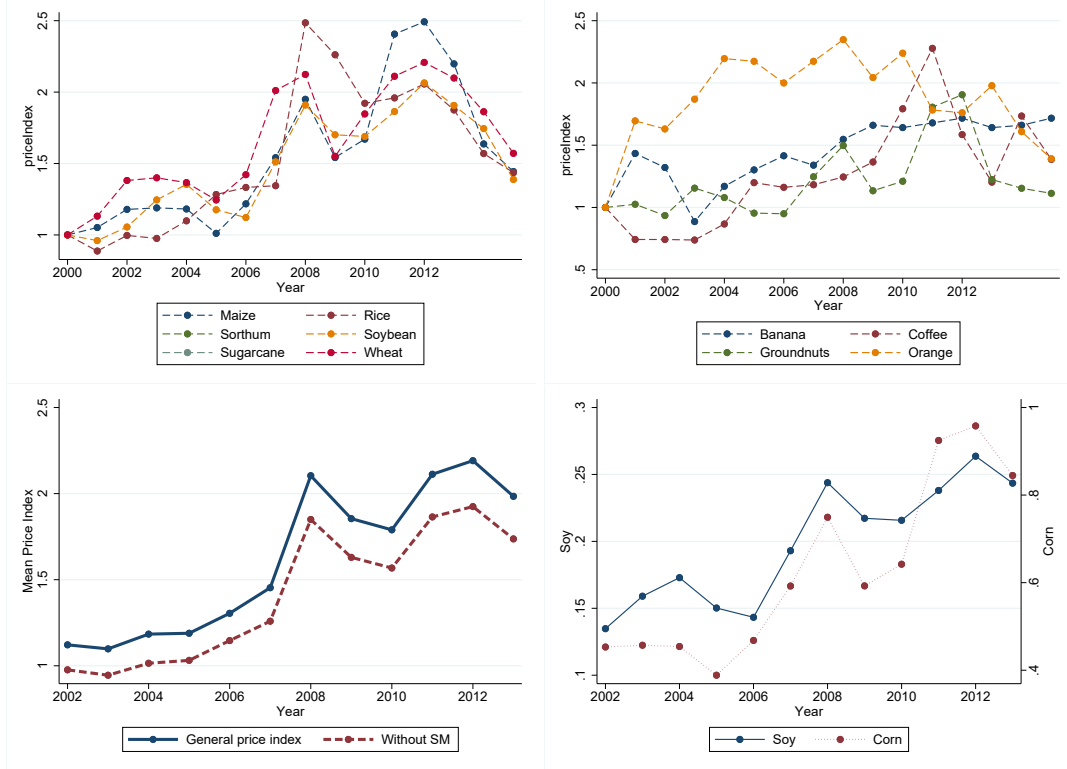
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<sup>13</sup>The most frequently (but not most extensively) planted crop in the Amazon, which is not part of our price index, is cassava. Cassava plantation accounted for less than 4% of the agricultural area in 2013. We exclude cassava since it is not an export crop, but mainly planted for own consumption or the domestic market.

<sup>14</sup>We are very grateful to Juliano Assunção, Clarissa Gandour, Romero Rocha and Rudi Rocha for sharing with us their data on rural credit and fines.



Figure 3: Price Indexes



Note: Upper charts present indexes of the real international agricultural prices, which we combine with municipality weights based on cultivated area in 2002 to construct municipality specific price indexes. Lower left chart shows the average of the general price index across municipalities, with and without soy. Lower right chart presents the mean of the municipality specific price indexes for soy and corn separately.

### 3.2 Identification strategy

In our empirical strategy we proceed in three steps. First, we estimate the effect of agricultural commodity prices on deforestation. Commodity prices have been used in the literature on conflict (Dube and Vargas, 2013; Bazzi and Blattman, 2014) and in the literature on the Dutch disease (Harding and Venables, 2016; Cust et al., 2019). To identify the direct effect of agriculture commodity prices on deforestation, we estimate various forms of the following equation:

$$DF_{it} = \beta_1 P_{a,it-1} + I_t + I_i + \epsilon_{it} \quad (2)$$

where  $DF_{it}$  denotes the log of the sum of deforestation in municipality  $i$  in year  $t$  (August  $t-1$  to August  $t$ ).  $P_{a,it-1}$  is the log of the municipality-specific price index, with area allocated to the different crops in 2002 as the weights (see section 2).  $I_i$  and  $I_t$  refer to municipality and

year fixed effects. The coefficient of interest,  $\beta_1$ , is identified to the extent the error-term  $\epsilon_{it}$  is uncorrelated with  $P_{a,it-1}$ , which is plausible given the pre-determined weights and international prices. Standard errors are clustered at the municipality level.

Second, we estimate how policies aimed at reducing deforestation affect the deforestation's response to international commodity prices. We expand equation 2 with the policy exposure at the municipality level. This amounts to estimating a triple differences model (DDD). Formally, we estimate DDD-models of the following form:

$$DF_{it} = \beta_1 P_{a,it-1} + \beta_2 P_{a,it-1} \times E_i \times A_{it} + \beta_3 P_{a,it-1} \times E_i^{dum} + P_{a,it-1} \times I_t \beta_4 + \beta_5 P_{a,it-1} \times F_{it-1} \\ + \gamma_1 F_{it-1} + \lambda_1 E_i \times A_{it} + E_i^{dum} \times I_t \lambda_2 + I_t + I_i + \epsilon_{it} \quad (3)$$

The main parameter of interest is  $\beta_2$  (the triple difference estimate), indicating how the price-effect depends on the presence of the policy. In general,  $E_i^{dum}$  indicates whether the municipality is ever directly exposed to the policy. For simplicity, we define it as a dummy for all three policies. It takes one if the municipality is ever on the blacklist, the area devoted to soybeans in the year before the Soy Moratorium is larger than zero,<sup>15</sup> or there is an expansion of protected areas in our sample period.

$E_i \times A_{it}$  is the policy treatment variable. For the blacklisting policy, it takes one if a municipality is on the blacklist in a given year and zero otherwise. For the soy moratorium, the policy treatment variable takes zero for the years before 2006 and then switches to the area devoted to soy production in the year before the moratorium was introduced. For the conservation zones, the policy treatment variable is the area allocated to conservation zones in any given year.

We include the interaction between the price and the ever dummy,  $E_i$ , allowing for a different price effect across the control and treated municipalities in all years. A full DDD-model requires the price to be interacted with the post dummy. We use instead the more flexible specification of interaction between the price and the year dummies, to allow for a differential price effect across all municipalities over time.<sup>16</sup> We include interactions between the ever dummy and the year

<sup>15</sup>In Table A.8, we use the log area soy planted in 2005 instead of treatment group dummy for the SM.

<sup>16</sup>Note that we present the direct price effect too,  $\beta_1$ , as one of the interactions with the year dummies is

dummies, to flexibly allow for different trends between the treatment and control groups. Note that the policy treatment variable  $E_i \times A_{it}$  is not collinear with these time-dummy interactions for the respective reasons: municipalities were put on the blacklist at different times; the area devoted to soy varies across municipalities; and the size and the timing of the conservation zones varies across municipalities. Finally, we include log of lagged forest cover,  $F_{it-1}$ , and its interaction with the price index.

To keep the model tractable, we estimate equation 3 separately for each policy. We discuss threats to identification in section 6, where we show robustness to a host of controls and policies.

### 3.3 Testing for pre-trends

Table 1: Testing for Pre-trends

	(1)	(2)	(3)	(4)	(5)	(6)
	PM DD	SM DD	CZ DD	PM DDD	SM DDD	CZ DDD
TreatGr=1 $\times$ Trend	-0.065* (0.038)	0.094* (0.054)	-0.124** (0.056)	-0.129 (0.091)	-0.053 (0.108)	-0.116 (0.111)
TreatGr=1 $\times$ L.Price				2.670 (1.859)	-4.198 (2.556)	-1.030 (2.100)
TreatGr=1 $\times$ Trend $\times$ L.Price				-0.147 (0.398)	1.039 (0.680)	0.387 (0.620)
Trend $\times$ L.Price				-0.194 (0.145)	-2.737*** (0.376)	-2.597*** (0.489)
L.Price				1.870*** (0.586)	8.700*** (1.289)	8.030*** (1.633)
Observations	2350	1410	1410	2350	1410	1410
Municipalities	470	470	470	470	470	470
R-sq	0.27	0.03	0.03	0.28	0.10	0.10

Note: The dependent variable is log of deforestation in a municipality in the years before the policy was implemented. DD indicates difference-in-difference versus DDD indicates triple differences, where the price variable represent the third difference. *Trend* is a trend variable, defined as Year-2001. *TreatGr* indicates if a municipality is in the control or treatment group. Years included are 2002-2005, as the Soy Moratorium was introduced in 2006. Regressions includes municipality and year fixed effects. In column 1-2, the assessed policy is the blacklisting policy (2002-2007), in column 3-4 it is the Soy Moratorium (2002-2005) and in column 5-6 it is the conservation zones (2002-2005). We take 2006 as the treatment year for conservation zones since it was the year with the highest expansion in protected areas, see figure ???. Includes municipality and year fixed effects. Standard errors are in parenthesis and clustered at the municipality level.

In table 1, we formally test for the identifying assumption of parallel counterfactual trends. We use the years before the policies were implemented, following Muralidharan and Prakash (2017). The dependent variable is log deforestation and parallel trends thus imply similar

dropped. Note that  $\beta_4$  and  $\lambda_2$  are vectors of coefficients.

growth rates. As indicated by the first row in columns 1-3, we can reject parallel trends for the policies in a DD-specification, i.e. when we compare only across the control and treatment group. Bringing in the agriculture commodity prices in columns 4-6, however, we cannot reject common trends as seen by the triple interaction term in row 3.

In Tables A.5, A.6 and A.7 we present pre-trend tests for 12 covariates. The coefficient on the triple interaction term is statistically insignificant in all cases, with the following few exceptions: the size of the area used for agriculture for the priority list policy; agriculture productivity and remaining forest for the conservation zones; and one or more credit measure for all three policies. However, we show in section 6 that our results are robust when we include any of these characteristics as controls. We also include pre-trend tests for the land shares for soy, corn and the rest, of which we use the 2002-values for the weights in the price index. We estimate insignificant coefficients on the triple interaction term in eight out of the nine cases.

## 4 Agricultural Commodity Prices and Policy Impact

Table 2 presents versions of equation 2, which confirm that higher agriculture commodity prices exert higher pressure on the forest. Column 1 simply includes municipality and year fixed effects in addition to the municipality specific price index. Column 2 adds time trend interaction with the price and column 3 adds time fixed effects interaction, lagged forest cover and interaction between the price and the lagged forest cover. The results show that a one percent increase in the price index increases deforestation by 0.47 percent. As the level of the price index over 2004-2013 was on average 56% higher than in 2003, this estimate implies that the annual deforestation was on average 23% higher than it would have been with the 2003-prices. The higher prices led to about 3.7 km<sup>2</sup> higher annual deforestation per municipality on average, corresponding to a total of about 17,000 km<sup>2</sup> across the 486 municipalities over the 10 years (see Table A.4).<sup>17</sup> The upper left panel of Figure 4 presents the estimated relationships between percentage increases in the price index and percentage increases in deforestation, with the observed price increase of 56% indicated with the vertical dashed line.<sup>18</sup>

<sup>17</sup>To compute the overall level of deforestation, we multiply the average reduction in deforestation due to the higher prices ( $\Delta Y_{cf}$ ) with the total number of treated municipalities over the period of the policy ( $N$ ).

<sup>18</sup>In their global study, Busch and Engelmann (2017) find similar price elasticities as we do: “We estimated that every additional US\$ 100 ha  $yr^{-1}$  in potential agricultural revenue increased the rate of deforestation by an average of 0.98% in Latin America, 1.60% in Africa, and 2.42% in Asia, controlling for other factors – a variation of 2.5 across continents. Average potential agricultural revenues were \$ 2978 ha  $yr^{-1}$ , \$ 2304 ha  $yr^{-1}$ ,

Table 2: Baseline Results Prices and Policies

	Prices only		
	(1) Price	(2) Price	(3) Price
L.Price	0.491*** (0.190)	0.654 (0.469)	4.222*** (0.553)
L.Forest cover			2.382*** (0.147)
L.Forest cover $\times$ L.Price			-0.305*** (0.020)
Observations	5170	5170	5170
Municipalities	470	470	470
R-sq	0.41	0.41	0.48
I $\times$ P			Yes
<b>Total price effect</b>			
dydx(P)	0.49	0.49	0.47
p-value	0.01	0.01	0.01

Note: The dependent variable is log deforestation. The price index is calculated by Equation 1 and included in the log-form. All area sizes used for the price-weights are measured at the municipality level for the year 2002, the initial year in our sample. Models are versions of Equation 2, where column 2 includes trend and trend interacted with the price and column 3 includes interactions between year dummies and the price. All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The bottom rows give the price effects, with and without the policy for the treated when relevant. The p-values are from an hypothesis test where H0 is that the effect listed above is zero. The marginal effects and the p-values are calculated with the margins package in stata.

Our main question is whether the priority municipality list (PM), the Soy Moratorium (SM), and conservation zones (CZ) reduce the pressure of higher commodity prices on deforestation. Table 3 presents our baseline estimates: Columns 4-6, based on Equation 3.<sup>19</sup> Columns 1-3 correspond to the DDD-specification in the pre-trend test Table 1 and are included for completeness. The main parameter of interest is the triple-difference estimate (captured by variable  $TreatGr \times Active \times L.Price$ ). We present the total price effect with and without the policy in the two bottom rows of the table, together with the difference between them and the p-value for the hypothesis test that this difference is equal to zero. Figure 4 shows the total price effects with and without the policies and illustrate the main point of this paper: the effect of the regulatory policies depends critically on the underlying deforestation pressure.

and \$ 3278 ha  $yr^{-1}$  on each continent respectively, implying a price elasticity of supply of deforestation of 0.29, 0.37, and 0.79 for each continent respectively. Brazil's restrictive policies had the effect of reducing post-2004 deforestation by 47% for a grid-cell with average characteristics, due in part to decoupling potential agricultural revenue from deforestation."

<sup>19</sup>The price effect is stronger in municipalities with lower levels of remaining forests, as shown in column 3. Such heterogeneity is not surprising given that our sample covers 486 municipalities and about 3.2 million square km.

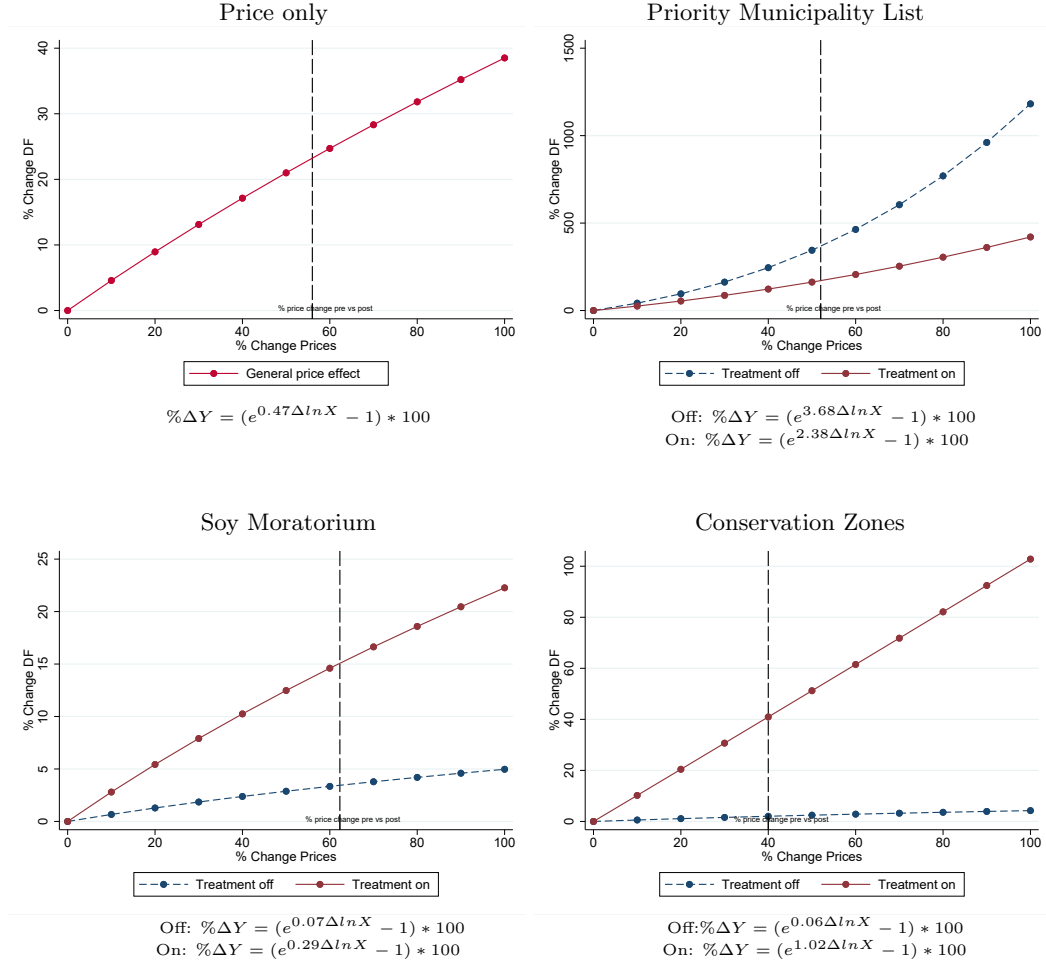
Table 3: Baseline Results Prices and Policies

	Policies (trend)			Policies (eq. 3)		
	(1) PM	(2) SM	(3) CZ	(4) PM	(5) SM	(6) CZ
TreatGr x Active x L.Price	-1.473** (0.574)	-0.154*** (0.037)	0.088** (0.038)	-1.301** (0.595)	0.027 (0.036)	0.168*** (0.031)
L.Forest cover				2.335*** (0.145)	2.578*** (0.155)	2.249*** (0.149)
L.Forest cover x L.Price				-0.286*** (0.022)	-0.285*** (0.020)	-0.376*** (0.022)
Observations	5170	5170	5170	5170	5170	5170
Municipalities	470	470	470	470	470	470
R-sq	0.42	0.44	0.41	0.49	0.52	0.50
I x P				Yes	Yes	Yes
<b>Total price effects, policy off/on</b>						
dydx(P) policy off	0.74	0.80	0.16	3.68	0.07	0.06
p-value	0.12	0.02	0.56	0.00	0.85	0.84
dydx(P) policy on	-0.73	-0.06	0.67	2.38	0.29	1.02
p-value	0.15	0.81	0.00	0.01	0.40	0.00
<b>Difference in total price effect</b>						
Difference	-1.47	-0.86	0.50	-1.30	0.22	0.96
p-value	0.01	0.00	0.02	0.03	0.45	0.00

Note: The dependent variable is log deforestation. The price index is calculated by Equation 1 and included in the log-form. All area sizes used for the price-weights are measured at the municipality level for the year 2002, the initial year in our sample. Columns include policies as indicated in the column headings. *Ever* and *Active* is defined according to the policy type as described in section 3. Columns 1-3 include time trends interacted with the price index as well as with the ever-treated dummy. Columns 4-6 are based on Equation 3 and include interactions between the price and year dummies and interactions between the ever-treated dummy and year dummies. All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The bottom rows give the price effects, with and without the policy for the treated when relevant. The p-values are from an hypothesis test where H0 is that the effect listed above is zero. The marginal effects and the p-values are calculated with the margins package in stata.

Comparing the effect of agriculture commodity prices on deforestation with and without the policies, as listed in the bottom rows in Table 3, we find that the priority list reduces the effect by about 1.3 percentage points (3.68 – 2.38). The effect is statistically significant. The price increase of 52% from the pre-policy period 2003-2007 to the post policy period 2008-2013 would have led to a 328% increase in deforestation in the treatment group in absence of the policy. With the policy in place, the price increase leads instead to a 149% increase in deforestation. Using the actual observed deforestation for the municipalities in the treatment group over the period 2008-2013, the priority list saved 39 km<sup>2</sup> of forest in every treated municipality on average per year, which sums up to 10,177 km<sup>2</sup> overall (see Table A.4 for the details of

Figure 4: Deforestation under different prices and treatments



Note: The figure illustrates the relative annual deforestation changes ( $Y$ ) at different relative price changes ( $X$ ). The estimates are based on columns 3 in Table 2 and 4-6 in Table 3 and the graphs are based on the formulas shown below each chart. For the three policy-charts, the difference between the two lines is the treatment effect on the treated. Vertical lines indicate the actual average price changes observed for the treated municipalities between the pre-treatment period and the treatment period.

these calculations). The upper right chart of Figure 4 illustrates how the policy contributes to avoiding large increases in deforestation when the price growth is high.

The Soy Moratorium does not have a statistically significant effect on how commodity prices affect deforestation, and the sign of the estimated coefficient actually suggests that the Soy Moratorium raised the deforestation pressure. This can also be seen in the lower left chart of Figure 4. We further explore the effects of the Soy Moratorium for the soy price, non-soy prices and the corn price in section 5.

Conservation zones amplify the price effect, which can be seen in the lower right chart of Figure 4. For illustration, we use the average price in the pre-policy years and the average price



in the post policy years, i.e. 1.31 and 1.83, where the pre and post policy years vary at the municipality level. Due to this 40% increase in the price index, expansion of zones increased annual deforestation outside of zones by  $6.1 \text{ km}^2$  per municipality or a total of  $6,039 \text{ km}^2$  (see Table A.4). These results are consistent with zones taking away land from the land supply and hence they increase the pressure on the remaining land. It is also possible that establishing conservation zones increases rivalry for remaining land and thus increases deforestation as a means of taking land into possession.<sup>20</sup>

## 5 Soy Moratorium and Different Crops

An important finding of this paper is that the Soy Moratorium does not reduce the impact of commodity prices on deforestation. This seems to stand in contrast to the influential study by Gibbs et al. (2015), which found that the Soy Moratorium is effective in reducing deforestation. The authors studied the extent to which soy has been cultivated on newly deforested land after the Soy Moratorium was introduced. In this section we show that the Soy Moratorium reduced the responsiveness of deforestation to the soy price, but that this was counteracted by an increased responsiveness to the price of other crops.

In table 4, we present estimates of our triple difference model, again based on equation 3, for the Soy Moratorium under different commodity price indexes. In column 1 we use a soy price index, in column 2 a price index excluding the soy price and in column 3 a corn price index. The negative and statistically significant coefficient of the triple interaction term in column 1 suggests that the Soy Moratorium significantly reduced deforestation related to the soy price. The magnitude means that the policy reduced annual deforestation by  $2.3 \text{ km}^2$  per treated municipality and by  $2,656 \text{ km}^2$  in total (see Table A.4 for the details).

Column 2, however, indicates that the impact of non-soy prices on deforestation increased significantly in the presence of the Soy Moratorium. The deforested area increased by  $5.1 \text{ km}^2$  annually per municipality and  $5,847 \text{ km}^2$  in total due to higher prices of other crops. As a result, the net increase in deforestation due to the policy is estimated at  $3,191 \text{ km}^2$  (Table A.4).

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<sup>20</sup>As mentioned in section 2, property rights in the Amazon are not well defined or defended. Thus, deforestation is still seen as a practice to obtain land titles which otherwise could be lost through invasion or expropriation Fearnside (2001). For completeness, we present estimates where the dependent variable is the deforestation within conservation zones only (column 6 in Tables A.9-A.11) and deforestation in the entire municipality (column 7 in Tables A.9-A.11). For deforestation inside zones, we do not find any significant reduction in the price effect. The results based on deforestation in the entire municipality are very similar to the baseline results.

Table 4: Soy Moratorium with Different Price Indexes

	SM: Different Prices (eq. 3)		
	(1) Psoy	(2) Pnon-soy	(3) Pcorn
TreatGr x Active x L.Price	-0.055** (0.023)	0.104*** (0.024)	0.017* (0.009)
L.Forest cover	2.629*** (0.630)	2.600*** (0.153)	2.150*** (0.154)
L.Forest cover x L.Price	-0.363*** (0.037)	-0.292*** (0.019)	-0.224*** (0.016)
Observations	1584	5170	5137
Municipalities	144	470	467
R-sq	0.64	0.52	0.50
I x P	Yes	Yes	Yes
<b>Total price effects, policy off/on</b>			
dydx(P) policy off	0.84	-1.13	3.97
p-value	0.19	0.00	0.05
dydx(P) policy on	0.39	-0.28	4.11
p-value	0.54	0.31	0.05
<b>Difference in total price effect</b>			
Difference	-0.45	0.85	0.14
p-value	0.02	0.00	0.05

Note: The dependent variable is log deforestation. The table repeats column 5 of table 3, but with alternative prices: Column 1 is based on the area of soy planted times the soy price. Column 2 is based on the agricultural price index excluding soy, using the area sizes allocated to each crop as weights (following Equation 1). Column 3 is based on the area of corn planted times the corn price. All area sizes used for the price-weights are measured at the municipality level for the year 2005, the year before the soy moratorium was introduced. All the price-variables are included in the log-form. All columns include municipal and year fixed effects. Standard errors are clustered at the municipality level. The bottom rows give the price effects, with and without the policy for the treated when relevant. The p-values are from an hypothesis test where H0 is that the effect listed above is zero. The marginal effects and the p-values are calculated with the margins package in stata.

Corn is a non-soy crop that has experienced remarkable expansion in recent years. While corn was a minor crop in the Brazilian Legal Amazon in 2006, corn production has since then quadrupled and become the second most important crop in the Legal Amazon in terms of export share, after soy (IBGE, 2017). In recent years, soy and corn combined accounted for over 95% of the vegetable exports of the region (SECEX, 2017). Corn has been found to grow under the same climatic and geological conditions as soy, and substitution between soy and corn in the soy producing areas is thus feasible (Jantalia et al., 2007). The Soy Moratorium might therefore have contributed to corn expansions. Our estimates suggest that leakage to corn can account for 20% of the deforestation leakage related to non-soy crops. Specifically, the estimated elasticity of deforestation with respect to the corn price increased by 0.14. This led to 1.0 km<sup>2</sup> higher annual deforestation on average across the treated municipalities and a total of 1,143 km<sup>2</sup> in

our sample (Table A.4).

These results point to a novel form of leakage related to the Soy Moratorium, which to the best of our knowledge has not been documented in the existing literature. The previous studies identify two other forms of leakage associated with this industry-driven initiative. First, extremely high deforestation rates during the preceding years made it possible that over 90% of soybean field extension occurred on land that had been previously cleared between 2006 to 2010 (Macedo et al., 2012). Second, the Soy Moratorium comprises only the Biome of the Legal Amazon, and increasing deforestation rates in the neighbouring Cerrado biome may have been linked to the Soy Moratorium (Gibbs et al., 2010).<sup>21</sup>

## 6 Robustness Checks

In this section, we present robustness checks for the results presented in table 3 and table 4. In Tables A.9-A.14, we control for a large set of omitted variables, check robustness to different samples and to different specifications. As we have more limited coverage for some of the control variables, column 1 in tables A.9 - A.14 presents our baseline model on the limited sample for comparison. We investigate robustness in terms of alternative definitions of the dependent variable and geographic characteristics in Tables ??-A.16.

**Agriculture** The municipalities in our sample differ in terms of how developed their agriculture sector already is, which may affect the pressure to deforest further and the implementation of the policies. In columns 2 and 3 in tables A.9-A.14, we address this by controlling for lagged areas allocated to agriculture and for agricultural productivity. In column 4, we control for population. These controls do not affect the conclusions of this study.

**Other policies** The three policies we focus on in this paper may be correlated with other policy efforts implemented by Brazil, as discussed in section 2. In columns 5-9 in tables A.9-A.14, we control for agricultural credits, given to crop production or cattle production, or the stringency of monitoring and law enforcement measured as the number of fines issued by the environmental police. If anything, our results become stronger with these controls.

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<sup>21</sup>The Brazilian Cerrado is another type of forest biome that covers most of Mato Grosso state. Mato Grosso in turn, is a state in the Southern part of the Amazon region, which hosts most of the large-scale farms and soybean producers.

Furthermore, the three policies that we consider may in certain municipalities overlap with and complement each other. For example, [Abman \(2014\)](#) points out that international beef and soy companies withdraw from buying these commodities from municipalities with priority status, suggesting a channel through which the policy worked that is similar to the Soy Moratorium. Seeking to insulate the effect of the different policies, column 10 in tables [A.9-A.14](#) include the two other policies. Our results remain robust to these specifications.

Finally, column 11 in tables [A.9-A.14](#) presents the results where we include as control variables the area registered in CAR at the municipality level interacted with year dummies. The CAR-variable is based on the CAR-registry as published in 2016 and is time-invariant. The results are very similar to the main results.

**Alternative specification** In our baseline specification, we include the lagged remaining forest and its interaction with the price as control variables. The purpose is to account for heterogeneity related to the potential for deforestation and earlier development. When we exclude these controls in column 12 in tables [A.9-A.14](#), we obtain similar results as for the baseline.

**Sample size** Our baseline sample excludes municipalities outside of the forest frontier, or the so-called arch of deforestation ([Levy et al., 2018](#)). In column 1 in the lower panel of tables [A.9-A.14](#), we show that our baseline results are robust to including the other municipalities in the Brazilian Amazon for which we have the necessary data.

**Could Brazil influence the world market price of soy?** Throughout our study period, Brazil was the second largest soy producer in the world, with a market share of minimum 23.5% in 2002 and maximum of 29.3% in 2013 ([FAO, 2018](#)). The number one producer was the US, with a market share of 36.4% on average. The production of soy in our study area, the Brazilian Amazon, constituted only 34% of the total production of soy in Brazil in 2013. While 60% of the total soy exports of Brazil were destined for Europe in 2002, about 75% of all exports went to China in 2013 ([SECEX, 2017](#)). To deal with the concern that Brazil is large enough to influence the world market price for soy, and hence potentially violating the assumption that the world price is exogenous to events in Brazil, we run robustness checks excluding the municipalities with the largest soy production in the Brazilian Amazon in column 2 in the lower panel of tables

[A.9-A.14](#). In our study period, those municipalities were responsible for up to 35% of the total Brazilian Amazonian soy production. In column 3, we exclude instead the 10% municipalities with the highest deforestation rates. Our results are robust to excluding either of these two types of large actors.

**The Global Forest Change dataset** In our analysis, we use Brazil’s National Space Research Institute’s (INPE) data on deforestation. The Brazilian government uses these data to monitor deforestation in the Brazilian Amazon. [Richards et al. \(2017\)](#) argue that the decision to use these data as a policing tool has incentivized landowners to find other ways to deforest and avoid compliance with Brazil’s official monitoring and enforcement system. They provide evidence of divergence between PRODES and other deforestation indicators after 2008, which implies that INPE’s dataset might overestimate the impacts of the policies on deforestation. In column 6 “Hansen” in Tables [A.9-A.14](#), we therefore use instead the Global Forest Change (GFC) dataset ([Hansen et al., 2013](#)). These data cover the entire municipalities. For comparison, we include estimates for deforestation “In zones” only in column 4 and for the “Entire” municipality in column 5. The “Entire”-column is thus comparable to the “Hansen”-column, and they show qualitatively the same effects as our baseline estimates, with two exceptions. First, the SM is found to increase forest loss related to the general commodity price index when forest loss is measured with the GFC data. Second, and consistent with the first, the SM is found to not reduce the impact of the soy price on forest loss when measured with the GFC data. These two discrepancies are consistent with the observation of [Richards et al. \(2017\)](#) regarding adaptation of different deforestation patterns. However, one caveat is that we do not find similar deviations for PM. Another caveat is that the robustness results for SM with the soy price in general are statistically less robust than our other results. For completeness we note that all coefficients in the column “In zones” across Tables [A.9-A.14](#) are statistically insignificant, which may not be surprising given that the areas within the conservation zones have seen low levels of deforestation.

**Exogenous weights in the price index?** As weights in the municipality specific price indexes, we use the share of agricultural land devoted to each crop. The weights need to balance two concerns. On the one hand, they need to be relevant and reflect the exposure of

each municipality to the international commodity prices. On the other hand, they should be exogenous to unobserved factors determining deforestation and the policies. Our price index thus has similarities with Bartik instruments, which are created by interacting local shares (such as initial industry shares) with a national time-varying variable (such as industry growth rates). [Goldsmith-Pinkham et al. \(2018\)](#) highlight the importance of exogenous local weights for identification in Bartik applications. Throughout this paper, we follow [Bazzi and Blattman \(2014\)](#) and use the land allocations in the initial year, 2002, to make the weights pre-determined.

To scrutinize the relevance of our price index, we use the average share of the crop areas over the entire sample period as weights instead of the weights from the initial year. These weights should better reflect the actual exposure to the international prices, especially if municipalities have seen large expansions or contractions in the area allocated to different crops. The results are presented in column 7 in the lower panel of Tables [A.9-A.11](#). Second, we use weights based on the crop area in 2005 in column 8, the year before the introduction of the SM (note that we for the soy, non-soy and corn prices always use the agricultural areas in 2005 for the weights).

To scrutinize the exogeneity of our price index, we show results for an agricultural price index weighted by potential yields (WPY) in column 9. Out of the 10 crops that we use in our baseline price index, we have the data to do this for 7 crops: Rice, Soybeans, Corn, Sugar cane, Banana, Citrus fruits and Cotton. Potential yields is a measure provided by the FAO GAEZ database, which calculates potential production based on geological and climatic conditions and is available at a pixel level. The data measure PY in kilograms per hectare for a crop in a given location and we constructed the mean PY at the municipality level by statistical zoning in QGIS. To create a sample-wide reference point for crop  $j$ , we calculated the mean PY across all municipalities:  $PY_j = \sum_{i=1}^N PY_{ij}/N$ . We then calculated the relative PY for crop  $j$  in each municipality  $i$ :  $rPY_{ij} = PY_{ij}/PY_j$ .  $rPY_{ij}$  reflects the productivity of the soil in municipality  $i$  in producing crop  $j$ , relative to the average of the Brazilian Amazon. We use  $rPY$  as the weights in the price index, which for municipality  $i$  over all crops  $j$  can be expressed as:  $P_{PY,it} = \sum_j rPY_{ij} * P_{jt}$ , where  $P_{jt}$  is our standard price from the world bank (set to 1 in 2000). As we use the log of the price index in the regressions, it does not matter that the weights do not necessarily sum to one.

Across all these three alternative weighing schemes, our results remain qualitatively and

quantitatively stable (see columns 7-9 in Tables [A.9-A.11](#)). Again, the notable exception is the Soy Moratorium, for which the triple interaction takes a negative coefficient in all three cases but is (marginally) statistically significant only with Potential Yield weights.

**Spatial correlation** In our baseline specification, we cluster the standard errors at the municipality level to deal with serial correlation. In addition, there might be spatial correlation across neighbouring municipalities.<sup>22</sup> We follow [Cameron et al. \(2011\)](#) and use two-way clustered standard errors (on municipality and state-year) in the second most right column in the lower panel of tables [A.9-A.14](#). In the most right column, we include instead state-year fixed effects as control variables. These robustness test do not change the conclusions of this study, although the triple interaction for the Soy Moratorium loses statistical significance for some of the separate price regressions.

**Controlling for geographical characteristics.** In our setting, characteristics that affect the profitability of agriculture may affect both the pressure to deforest and where the government choose to implement the policies. To test whether our triple-difference estimates pick up the effects of geographic characteristics that may affect the profitability of agriculture, we include interactions between the prices and the following five geographic characteristics: *nutrient*(1) concentration refers to soil fertility that is particularly important for low input farming; *nutrient*(2) concentration is particularly relevant for the effectiveness of fertiliser application; *oxygen* availability in the soil is particularly important for root development; *root* refers to soil volume limitations of a soil unit, affecting penetration and constraining yield formation; and *access* provides the estimated travel time to the nearest city with 50 000 or more inhabitants and plausibly also accounts for transportation costs. Tables [A.15](#) and [A.16](#) present the results for the models in table [3](#) and table [4](#), respectively. We conclude that our results are robust and do not reflect variation in these geographic characteristics.



Table 5: Local Economic Development versus Carbon Loss

	Crop value	Carbon loss
	(1)	(2)
	Price	Price
Observations	5104	5104
Municipalities	464	464
R-sq	0.08	0.46
I x P	Yes	Yes
Initial x P	Yes	Yes
<b>Total price effect</b>		
dydx(P)	0.31	0.93
p-value	0.00	0.00

Note: Dependent variables are log total municipal crop production value and log carbon loss in the entire municipality. Specifications are based on equation 2 and include interactions between the price and year dummies as well as interactions between the policy dummy and year dummies. We use contemporaneous prices for the crop production value estimations, as crop production value is measured for year  $t$ , while the deforestation and hence carbon is measured from August in year  $t - 1$  to August in year  $t$ . All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The samples are restricted to cover municipalities with both crop production value and carbon data. Section 3.1 explains the carbon data.

## 7 Economic Development versus Carbon Loss

Is there a trade-off between local economic development and the global public good of storing carbon in forests? To study this question, we bring in data on the production value of agricultural crops, which we also break down into the value of soy, corn and the rest. On the forest side, we use data on carbon outside of conservation zones, as described in section 3. We measure production value as well as carbon in 2020 USD, where the latter is valued at 50 USD per tonne of CO<sub>2</sub>. We use the same specification as we do for deforestation, such that the dependent variables are the first difference of the log of production value and the log of carbon loss. The coefficients for the production values thus pick up changes in growth rates.

Table 5 presents simple price-only models for total production value and carbon loss (equation 2). We find that a one percent increase in commodity prices increase the growth of agricultural crop production value by 0.31 percentage points (bottom row of Table 5). Carbon loss increases by 0.93 percent for a one percent price increase. In Appendix Table A.17, we present estimates also for the three production values of corn, soy and the rest, and we include specifications with lagged dependent variables to take potential dynamics into account. For total production value and non-soy non-corn production value, the effects are similar and lags of the

<sup>22</sup>Municipalities within a Brazilian state do not only share geographical proximity but also political, legislative and cultural commonalities.

dependent variable decreases the effect size. For the value of soy and corn production, we find insignificant price effects in these models.

Table 6: Local Economic Development versus Carbon Loss

	Crop value			Carbon loss		
	(1) PM	(2) SM	(3) CZ	(4) PM	(5) SM	(6) CZ
TreatGr x Active x Price	-1.411** (0.643)	0.062** (0.028)	0.023 (0.019)			
L.Initial x Price	0.096*** (0.018)	0.105*** (0.023)	0.095*** (0.017)			
TreatGr x Active x L.Price				-1.246** (0.617)	0.024 (0.041)	0.161*** (0.035)
L.Initial x L.Price				-0.244*** (0.024)	-0.246*** (0.022)	-0.332*** (0.025)
L.Initial	-0.499*** (0.024)	-0.497*** (0.025)	-0.501*** (0.023)	2.660*** (0.176)	2.988*** (0.188)	2.531*** (0.182)
Observations	5104	5104	5104	5104	5104	5104
Municipalities	464	464	464	464	464	464
R-sq	0.29	0.31	0.29	0.47	0.49	0.48
I x P	Yes	Yes	Yes	Yes	Yes	Yes
<b>Total price effects, policy off/on</b>						
dydx(P) policy off	0.50	-0.47	-0.07	3.63	0.15	0.45
p-quant	0.23	0.07	0.70	0.00	0.67	0.22
dydx(P) policy on	-0.91	-0.12	0.06	2.38	0.34	1.36
p-quant	0.13	0.52	0.75	0.02	0.35	0.00
<b>Difference in total price effect</b>						
Difference	-1.41	0.35	0.13	-1.25	0.19	0.92
p-quant	0.03	0.03	0.24	0.04	0.56	0.00

Note: Dependent variables are log total municipal crop production value and log carbon loss in the entire municipality. Specifications are based on equation 3 and include interactions between the price and year dummies as well as interactions between the policy dummy and year dummies. We use contemporaneous prices for the crop production value estimations, as crop production value is measured for year  $t$ , while the deforestation and hence carbon is measured from August in year  $t - 1$  to August in year  $t$ . All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The samples are restricted to cover municipalities with both crop production value and carbon data. Section 3.1 explains the carbon data.

Next, we augment the simple model with the policies (equation 3). Table 6 shows similar effects as for deforestation, with negative effects on total production value and carbon loss due to PM, and positive effects due to CZ. For SM, we find a positive effect on total production value and no effect on carbon loss. Appendix Table A.18 reveals heterogeneity consistent with our findings for deforestation. Most interestingly, SM increases the commodity price effect on all production value measures except the value of soy production, which it instead decreases

substantially. PM reduces the effect of commodity prices on total value, the non-soy non-corn value and carbon loss. CZ increases the value of non-soy non-corn production and carbon loss. These results are consistent with our general results: PM effectively reduces agricultural production value expansions related to booming agricultural commodity prices; SM leads to substitution away from soy values to other crop values; and CZ leads to some expansion of agricultural production values.

We now value the expansion in agricultural production values against the carbon loss in a stylized cost-benefit analysis. We focus on total crop value and use the estimated shift in the growth rate to assess the expansion in production capacity. We calculate the present value of the additional value creation if the estimated growth differential is allowed to work for one year.<sup>23</sup> We assume a 10% discount rate and a 15% profit margin, consistent with other studies (Busch and Engelmann, 2017).<sup>24</sup>

For carbon loss, we consider the estimated carbon loss for one year. Emission of the carbon stock already stored in forest is a one time emission and is conceptually comparable to the present value of the increase in the profits from crop production. We add an estimate for sequestration, i.e. the carbon the forest could have sunk if it were kept standing, as described in section 3. We think of the change in profits as a measure of the local social cost of carbon, i.e. what one would need to pay in compensation to make the farmers willing to abstain from the agricultural expansion. As discussed in section 3, both our economic valuation and carbon loss valuation miss potentially valuable aspects.

Table A.21 presents the results of our cost-benefit analysis. We find that one would need to pay farmers about 15 USD per tonne of CO<sub>2</sub> to make them indifferent between letting the forest stand and enjoy the agricultural value expansion related to a general increase in commodity prices. For the PM policy, we estimate this value to be 42 USD per tonne of CO<sub>2</sub>. For the Soy Moratorium, we find a positive effect on crop production value but no effect on carbon. Hence there is no trade off (and using the coefficients then yields a very high carbon price). Finally, for CZ we find only a modest (insignificant) coefficient on crop production value compared to the effect on carbon loss, and the local social cost of carbon is close to 4 USD per tonne of CO<sub>2</sub>.

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<sup>23</sup>Instead of using the present value of the increase in crop value, we could have used the annual figure as a measure of how much one would need to pay to postpone the deforestation by one year; i.e. the “rental price” of the stock of carbon.

<sup>24</sup>The data presented in Zalles et al. (2019) suggest profit margins in the range of less than zero to roughly 40% in Soy Bean production in Mato Grosso over the period 2000-2014.

As an alternative to using the estimated shifts in the value of crop production, we can use the mean value of crop production per hectare in a “plot-by-plot calculation”. As an example, our data suggest a yield of about 3 tonne soy per hectare per year and a price of about 400 USD per tonne. The present values are then 12,000 USD of the revenues and 1,800 USD of the profits. For the overall crop production, the value in our data is 1,471 USD per hectare per year over 2004-2013. With a 15% profit margin and a 10% discount rate, the present value is then 2,207 USD. These figures are in line with other studies.<sup>25</sup> The estimated changes in forest cover and CO<sub>2</sub> then translate into a carbon price of 2.6 USD/tCO<sub>2</sub> for the general price increase.<sup>26</sup> Using the mean values of total production value in the treated groups, the corresponding figures are 6.1, 6.2 and 6.4 USD/tCO<sub>2</sub> for PM, SM and CZ, respectively.

Finally, we note that our estimates imply an average carbon density of about USD 43,000 per hectare of forest cleared due to the general increase in agricultural commodity prices. For the estimates related to PM, SM and CZ policies, the corresponding figures are USD 22,000, USD 21,000 and USD 25,000, respectively. Thus, the general price increase may have induced deforestation in areas with high carbon density. The policies have, in comparison, induced reduction in deforestation in areas with relatively lower carbon density. For given land returns, this contributes to a low carbon price in the case of a general price increase and a higher carbon price in the policy cases.

Our stylized cost benefit calculations are informative on the cost of avoided deforestation as an abatement technology. Our plot-by-plot estimates of 2.6-6.4 USD/tCO<sub>2</sub> are lower than some of the values in the literature. [Busch and Engelmann \(2017\)](#) report figures on agricultural

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<sup>25</sup>For comparison, McKinsey suggested in their Global Greenhouse Gas Abatement Cost Curve from 2009 a “PV for soy in intensive agriculture at 4% discount rate to be USD 3,000-5,000 per hectare” in South America ([Nauciel and Enkvist, 2009](#)). This corresponds to about 1,400 to 2,400 in 2020-USD with a 10% discount rate; we assume they used 2010 prices in the report and use the accumulated inflation of 19% in the US CPI from 2010 to 2020 to convert into 2020-USD. [Busch and Engelmann \(2017\)](#) report potential agricultural revenue of USD 2,978 per hectare per year in Latin America. With a profit margin of 15%, this amounts to a present value of about USD 4,500 per hectare given a 10 % discount rate. [Langemeier and Purdy \(2019\)](#) present examples on soy farming in major soy producing countries over 2013-2017. For soy bean production in Mato Grosso, a state in our sample, they find that the yield is about 3.25 tonne per hectare and gross revenue minus costs per hectare is about 250 USD per hectare. If so, this would mean a PV of 2,500 USD per hectare with a 10% discount rate.

<sup>26</sup>We use the estimates for deforestation and carbon loss reported in Tables [A.4](#) and [A.21](#) to arrive at these numbers as follows. If the entire estimated deforested area is used for overall crop production, the present value of the associated profits (per municipality-year) would be:  $2,207 \text{ USD/ha} \times 100 \text{ ha/km}^2 \times 3.7 \text{ km}^2 = 816,590 \text{ USD}$ , where  $3.7 \text{ km}^2$  is the estimated change in deforestation per municipality-year. The value of the estimated loss in carbon per municipality-year is  $16,000,000 \text{ USD}/50 \text{ USD/tCO}_2 = 320,000 \text{ tCO}_2$ , as we measure the carbon at  $50 \text{ USD/tCO}_2$  (in millions). The ratio of the economic value to the carbon loss gives a local carbon price:  $816,590 \text{ USD}/320,000 \text{ tCO}_2 = 2.6 \text{ USD/tCO}_2$ . We follow the same procedure for the carbon prices associated with the policies.

revenue, forest loss and carbon density from which we can back out an average shadow value of 11 USD per tonne of CO<sub>2</sub> for Latin America over 2001-2012, when CO<sub>2</sub> is valued at USD 50 per tonne.<sup>27</sup> Overmars et al. (2014), using integrated assessment modelling and quantifying the economic opportunity cost of deforestation in terms of lost crop production value, find that the price per tonne CO<sub>2</sub> saved via avoided deforestation varies between USD 2 and 9 per tonne in Central and South America and between 20 and 60 USD per tonne in Southeast Asia (on average, over the 2005–2030 period).<sup>28</sup>

In contrast, our values based on the estimated effects of the general price increase and the PM-policy, i.e. 15 and 43 USD/tCO<sub>2</sub>, are higher than what the literature cited above suggests. Our estimates highlight that the economic losses related to avoiding deforestation may be broader than the often used plot-by-plot approach suggest. Our estimates are based on changes in commodity prices and hence pick up value changes for the entire agricultural sector. The changes in value that we pick up are thus not necessarily related to changes in deforestation and land supply. A higher crop price benefits all production. On the other hand, the plot-by-plot approach may be a too narrow measure of the actual economic benefits of expanding agriculture, as there may be important local economies of scale. Our estimates could pick up that places with a booming agricultural sector, due to booming agricultural commodity prices or lack of restrictive policies, may see investments and growth related to other aspects than current land supply. The development of the agricultural sector has been seen as key for the economic growth seen in Mato Grosso state (Richards et al., 2015), and using broader GDP measures could further increase the carbon costs related to the policies. Gillingham and Stock (2018) report costs of different abatement policies based on a compilation of economic studies. The costs show huge variation, with reforestation at 1-10 2017-USD/tCO<sub>2</sub> and reducing federal coal leasing at 33-68 2017-USD/tCO<sub>2</sub>, as two examples. Compared to their list, reducing deforestation in Brazil may be a cheap alternative.

Our stylized cost benefit calculations also shed light on to which extent the marginal cost

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<sup>27</sup>Busch and Engelmann (2017) report potential agricultural revenue of USD 2,978 per hectare per year in Latin America. With a profit margin of 15% and a 10 % discount rate, this amounts to a present value of about USD 4,500 per hectare. In their estimates, 49.2 million hectare deforestation correspond to 19.2 Giga tonnes of CO<sub>2</sub> emissions in Latin America over 2001-2012. This results in about 11 USD per tonne of CO<sub>2</sub>:  $49.2 * 10^6 * 4467 / (19.2 * 10^9) = 11.4$ . Their carbon emissions per hectare of forest corresponds to about USD 19,500 when valued at USD 50 per tonne of CO<sub>2</sub>.

<sup>28</sup>Kindermann et al. (2008) also find that the cost of reducing emissions through avoided deforestation is lowest in Africa and highest in South East Asia, with Central and South America in between. They find that avoiding deforestation can be cost effective compared to other abatement technologies.

of cutting CO<sub>2</sub> emissions by reducing deforestation has been harmonized across space in Brazil. Our plot-by-plot estimates suggest remarkably similar carbon prices across the three policies. Both the carbon density and the actual value creation per hectare are behind these results. Policies that reach the same marginal costs everywhere are likely to be successful in minimizing the cost of a given reduction in CO<sub>2</sub> emissions; cost-minimizing agents would reduce emissions where it is cheapest to do so, until marginal costs are harmonized. [Assunção et al. \(2019\)](#) study optimal counterfactual targeting of municipalities under the PM-policy, given that the authorities aim at minimizing deforestation or carbon emissions given a monitoring resource constraint in terms of either the total area that can be monitored or the total number of municipalities that can be on the list.<sup>29</sup> The forgone economic value of protecting a given stock of carbon is another constraints that should be considered by the authorities to achieve economic efficiency. Our plot-by-plot calculations suggest that the three policies we study may have been well targeted. Our crop value estimates, on the other hand, suggest that the PM policy may have been expensive in terms of the forgone economic value. This may not come as a surprise, as it was targeted on the municipalities with especially high deforestation rates, consistent with large expansions in agriculture due to promising economic opportunities. We leave it to future research to evaluate the broader economic effects of deforestation, which can help narrowing down the actual abatement costs of reduced deforestation.

## 8 Conclusion

Agricultural commodity prices may be high in the coming decades as growth in crop yields may stagnate due to climate change ([Iizumi et al., 2017](#); [Wiebe et al., 2015](#)), as the use of land regulation policies increase ([Harstad and Mideksa, 2017](#)), and as the world’s population and incomes increase ([FAO, 2017](#)). In this paper, we investigated the effectiveness of three command-and-control policies in protecting tropical forests confronted with higher agricultural commodity prices. We studied the Brazilian Legal Amazon, part of the world’s largest tropical rainforest and a key supplier of agriculture commodities such as soy and corn to the world market. Our results showed that protection of specific areas (conservation zones) and targeting a specific

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<sup>29</sup>They find that the carbon emissions were at least 8 percent higher than it could have been under their optimal list of municipalities. They also find, however, that selecting municipalities on the list randomly would result in 34 percent higher deforestation.

crop (Soy Moratorium) induce leakage within municipalities. Prioritizing entire municipalities in monitoring and law enforcement efforts (blacklisting) is, in contrast, effective in reducing deforestation related to international agricultural commodity prices.

We illustrated the costs and benefits of the policies with data on crop production values and carbon loss. Our estimates cover neither all costs nor all benefits, but they suggest that there are real trade-offs between local economic growth and global carbon storage. Future analysis could investigate the mechanisms through which the policies affect local economic outcomes. This could help local and international policy makers in designing policies to either dampen the negative local economic effects or to compensate the local stakeholders through transfers.



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## A Online Appendix: Extra Graphs and Tables

*Table A.1: Data Sources*

Abbreviation	Description	Unit	Source
DF	Annual deforestation on municipal level	$km^2$	<a href="#">INPE(2016)</a>
F	Area in a municipality which is covered by forest	$km^2$	<a href="#">INPE(2016)</a>
PI agriculture	Price Index of agricultural crops produced in a municipality	%	Own Calculation
Price crops	World price banana, coffee, corn, groundnut, orange, rice, rubber, sorgham, soybean, sugar, wheat	%	<a href="#">World Bank</a>
Area Agriculture	Area in a municipality used for agricultural harvest	$km^2$	<a href="#">IGBE/PAM (2016)</a>
Area in zone	Area in a municipality which is part of a protection zone	$km^2$	<a href="#">INPE(2016)</a>
Soy fields	Spatial reference for soy fields	$km^2$	<a href="#">Gibbs et al. (2015)</a>
GDP	Gross Domestic Product in a municipality	1000R\$	<a href="#">IBGE/PIB(2016)</a>
Carbon	Annual change in carbon mass stored in municipal forest area	tons	<a href="#">INPE (2017)</a>
Labour	Number of employees in a municipality	count	<a href="#">IBGE/CCE(2015)</a>
Agricultural Productivity	Quantity harvested by hectar planted Value generated by hectar planted	kg/ha	<a href="#">IGBE/PAM (2016)</a>
Credit	The normalized total value of credit concessions in a given municipality in a given year		<a href="#">Assunção et al. (2019)</a>
Fines	The log of the annual number of environmental fines applied at the municipality level in the previous year		<a href="#">Assunção et al. (2019)</a>

Table A.2: Descriptive statistics

	Count	Mean	SD	Min.	Max.
DF (outside, km2)	5,170	22.36	55.24	0.00	989.41
DF full (km2)	5,170	23.41	57.92	0.00	989.41
DF inside (km2)	2,266	2.39	10.83	0.00	312.04
F (outside, km2)	4,700	2,772.19	5,560.61	0.55	37,733.56
F full (km2)	4,700	3,882.88	8,454.27	0.55	65,041.64
F inside (km2)	2,060	2,534.10	5,783.78	0.00	42,037.13
DC full (mn tonnes)	5,170	0.30	0.71	0.00	11.00
DC full (USD mn, at 50 USD/tCO2)	5,170	54.83	130.15	0.00	2,017.02
DC outside (USD mn, at 50 USD/tCO2)	5,170	52.17	123.37	0.00	1,881.00
DC inside (USD mn, at 50 USD/tCO2)	2,167	6.33	25.25	0.00	681.70
C full (mn tonnes)	4,700	53.88	120.90	0.01	929.69
C full (USD mn, at 50 USD/tCO2)	4,700	9,878.21	22,165.55	1.39	170443.89
C outside (USD mn, at 50 USD/tCO2)	4,700	6,940.02	14,552.82	0.71	102964.83
C inside (USD mn, at 50 USD/tCO2)	1,970	7,009.89	15,509.20	0.23	108431.34
Population	5,170	29,737.66	88,650.76	1,200.00	1.73e+06
P level	5,170	1.66	0.42	0.83	2.48
Psoy level	5,170	0.20	0.39	0.00	1.84
Pnonsoy level	5,170	1.45	0.56	0.11	2.48
Pcorn level	5,170	0.64	0.44	0.00	2.45
E (prio)	5,170	0.10	0.31	0.00	1.00
E x A (prio)	5,170	0.05	0.22	0.00	1.00
E (soy)	5,170	0.31	0.46	0.00	1.00
Area soy 2005	5,170	4,525.63	20,569.17	0.00	253252.00
Active (soy)	5,170	0.73	0.45	0.00	1.00
E (zones)	5,170	0.29	0.45	0.00	1.00
Area zones	5,170	763.41	3,577.87	0.00	39,573.00
Labour	5,167	3,763.85	22,436.23	1.00	557950.00
Wage	5,167	2,816.66	1,515.40	230.00	17,602.40
total credit	4,221	10.62	24.90	0.00	403.32
credit crop	4,221	5.64	22.75	0.00	398.70
credit cattle	4,221	4.99	7.46	0.00	78.05
Flora-related fines (number)	4,664	10.12	25.73	0.00	553.00
Flora-related fines (value)	4,664	2.97e+06	1.39e+07	0.00	3.24e+08
Productivity (IGBE)	5,170	2,043.83	1,317.78	46.10	8,087.94
Agricultural Area	5,170	16,489.13	64,596.42	12.00	1.04e+06
Municipality Area	5,170	6,593.63	9,892.41	150.20	72,954.50
F/Municipality Area	4,700	0.26	0.23	0.00	1.00
C/Municipality Area	4,700	0.81	0.73	0.00	2.84
C/F (2002)	470	4.34	10.08	1.02	152.55
Mean C full per hectare 2000 (USD, at 50 USD/tCO2)	5,170	11,151.66	6,696.88	1,054.92	27,704.18
Mean C outside per hectare 2000 (USD, at 50 USD/tCO2)	5,170	10,817.45	6,541.34	439.97	27,703.04
Mean C inside per hectare 2000 (USD, at 50 USD/tCO2)	2,266	15,728.93	7,941.45	580.31	27,970.74
Observations	5170				

Table A.3: Descriptive statistics: Treated Groups

General price index, 2003 vs. 2004-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
DF (outside, km2)	52.49	102.65	0.00	989.41	19.35	46.95	0.00	696.86
P level	1.10	0.09	0.87	1.70	1.72	0.40	0.83	2.48
Observations	470				4700			
Priority municipality list, 2003-2007 vs. 2008-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
DF (outside, km2)	156.13	138.60	2.98	989.41	48.62	56.75	0.00	447.35
P level	1.32	0.29	0.98	2.31	2.01	0.17	1.63	2.40
Observations	282				257			
Soy Moratorium, 2003-2005 vs. 2006-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
DF (outside, km2)	66.22	103.11	0.00	781.74	14.62	31.62	0.00	318.90
P level	1.16	0.10	0.83	1.95	1.84	0.33	1.01	2.45
Psoy level	0.52	0.33	0.00	1.21	0.72	0.47	0.00	1.84
Pnonsoy level	0.66	0.31	0.11	1.77	1.09	0.53	0.13	2.42
Pcorn level	0.23	0.18	0.00	1.04	0.38	0.32	0.00	2.17
Observations	432				1152			
Conservation Zones, Municipality specific pre and post periods								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
DF (outside, km2)	52.14	93.49	0.00	781.74	22.40	49.75	0.00	564.11
P level	1.31	0.31	0.90	2.45	1.83	0.32	1.06	2.43
Observations	511				996			

Table A.4: Effects on deforestation (DF)

<i>Effects on DF of general agricultural commodity price index under PM, SM and CZ</i>												
		$\beta$	$P_{pre}$	$P_{post}$	$\% \Delta P$	$\% \Delta Y^i$	$\bar{Y}$	$Y_{cf}^i$	$\Delta Y_{cf}$	$\% \Delta Y_{cf}$	N obs	$N \times \Delta Y_{cf}$
Price	On	0.47	1.10	1.72	56.4	23.4	19.4	15.7	3.7		4700	17,234
Prio	Off	3.68	1.32	2.01	52.3	369.9		84.0				
Prio	On	2.38	1.32	2.01	52.3	172.0	48.6	17.9	-35.4	-42.1	257	-9,090
SM	Off	0.07	1.16	1.84	58.6	3.3		13.2				
SM	On	0.29	1.16	1.84	58.6	14.3	14.6	12.8	1.4	10.7	1152	1,626
CZ	Off	0.06	1.31	1.83	39.7	2.0		16.3				
CZ	On	1.02	1.31	1.83	39.7	40.6	22.4	15.9	6.1	37.8	996	6,125

<i>Effects on DF of different prices under SM</i>												
Price		$\beta$	$P_{pre}$	$P_{post}$	$\% \Delta P$	$\% \Delta Y^i$	$\bar{Y}$	$Y_{cf}^i$	$\Delta Y_{cf}$	$\% \Delta Y_{cf}$	N obs	$N \times \Delta Y_{cf}$
Soy	Off	0.84	0.52	0.72	38.5	31.4		16.9				
Soy	On	0.39	0.52	0.72	38.5	13.5	14.6	12.9	-2.3	-13.6	1152	-2,656
Non-soy	Off	-1.13	0.66	1.09	65.2	-43.3		9.5				
Non-soy	On	-0.28	0.66	1.09	65.2	-13.1	14.6	16.8	5.1	53.2	1152	5,847
Corn	Off	3.97	0.23	0.38	65.2	634.0		13.6				
Corn	On	4.11	0.23	0.38	65.2	687.4	14.6	1.9	1.0	7.3	1152	1,143

Note: Table provides treatment effects on the treated, with ( $i = on$ ) and without ( $i = off$ ) the policy.  $\% \Delta P = (P_{post}/P_{pre} - 1) * 100$  gives the price increase in percent;  $\% \Delta Y^i = (e^{\beta^i \Delta \ln(P)} - 1) * 100$  gives the increase in  $Y$  in percent;  $\bar{Y}$  is the mean of actual DF in the treated municipality-years measured in  $\text{km}^2$ , i.e. with policy and price increase.  $Y_{cf}^i$  is the counterfactual DF, let  $\gamma^i = \% \Delta Y^i / 100$ :  $Y_{cf}^{on} = \frac{\bar{Y}}{(1+\gamma^i)}$  gives the counterfactual  $Y$  in the absence of the policy and in absence of the price increase, while  $Y_{cf}^{off} = Y_{cf}^{on} (1 + \gamma^i)$  gives the counterfactual  $Y$  in the presence of the price increase but without the policy;  $\Delta Y_{cf} = Y_{cf}^{off} - \bar{Y}$  gives the difference due to the policy for the actual price increase and  $\% \Delta Y_{cf} = (Y_{cf}^{off} / \bar{Y} - 1) * 100$  gives the same in percent.  $\beta^i$  estimates in upper panel are from columns 3 and 4-6 in Table 2 and Table 3, respectively.  $\beta^i$  estimates in lower panel are from Table 4. The necessary descriptive statistics are from Table A.3.

Table A.5: Testing the Parallel Pre-trends in Covariates: Priority Municipalities

	(1) DF	(2) F	(3) Labour	(4) Wage	(5) GDP	(6) Cred total	(7) Cred crop	(8) Cred cattle	(9) Fines count	(10) Fines value	(11) kg/ha	(12) Ag area	(13) Zones Area	(14) W Soy	(15) W corn	(16) W Rest
TreatGr=1 $\times$ Trend	-0.111 (0.094)	0.003 (0.004)	-0.017 (0.037)	-0.017 (0.017)	-0.001 (0.024)	-0.013 (0.056)	0.164** (0.071)	0.045 (0.061)	0.107 (0.124)	0.003 (0.379)	0.055* (0.030)	0.141*** (0.054)	-0.036 (0.147)	0.003 (0.010)	0.005 (0.011)	-0.010 (0.009)
TreatGr=1 $\times$ L.Price	2.256 (1.926)	-0.186 (0.116)	0.566 (1.006)	-0.317 (0.346)	0.986 (0.641)	-1.264 (1.952)	3.918** (1.790)	-4.056** (1.792)	2.417 (2.832)	10.610 (9.155)	-0.097 (0.706)	4.581*** (1.349)	-6.438 (5.479)	-0.401 (0.253)	-0.052 (0.230)	0.462 (0.313)
TreatGr=1 $\times$ Trend $\times$ L.Price	-0.073 (0.413)	0.022 (0.021)	-0.130 (0.199)	0.070 (0.086)	-0.146 (0.122)	0.176 (0.374)	-1.030*** (0.381)	0.427 (0.362)	-0.100 (0.579)	-0.671 (1.834)	-0.101 (0.138)	-1.043*** (0.280)	1.049 (0.920)	0.053 (0.046)	0.014 (0.049)	-0.066 (0.055)
Trend $\times$ L.Price	-0.298* (0.170)	0.022 (0.024)	0.065 (0.139)	-0.083** (0.040)	0.167*** (0.037)	0.017 (0.131)	0.129 (0.126)	-0.135 (0.118)	0.080 (0.249)	-0.118 (1.096)	0.044 (0.094)	0.170 (0.149)	2.828*** (0.699)	-0.064*** (0.016)	0.112*** (0.030)	-0.042* (0.025)
L.Price	2.381*** (0.682)	-0.040 (0.104)	-0.147 (0.666)	0.294 (0.189)	-0.467*** (0.177)	1.203** (0.512)	0.709 (0.465)	0.907* (0.496)	-0.235 (1.076)	-1.515 (4.804)	-0.349 (0.353)	-0.350 (0.594)	-11.891*** (2.935)	0.289*** (0.069)	-0.296** (0.115)	-0.002 (0.106)
Observations	2350	2350	2347	2347	2339	2345	2345	2345	2120	2120	2350	2350	2350	2350	2350	2350
Municipalities	470	470	470	470	469	469	469	469	424	424	470	470	470	470	470	470
R-sq	0.27	0.45	0.19	0.36	0.32	0.17	0.13	0.15	0.23	0.14	0.01	0.05	0.15	0.08	0.04	0.08

Note: The dependent variable is log of the variable indicated in the column headings, except for the share of agricultural area allocated to soy, corn and the rest (indicated W). *Trend* is a trend variable, defined as Year-2001. *TreatGr* indicates if a municipality is in the control or treatment group. Years included are 2002-2007, as the blacklisting policy started in 2008 for the first municipalities. Includes municipality and year fixed effects. The standard errors in parenthesis are clustered at the municipality level.

Table A.6: Testing the Parallel Pre-trends in Covariates: Soy Moratorium

	(1) DF	(2) F	(3) Labour	(4) Wage	(5) GDP	(6) Cred total	(7) Cred crop	(8) Cred cattle	(9) Fines count	(10) Fines value	(11) kg/ha	(12) Ag area	(13) Zones Area	(14) W Soy	(15) W corn	(16) W Rest
TreatGr=1 $\times$ Trend	-0.085 (0.124)	0.020*** (0.008)	0.008 (0.064)	-0.009 (0.027)	0.008 (0.021)	-0.070 (0.063)	0.161** (0.067)	-0.213*** (0.065)	0.101 (0.114)	0.473 (0.624)	-0.090** (0.035)	0.372*** (0.062)	-0.104 (0.193)	0.096*** (0.014)	-0.054*** (0.014)	-0.037*** (0.012)
TreatGr=1 $\times$ L.Price	-5.458* (2.913)	0.287* (0.156)	-1.967 (2.272)	0.658 (0.571)	0.352 (0.478)	-4.654*** (1.517)	-2.876* (1.707)	-6.664*** (1.632)	-1.850 (3.032)	-6.020 (16.408)	-0.801 (0.842)	1.904 (1.267)	0.290 (6.305)	-1.281*** (0.398)	1.202*** (0.382)	0.111 (0.270)
TreatGr=1 $\times$ Trend $\times$ L.Price	1.408* (0.782)	-0.092** (0.045)	0.271 (0.529)	-0.142 (0.150)	-0.163 (0.128)	1.477*** (0.388)	0.926** (0.433)	1.611*** (0.395)	0.532 (0.744)	1.391 (3.953)	0.436* (0.225)	-0.647* (0.358)	0.337 (1.535)	0.134 (0.085)	-0.237** (0.098)	0.082 (0.069)
Trend $\times$ L.Price	-3.292*** (0.448)	0.086** (0.034)	0.010 (0.269)	-0.095 (0.102)	0.140* (0.078)	-0.334 (0.214)	-0.355* (0.195)	-0.281 (0.214)	-0.180 (0.406)	-0.913 (1.909)	-0.130 (0.150)	0.564** (0.245)	1.763* (0.958)	-0.003 (0.003)	0.177*** (0.055)	-0.157*** (0.050)
L.Price	10.471*** (1.519)	-0.331*** (0.096)	0.116 (1.218)	0.331 (0.344)	0.001 (0.249)	1.478* (0.821)	1.417** (0.691)	1.299 (0.809)	-0.513 (1.438)	-1.593 (7.169)	0.271 (0.394)	-1.109* (0.648)	-11.353*** (4.128)	-0.040 (0.031)	-0.360** (0.155)	0.373*** (0.143)
Observations	1410	1410	1407	1407	1403	1407	1407	1407	1272	1272	1410	1410	1410	1410	1410	1410
Municipalities	470	470	470	470	469	469	469	469	424	424	470	470	470	470	470	470
R-sq	0.10	0.45	0.08	0.25	0.23	0.20	0.30	0.07	0.13	0.07	0.01	0.22	0.13	0.31	0.17	0.04

Note: The dependent variable is log of the variable indicated in the column headings, except for the share of agricultural area allocated to soy, corn and the rest (indicated W). *Trend* is a trend variable, defined as Year-2001. *TreatGr* indicates if a municipality is in the control or treatment group. Years included are 2002-2005, as the Soy Moratorium was introduced in 2006. Includes municipality and year fixed effects. The standard errors in parenthesis are clustered at the municipality level.

Table A.7: Testing the Parallel Pre-trends in Covariates: Zones

	(1) DF	(2) F	(3) Labour	(4) Wage	(5) GDP	(6) Cred total	(7) Cred crop	(8) Cred cattle	(9) Fines count	(10) Fines value	(11) kg/ha	(12) Ag area	(13) Zones Area	(14) W Soy	(15) W corn	(16) W Rest
TreatGr=1 × Trend	-0.115 (0.128)	0.024*** (0.007)	-0.079 (0.080)	-0.003 (0.035)	0.031 (0.020)	0.147** (0.064)	0.176*** (0.056)	0.040 (0.072)	0.193 (0.130)	0.024 (0.622)	0.071* (0.040)	-0.053 (0.065)	1.354*** (0.291)	0.000 (0.011)	-0.003 (0.015)	-0.000 (0.012)
TreatGr=1 × L.Price	-1.129 (2.442)	-0.225 (0.147)	-1.756 (1.729)	-0.327 (0.577)	0.431 (0.417)	2.225 (1.354)	2.202* (1.161)	1.526 (1.499)	-1.301 (2.532)	-9.882 (12.515)	1.921** (0.773)	-1.751 (1.218)	-11.604** (5.905)	0.066 (0.167)	-0.276 (0.292)	0.167 (0.248)
TreatGr=1 × Trend × L.Price	0.380 (0.729)	0.059 (0.045)	0.519 (0.425)	0.092 (0.176)	-0.110 (0.118)	-0.826** (0.370)	-1.068*** (0.319)	-0.252 (0.413)	0.333 (0.700)	3.389 (3.392)	-0.560** (0.253)	0.362 (0.406)	1.362 (1.611)	-0.022 (0.051)	0.102 (0.100)	-0.058 (0.081)
Trend × L.Price	-3.053*** (0.578)	-0.004 (0.040)	-0.155 (0.294)	-0.160* (0.089)	0.127 (0.082)	0.310 (0.214)	0.111 (0.251)	0.274 (0.247)	-0.563 (0.370)	-3.036 (2.341)	0.263** (0.119)	0.004 (0.183)	-0.138 (0.085)	-0.051 (0.032)	0.126** (0.059)	-0.076 (0.048)
L.Price	9.560*** (1.898)	0.022 (0.122)	0.376 (1.241)	0.556 (0.366)	-0.104 (0.274)	0.081 (0.811)	1.518 (0.951)	-1.468* (0.866)	1.432 (1.437)	6.405 (8.741)	-0.920** (0.403)	1.879*** (0.668)	-0.326 (0.228)	0.138 (0.114)	-0.315* (0.175)	0.185 (0.159)
Observations	1410	1410	1407	1407	1403	1407	1407	1407	1272	1272	1410	1410	1410	1410	1410	1410
Municipalities	470	470	470	470	469	469	469	469	424	424	470	470	470	470	470	470
R-sq	0.10	0.49	0.08	0.25	0.23	0.19	0.24	0.05	0.14	0.07	0.01	0.11	0.33	0.08	0.05	0.03

Note: The dependent variable is log of the variable indicated in the column headings, except for the share of agricultural area allocated to soy, corn and the rest (indicated W). *Trend* is a trend variable, defined as Year-2001. *TreatGr* indicates if a municipality is in the control or treatment group. Years included are 2002-2005, as 2006 was the year with the highest expansion of protected areas, see figure ?? . Includes municipality and year fixed effects. The standard errors in parenthesis are clustered at the municipality level.



Table A.8: Robustness continuous treatment variable: Soy Moratorium

	(1) P	(2) Psoy	(3) Pnon-soy	(4) Pcorn
TreatGr x Active $\times$ L.Price	-0.077 (0.094)	-0.070*** (0.025)	0.143*** (0.019)	0.031*** (0.009)
L.Forest cover	2.620*** (0.157)	2.647*** (0.630)	2.580*** (0.153)	2.178*** (0.156)
L.Forest cover $\times$ L.Price	-0.295*** (0.019)	-0.420*** (0.046)	-0.286*** (0.018)	-0.230*** (0.015)
Observations	5170	1584	5170	5137
Municipalities	470	144	470	467
R-sq	0.52	0.65	0.52	0.50
I x P	Yes	Yes	Yes	Yes
<b><i>Total price effects, policy off/on</i></b>				
dydx(P) policy off	1.35	0.36	-1.11	5.09
p-value	0.04	0.53	0.00	0.02
dydx(P) policy on	0.72	-0.21	0.06	5.34
p-value	0.06	0.71	0.82	0.02
<b><i>Difference in total price effect</i></b>				
Difference	-0.63	-0.57	1.17	0.26
p-value	0.41	0.01	0.00	0.00

Note: As column 5 in table 3, but modified by using the log area soy planted in 2005 instead of treatment group dummy.

Table A.9: Robustness: Priority Municipalities

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Baseline	Ag area	kg/ha	Pop	Cred total	Cred crop	Cred cattle	Fines count	Fines value	Pol	CAR	Ex cover
TreatGr x Active x L.Price	-1.706*** (0.620)	-1.712*** (0.619)	-1.674*** (0.622)	-1.706*** (0.620)	-1.723*** (0.619)	-1.741*** (0.619)	-1.711*** (0.621)	-1.753*** (0.624)	-1.753*** (0.625)	-1.394** (0.596)	-1.611*** (0.618)	-1.885*** (0.623)
cntr1		-0.036 (0.027)	0.084*** (0.031)		0.040* (0.021)	0.043* (0.023)	0.020 (0.022)	-0.000 (0.012)	0.000 (0.002)			
cntr3										-0.074*** (0.009)		
cntr4										0.056*** (0.010)		
Observations	4221	4221	4221	4221	4221	4221	4221	3807	3807	4221	4185	4221
Municipalities	469	469	469	469	469	469	469	423	423	469	465	469
R-sq	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.49	0.48	0.40
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	-1.71	-1.71	-1.67	-1.71	-1.72	-1.74	-1.71	-1.75	-1.75	-1.39	-1.61	-1.89
p-value	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.02	0.01	0.00

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	All	Ex top soy	Ex 10% DF	In zones	Entire	Hansen	W mean	W 2005	W PY	SY cl	SY dum
TreatGr x Active x L.Price	-1.272** (0.587)	-1.741*** (0.623)	-2.020*** (0.744)	-0.875 (0.643)	-1.714*** (0.621)	-1.132** (0.517)	-1.567* (0.814)	-1.195 (0.750)	-1.614*** (0.528)	-1.706** (0.757)	-1.061* (0.584)
Observations	6589	4176	3825	1845	4221	4194	4221	4221	4221	4221	4221
Municipalities	599	464	425	205	469	466	469	469	469		
R-sq	0.41	0.46	0.44	0.24	0.45	0.26	0.46	0.45	0.49	0.87	0.90
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>											
Difference	-1.27	-1.74	-2.02	-0.88	-1.71	-1.13	-1.57	-1.20	-1.61		
p-value	0.03	0.01	0.01	0.17	0.01	0.03	0.05	0.11	0.00		

Note: As column 4 in table 3, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Columns (9)-(11) in the lower panel are with price indexes with alternative measures of weights: average shares of crops; average weights over 2003-2005 and potential yields, respectively.

Table A.10: Robustness: Soy Moratorium

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Baseline	Ag area	kg/ha	Pop	Cred total	Cred crop	Cred cattle	Fines count	Fines value	Pol	CAR	Ex cover
TreatGr x Active x L.Price	-0.036 (0.040)	-0.037 (0.040)	-0.033 (0.040)	-0.036 (0.040)	-0.035 (0.040)	-0.036 (0.040)	-0.040 (0.040)	-0.074* (0.043)	-0.073* (0.043)	-0.030 (0.040)	-0.054 (0.040)	-0.111*** (0.043)
cntr1		0.015 (0.027)	0.082*** (0.029)		0.036* (0.021)	0.032 (0.023)	0.037* (0.021)	-0.011 (0.012)	-0.000 (0.002)			
cntr2										-0.217** (0.089)		
cntr4										0.052*** (0.010)		
Observations	4221	4221	4221	4221	4221	4221	4221	3807	3807	4221	4185	4221
Municipalities	469	469	469	469	469	469	469	423	423	469	465	469
R-sq	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50	0.50	0.50	0.51	0.41
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	-0.29	-0.30	-0.27	-0.29	-0.28	-0.29	-0.33	-0.61	-0.60	-0.17	-0.30	-0.91
p-value	0.37	0.35	0.40	0.37	0.39	0.37	0.32	0.08	0.09	0.46	0.18	0.01

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	All	Ex top soy	Ex 10% DF	In zones	Entire	Hansen	W mean	W 2005	W PY	SY cl	SY dum
TreatGr x Active x L.Price	0.002 (0.029)	-0.033 (0.043)	-0.034 (0.044)	0.050 (0.039)	-0.046 (0.040)	0.116*** (0.034)	-0.028 (0.039)	-0.029 (0.040)	-0.054* (0.031)	-0.036 (0.059)	0.038 (0.041)
Observations	6589	4176	3825	1845	4221	4194	4221	4221	4221	4221	4221
Municipalities	599	464	425	205	469	466	469	469	469		
R-sq	0.43	0.48	0.48	0.23	0.49	0.29	0.49	0.49	0.50	0.88	0.90
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>											
Difference	0.02	-0.27	-0.28	0.41	-0.38	0.95	-0.23	-0.24	-0.45		
p-value	0.95	0.44	0.44	0.20	0.25	0.00	0.48	0.46	0.08		

Note: As column 5 in table 3, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Columns (9)-(11) in the lower panel are with price indexes with alternative measures of weights: average shares of crops; average weights over 2003-2005 and potential yields, respectively.

Table A.11: Robustness: Conservation Zones

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Baseline	Ag area	kg/ha	Pop	Cred total	Cred crop	Cred cattle	Fines count	Fines value	Pol	CAR	Ex cover
TreatGr x Active x L.Price	0.191*** (0.030)	0.191*** (0.030)	0.188*** (0.030)	0.191*** (0.030)	0.193*** (0.030)	0.191*** (0.030)	0.193*** (0.030)	0.190*** (0.031)	0.190*** (0.031)	0.146*** (0.031)	0.181*** (0.030)	0.108*** (0.037)
cntr1		-0.049* (0.026)	0.071** (0.030)		0.047** (0.020)	0.034 (0.022)	0.029 (0.020)	-0.008 (0.012)	0.000 (0.002)			
cntr2										-0.192** (0.091)		
cntr3										-0.072*** (0.009)		
Observations	4221	4221	4221	4221	4221	4221	4221	3807	3807	4221	4185	4221
Municipalities	469	469	469	469	469	469	469	423	423	469	465	469
R-sq	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.49	0.49	0.39
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	1.09	1.09	1.07	1.09	1.10	1.09	1.10	1.08	1.08	0.83	1.03	0.61
p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	All	Ex top soy	Ex 10% DF	In zones	Entire	Hansen	W mean	W 2005	W PY	SY cl	SY dum
TreatGr x Active x L.Price	0.205*** (0.028)	0.186*** (0.030)	0.201*** (0.033)	-0.011 (0.025)	0.190*** (0.031)	0.060** (0.029)	0.197*** (0.032)	0.204*** (0.031)	0.136*** (0.027)	0.191*** (0.041)	0.100*** (0.027)
Observations	6589	4176	3825	1845	4221	4194	4221	4221	4221	4221	4221
Municipalities	599	464	425	205	469	466	469	469	469		
R-sq	0.43	0.46	0.46	0.23	0.46	0.26	0.47	0.46	0.49	0.87	0.90
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>											
Difference	1.17	1.06	1.15	-0.06	1.08	0.34	1.12	1.16	0.77		
p-value	0.00	0.00	0.00	0.65	0.00	0.04	0.00	0.00	0.00		

Note: As column 4 in table 3, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Columns (9)-(11) in the lower panel are with price indexes with alternative measures of weights: average shares of crops; average weights over 2003-2005 and potential yields, respectively.

Table A.12: Soy Moratorium: Soy Price

	(1) Baseline	(2) Ag area	(3) kg/ha	(4) Pop	(5) Cred total	(6) Cred crop	(7) Cred cattle	(8) Fines count	(9) Fines value	(10) Pol	(11) CAR	(12) Ex cover
TreatGr x Active x L.Price	-0.042 (0.025)	-0.041 (0.025)	-0.042* (0.025)	-0.042 (0.025)	-0.042 (0.025)	-0.041 (0.025)	-0.041 (0.025)	-0.037 (0.026)	-0.037 (0.026)	-0.047** (0.024)	-0.051** (0.024)	-0.029 (0.028)
cntr1		-0.002 (0.043)	0.065 (0.055)		-0.080* (0.041)	-0.010 (0.033)	-0.046 (0.041)	-0.003 (0.023)	-0.002 (0.004)			
cntr2										-0.211 (0.140)		
cntr4										0.061*** (0.019)		
Observations	1296	1296	1296	1296	1296	1296	1296	1107	1107	1296	1278	1296
Municipalities	144	144	144	144	144	144	144	123	123	144	142	144
R-sq	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.64	0.64	0.63	0.65	0.56
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	-0.34	-0.34	-0.35	-0.34	-0.34	-0.34	-0.34	-0.31	-0.30	-0.26	-0.29	-0.24
p-value	0.10	0.10	0.09	0.10	0.10	0.10	0.11	0.16	0.16	0.05	0.03	0.30

	(1) All	(2) Ex top soy	(3) Ex 10% DF	(4) In zones	(5) Entire	(6) Hansen	(7) SY cl	(8) SY dum
TreatGr x Active x L.Price	-0.016 (0.020)	-0.034 (0.026)	-0.040 (0.028)	0.007 (0.022)	-0.044* (0.027)	-0.008 (0.018)	-0.042 (0.027)	-0.004 (0.019)
Observations	1925	1251	1098	441	1296	1296	1296	1296
Municipalities	175	139	122	49	144	144		
R-sq	0.60	0.60	0.61	0.29	0.62	0.38	0.90	0.92
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>								
Difference	-0.13	-0.28	-0.33	0.06	-0.36	-0.07		
p-value	0.42	0.18	0.14	0.73	0.10	0.65		

Note: Robustness checks on table 4, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Price index based on crop area in 2005.

Table A.13: Soy Moratorium: Non-soy Prices

	(1) Baseline	(2) Ag area	(3) kg/ha	(4) Pop	(5) Cred total	(6) Cred crop	(7) Cred cattle	(8) Fines count	(9) Fines value	(10) Pol	(11) CAR	(12) Ex cover
TreatGr x Active x L.Price	0.061** (0.027)	0.061** (0.027)	0.062** (0.027)	0.061** (0.027)	0.059** (0.028)	0.060** (0.028)	0.059** (0.027)	0.042 (0.030)	0.042 (0.030)	0.078*** (0.027)	0.050* (0.026)	0.026 (0.033)
cntr1		0.020 (0.026)	0.091*** (0.029)		0.033 (0.021)	0.034 (0.023)	0.033 (0.021)	-0.012 (0.012)	-0.001 (0.002)			
cntr2										-0.221** (0.088)		
cntr4										0.056*** (0.010)		
Observations	4221	4221	4221	4221	4221	4221	4221	3807	3807	4221	4185	4221
Municipalities	469	469	469	469	469	469	469	423	423	469	465	469
R-sq	0.48	0.48	0.49	0.48	0.48	0.48	0.48	0.49	0.49	0.49	0.50	0.41
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	0.50	0.50	0.51	0.50	0.49	0.49	0.49	0.35	0.35	0.43	0.28	0.22
p-value	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.16	0.15	0.00	0.05	0.43

	(1) All	(2) Ex top soy	(3) Ex 10% DF	(4) In zones	(5) Entire	(6) Hansen	(7) SY cl	(8) SY dum
TreatGr x Active x L.Price	0.061** (0.026)	0.030 (0.032)	0.058* (0.030)	0.002 (0.021)	0.059** (0.028)	0.065*** (0.023)	0.061 (0.047)	0.083*** (0.024)
Observations	6567	4176	3825	1845	4221	4194	4221	4221
Municipalities	597	464	425	205	469	466		
R-sq	0.43	0.47	0.47	0.22	0.48	0.28	0.88	0.90
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>								
Difference	0.50	0.25	0.48	0.01	0.49	0.53		
p-value	0.02	0.34	0.05	0.94	0.03	0.00		

Note: Robustness checks on table 4, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Price index based on crop area in 2005.

Table A.14: Soy Moratorium: Corn Price

	(1) Baseline	(2) Ag area	(3) kg/ha	(4) Pop	(5) Cred total	(6) Cred crop	(7) Cred cattle	(8) Fines count	(9) Fines value	(10) Pol	(11) CAR	(12) Ex cover
TreatGr x Active x L.Price	0.017* (0.009)	0.017* (0.009)	0.017*** (0.009)	0.017* (0.009)	0.017* (0.009)	0.017* (0.009)	0.017* (0.009)	0.021** (0.009)	0.021** (0.009)	0.015* (0.009)	0.015* (0.008)	0.019** (0.009)
cntr1		0.008 (0.027)	0.085*** (0.030)		0.043** (0.021)	0.034 (0.023)	0.041* (0.021)	-0.020* (0.012)	-0.001 (0.002)			
cntr2										-0.333*** (0.091)		
cntr4										0.042*** (0.010)		
Observations	4194	4194	4194	4194	4194	4194	4194	3798	3798	4194	4158	4194
Municipalities	466	466	466	466	466	466	466	422	422	466	462	466
R-sq	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.48	0.48	0.48	0.50	0.41
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>												
Difference	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.17	0.18	0.08	0.08	0.16
p-value	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.02	0.02	0.08	0.05	0.04

	(1) All	(2) Ex top soy	(3) Ex 10% DF	(4) In zones	(5) Entire	(6) Hansen	(7) SY cl	(8) SY dum
TreatGr x Active x L.Price	0.020** (0.008)	0.019** (0.009)	0.014 (0.010)	0.007 (0.006)	0.017** (0.009)	0.011* (0.006)	0.017* (0.009)	0.003 (0.007)
Observations	6457	4149	3807	1836	4194	4167	4194	4194
Municipalities	587	461	423	204	466	463		
R-sq	0.42	0.46	0.46	0.20	0.47	0.28	0.87	0.90
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>								
Difference	0.17	0.16	0.12	0.06	0.14	0.09		
p-value	0.01	0.03	0.16	0.30	0.05	0.10		

Note: Robustness checks on table 4, but modified as indicated in column heading (see the text in section 6). Lower panel columns 1 and 2 run with reghdfe in stata to allow for two-way clustering. Price index based on crop area in 2005.

Table A.15: Controlling for Geography: Three Policies

	PM					SM					CZ				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Access	Nutrient1	Nutrient2	Oxygen	Roots	Access	Nutrient1	Nutrient2	Oxygen	Roots	Access	Nutrient1	Nutrient2	Oxygen	Roots
TreatGr x Active x L.Price	-1.340** (0.599)	-1.298** (0.598)	-1.267** (0.596)	-1.226* (0.634)	-1.370** (0.596)	0.026 (0.036)	0.029 (0.036)	0.035 (0.036)	0.039 (0.036)	0.032 (0.036)	0.168*** (0.031)	0.171*** (0.032)	0.159*** (0.032)	0.144*** (0.031)	0.163*** (0.032)
Geography x L.Price	0.162* (0.085)	0.041 (0.067)	0.169*** (0.057)	0.246*** (0.047)	0.098** (0.042)	0.187** (0.084)	0.030 (0.063)	0.156*** (0.057)	0.220*** (0.046)	0.045 (0.040)	0.065 (0.087)	-0.031 (0.064)	0.107* (0.057)	0.189*** (0.048)	0.063 (0.043)
Observations	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170	5170
Municipalities	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
R-sq	0.49	0.49	0.49	0.50	0.49	0.52	0.52	0.52	0.53	0.52	0.50	0.50	0.50	0.51	0.50
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>															
Difference	-1.34	-1.30	-1.27	-1.23	-1.37	0.15	0.16	0.20	0.22	0.18	0.96	0.98	0.91	0.82	0.93
p-value	0.03	0.03	0.03	0.05	0.02	0.46	0.42	0.33	0.28	0.38	0.00	0.00	0.00	0.00	0.00

Note: As columns 4-6 in table 3, but including price interaction with geographical characteristic as indicated in column headings. See section 6 for a description of these characteristics.



Table A.16: Controlling for Geography: Soy prices vs Non-soy Prices vs. Corn Prices

	SM Psoy					SM Pnon-soy					SM Pcorn				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Access	Nutrient1	Nutrient2	Oxygen	Roots	Access	Nutrient1	Nutrient2	Oxygen	Roots	Access	Nutrient1	Nutrient2	Oxygen	Roots
TreatGr x Active x L.Price	-0.055** (0.023)	-0.054** (0.022)	-0.055** (0.022)	-0.055** (0.022)	-0.054** (0.022)	0.103*** (0.024)	0.104*** (0.024)	0.106*** (0.024)	0.103*** (0.023)	0.104*** (0.024)	0.017** (0.009)	0.017* (0.009)	0.017* (0.009)	0.018** (0.009)	0.017* (0.009)
Geography x L.Price	0.037 (0.200)	0.249 (0.162)	0.327*** (0.105)	0.219* (0.119)	0.104 (0.079)	0.192** (0.079)	0.019 (0.061)	0.141*** (0.052)	0.202*** (0.044)	0.032 (0.036)	0.111* (0.064)	-0.033 (0.051)	0.052 (0.043)	0.099*** (0.036)	-0.016 (0.028)
Observations	1584	1584	1584	1584	1584	5170	5170	5170	5170	5170	5137	5137	5137	5137	5137
Municipalities	144	144	144	144	144	470	470	470	470	470	467	467	467	467	467
R-sq	0.64	0.64	0.64	0.64	0.64	0.52	0.52	0.52	0.52	0.52	0.50	0.50	0.50	0.50	0.50
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>Difference in total price effect</i>															
Difference	-0.31	-0.30	-0.30	-0.30	-0.30	0.57	0.58	0.59	0.58	0.58	0.10	0.09	0.09	0.10	0.09
p-value	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.05	0.04	0.05

Note: As column 5 in table 3, but including price interaction with geographical characteristic as indicated in column headings. See section 6 for a description of these characteristics. Columns 1-5 for soy price only, columns 6-10 for non-soy prices only and columns 11-15 for corn price only.

Table A.17: Agriculture GDP and Carbon Loss Outside CZs

	Value <sup>†</sup>			Crop value Soy			Value Corn			Value Rest			Carbon loss		
	(1) Price	(2) Price	(3) Price	(4) Price	(5) Price	(6) Price	(7) Price	(8) Price	(9) Price	(10) Price	(11) Price	(12) Price	(13) Price	(14) Price	(15) Price
den															
L.dep var		-0.236*** (0.022)	-0.302*** (0.029)		-0.219*** (0.038)	-0.246*** (0.044)		-0.265*** (0.019)	-0.336*** (0.023)		-0.265*** (0.020)	-0.327*** (0.025)		0.131*** (0.021)	0.130*** (0.017)
den2															
L2.dep var			-0.238*** (0.022)			-0.099** (0.046)			-0.228*** (0.020)			-0.251*** (0.020)			0.074*** (0.013)
Observations	5104			850			5052			5104			5104		
Municipalities	464			85			464			464			464		
R-sq	0.08			0.34			0.08			0.07			0.46		
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Initial x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Total price effect</b>															
dydx(P)	0.31	0.26	0.11	-0.45	-0.30	-0.47	0.23	0.26	0.27	0.43	0.34	0.14	0.93	1.05	0.79
p-value	0.00	0.01	0.22	0.44	0.57	0.38	0.34	0.25	0.16	0.00	0.00	0.18	0.00	0.00	0.00

Note: Dependent variables are log total municipal GDP and log carbon loss in the entire municipality. The carbon stock in municipality  $i$  in year  $t$  is calculated as  $C_t^{Entire} = F_t^{Entire} * (C_{2000}^{Entire} / F_{2000}^{Entire})$ , i.e. the remaining forest scaled with the carbon per forest cover in the initial year. Similarly, we calculate the reduction in carbon stock as  $DC_t^{Entire} = DF_t^{Entire} * (C_{2000}^{Entire} / F_{2000}^{Entire})$ . Specifications are based on equation 3 and include interactions between the price and year dummies. The GDP model also includes lagged dependent variable to account for dynamics in GDP. We use contemporaneous prices for the GDP estimations, as GDP is measured for year  $t$ , while the deforestation and hence carbon is measured from August in year  $t - 1$  to August in year  $t$ . All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The samples are restricted to cover municipalities with both GDP and carbon data.

Table A.18: Various Measures of Agriculture Value and Carbon Loss Outside CZs

	Value			Value Soy			Value Corn			Value Rest			Carbon loss		
	(1) PM	(2) SM	(3) CZ	(4) PM	(5) SM	(6) CZ	(7) PM	(8) SM	(9) CZ	(10) PM	(11) SM	(12) CZ	(13) PM	(14) SM	(15) CZ
TreatGr x Active x Price	-1.411** (0.643)	0.062** (0.028)	0.023 (0.019)	-1.052 (1.035)	-0.361*** (0.101)	-0.096 (0.059)	-0.999 (0.946)	0.172*** (0.048)	-0.027 (0.032)	-1.483** (0.720)	0.060** (0.029)	0.057*** (0.022)			
L.Initial x Price	0.096*** (0.018)	0.105*** (0.023)	0.095*** (0.017)	0.102** (0.040)	0.453*** (0.097)	0.105** (0.040)	0.054** (0.026)	-0.035 (0.028)	0.071*** (0.024)	0.082*** (0.021)	0.115*** (0.022)	0.062*** (0.020)			
TreatGr x Active x L.Price													-1.246** (0.617)	0.024 (0.041)	0.161*** (0.035)
L.Initial x L.Price													-0.244*** (0.024)	-0.246*** (0.022)	-0.332*** (0.025)
L.Initial	-0.499*** (0.024)	-0.497*** (0.025)	-0.501*** (0.023)	-0.576*** (0.033)	-0.740*** (0.049)	-0.567*** (0.031)	-0.501*** (0.025)	-0.467*** (0.025)	-0.509*** (0.025)	-0.524*** (0.024)	-0.541*** (0.026)	-0.519*** (0.024)	2.660*** (0.176)	2.988*** (0.188)	2.531*** (0.182)
Observations	5104	5104	5104	1276	1276	1276	5052	5052	5052	5104	5104	5104	5104	5104	5104
Municipalities	464	464	464	166	166	166	464	464	464	464	464	464	464	464	464
R-sq	0.29	0.31	0.29	0.52	0.53	0.52	0.29	0.31	0.29	0.30	0.32	0.30	0.47	0.49	0.48
I x P	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Total price effects, policy off/on</b>															
dydx(P) policy off	0.50	-0.47	-0.07	0.95	2.38	-0.45	-1.95	-1.53	-0.29	1.59	-0.48	-0.09	3.63	0.15	0.45
p-quant	0.23	0.07	0.70	0.34	0.00	0.47	0.02	0.00	0.49	0.01	0.12	0.70	0.00	0.67	0.22
dydx(P) policy on	-0.91	-0.12	0.06	-0.10	0.37	-1.00	-2.95	-0.57	-0.44	0.11	-0.14	0.23	2.38	0.34	1.36
p-quant	0.13	0.52	0.75	0.92	0.34	0.09	0.00	0.09	0.34	0.88	0.56	0.28	0.02	0.35	0.00
<b>Difference in total price effect</b>															
Difference	-1.41	0.35	0.13	-1.05	-2.01	-0.55	-1.00	0.96	-0.15	-1.48	0.33	0.32	-1.25	0.19	0.92
p-quant	0.03	0.03	0.24	0.31	0.00	0.10	0.29	0.00	0.40	0.04	0.04	0.01	0.04	0.56	0.00

Note: Dependent variables are log total municipal GDP and log carbon loss in the entire municipality. The carbon stock in municipality  $i$  in year  $t$  is calculated as  $C_t^{Entire} = F_t^{Entire} * (C_{2000}^{Entire} / F_{2000}^{Entire})$ , i.e. the remaining forest scaled with the carbon per forest cover in the initial year. Similarly, we calculate the reduction in carbon stock as  $DC_t^{Entire} = DF_t^{Entire} * (C_{2000}^{Entire} / F_{2000}^{Entire})$ . Specifications are based on equation 3 and include interactions between the price and year dummies. The GDP model also includes lagged dependent variable to account for dynamics in GDP. We use contemporaneous prices for the GDP estimations, as GDP is measured for year  $t$ , while the deforestation and hence carbon is measured from August in year  $t - 1$  to August in year  $t$ . All columns include municipal and year fixed effects and the standard errors shown in parentheses are clustered on the municipality level. The samples are restricted to cover municipalities with both GDP and carbon data.

Table A.19: Descriptive statistics GDP and Carbon: Treated Groups

General price index, 2003 vs. 2004-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dln Value agriculture	0.29	0.44	-1.59	2.90	0.07	0.46	-3.79	3.88
Dln Value soy	0.92	0.89	-0.56	4.44	0.19	0.66	-3.18	4.08
Dln Value corn	0.34	0.65	-2.35	3.21	0.01	0.68	-4.38	5.86
Dln Value rest	0.25	0.47	-1.67	2.24	0.05	0.52	-3.75	4.26
Value agriculture (USD mn)	17.55	69.70	0.14	817.63	23.99	88.32	0.06	1,342.98
Value soy (USD mn)	9.29	54.78	0.00	716.39	12.19	59.02	0.00	912.04
Value corn (USD mn)	1.98	7.58	0.00	96.34	3.07	14.93	0.00	362.16
Value rest (USD mn)	6.28	14.27	0.08	105.51	8.73	22.22	0.05	427.81
Yield (V) agriculture	1,079.11	716.42	293.62	10,619.93	1,471.43	1,209.67	205.96	18,583.66
Yield (V) soy	1,237.85	271.02	298.43	1,804.87	1,184.21	388.53	0.00	3,546.20
Yield (V) corn	558.12	299.24	62.07	1,969.61	555.83	333.08	0.00	2,924.12
Yield (V) rest	1,254.17	855.46	275.90	10,959.25	1,901.47	1,640.38	237.94	20,996.96
Yield agriculture	5.99	8.53	1.23	77.74	6.57	7.98	0.49	83.96
Yield soy	2.77	0.38	1.50	3.48	2.85	0.37	0.75	4.50
Yield corn	1.69	0.92	0.35	5.40	2.01	1.20	0.03	8.00
Yield rest	7.60	9.82	1.08	78.44	8.51	9.50	0.49	92.51
P agriculture	248.75	120.05	27.94	927.17	274.16	130.98	19.47	1,502.68
P soy	446.71	84.82	162.78	654.24	413.53	121.48	0.00	1,182.07
P corn	337.54	90.45	88.67	743.08	299.15	100.06	0.00	1,462.51
P rest	234.44	132.69	27.71	983.91	283.18	169.83	17.31	1,629.38
DC outside (USD mn, at 50 USD/tCO2)	116.41	211.44	0.00	1,863.28	46.34	109.65	0.00	1,881.00
P level	1.10	0.09	0.87	1.70	1.72	0.40	0.83	2.48
Observations	464				4640			

Priority municipality list, 2003-2007 vs. 2008-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dln Value agriculture	0.08	0.45	-1.41	1.75	0.14	0.40	-1.23	2.13
Dln Value soy	0.29	0.89	-1.47	4.44	0.38	0.63	-1.51	3.22
Dln Value corn	0.05	0.69	-4.06	3.22	0.14	0.81	-2.86	3.56
Dln Value rest	0.05	0.63	-2.37	3.36	0.06	0.43	-2.43	1.36
Value agriculture (USD mn)	30.74	61.93	1.26	520.09	55.75	102.94	1.44	600.11
Value soy (USD mn)	16.62	47.27	0.00	407.92	35.49	81.27	0.00	475.75
Value corn (USD mn)	3.27	5.67	0.02	39.21	8.19	17.01	0.04	147.70
Value rest (USD mn)	10.85	13.62	0.71	116.87	12.06	12.76	0.87	77.78
Yield (V) agriculture	1,088.94	541.36	360.48	3,863.79	1,811.79	1,227.07	280.54	9,416.13
Yield (V) soy	1,026.76	327.01	447.11	1,804.87	1,369.91	329.66	487.35	2,562.00
Yield (V) corn	572.92	304.86	62.07	2,042.24	792.75	416.57	103.97	2,151.33
Yield (V) rest	1,347.82	791.76	372.46	5,926.13	2,398.24	1,607.97	301.26	10,904.03
Yield agriculture	5.16	4.57	1.53	29.62	5.71	3.86	1.20	25.60
Yield soy	2.89	0.32	1.40	3.50	3.03	0.34	0.75	3.60
Yield corn	2.32	1.15	0.40	6.34	3.11	1.52	0.40	6.43
Yield rest	6.63	6.69	1.45	47.40	7.71	6.46	1.32	43.70
P agriculture	260.54	106.60	39.77	584.36	341.66	117.75	64.12	839.23
P soy	355.51	107.09	206.09	626.69	452.91	98.74	211.79	779.77
P corn	267.35	97.54	71.28	743.08	272.73	98.53	71.28	779.77
P rest	273.89	143.35	33.03	801.64	373.86	178.37	40.16	944.39
DC outside (USD mn, at 50 USD/tCO2)	344.60	311.50	4.30	1,881.00	113.19	137.09	0.00	1,001.67
P level	1.32	0.29	0.98	2.31	2.01	0.17	1.63	2.40
Observations	282				257			

Note: Value refers to the total value of crop production, Yield (V) is the mean value of crop production per hectare, Yield is the mean quantity produced per hectare, P is the implicit average price, calculated as Value/Quantity. All variables measured at the municipality level. "agriculture" refers to aggregates across the ten crops used in this study. *Dln* refers to first difference of logs. See section 3 for more details on the data.

Table A.20: Descriptive statistics GDP and Carbon: Treated Groups

Soy Moratorium, 2003-2005 vs. 2006-2013								
	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dln Value agriculture	0.26	0.55	-1.62	3.13	0.09	0.44	-2.85	2.13
Dln Value soy	0.47	0.94	-1.94	4.44	0.14	0.55	-3.18	3.22
Dln Value corn	0.07	0.78	-2.94	3.21	0.12	0.80	-4.38	3.76
Dln Value rest	0.23	0.67	-2.54	4.26	0.02	0.57	-2.99	2.57
Value agriculture (USD mn)	54.68	134.40	0.23	1,103.04	66.44	152.31	0.06	1,342.98
Value soy (USD mn)	33.63	98.74	0.00	888.75	40.11	100.97	0.00	912.04
Value corn (USD mn)	4.08	11.01	0.00	96.34	9.64	28.45	0.00	362.16
Value rest (USD mn)	16.97	34.70	0.08	345.16	16.69	35.53	0.06	427.81
Yield (V) agriculture	1,160.72	538.45	288.71	5,083.88	1,508.75	1,035.26	384.84	10,609.77
Yield (V) soy	1,124.77	326.29	90.80	2,062.29	1,190.79	389.65	248.98	3,546.20
Yield (V) corn	624.23	288.20	195.06	2,042.24	719.94	311.54	200.80	2,151.33
Yield (V) rest	1,440.33	924.24	364.82	7,359.97	2,188.71	1,798.83	297.11	15,588.29
Yield agriculture	5.38	8.51	1.82	71.71	6.08	9.11	0.06	83.96
Yield soy	2.70	0.39	0.96	3.60	2.91	0.32	0.75	3.60
Yield corn	2.50	0.94	0.60	5.98	3.10	1.29	0.60	6.69
Yield rest	7.24	10.65	1.60	76.73	8.82	12.01	0.88	92.51
P agriculture	303.38	118.68	19.47	927.17	316.42	119.83	24.07	1,013.08
P soy	416.99	109.37	30.89	662.30	407.44	121.46	135.81	1,182.07
P corn	263.48	96.71	92.65	581.93	248.64	88.28	71.28	585.05
P rest	306.39	198.33	17.31	1,629.38	345.77	190.42	22.75	1,135.37
DC outside (USD mn, at 50 USD/tCO2)	128.45	211.80	0.00	1,881.00	30.57	71.74	0.00	831.41
P level	1.16	0.10	0.83	1.95	1.84	0.33	1.01	2.45
Psoy level	0.52	0.33	0.00	1.21	0.72	0.47	0.00	1.84
Pnonsoy level	0.66	0.31	0.11	1.77	1.09	0.53	0.13	2.42
Pcorn level	0.23	0.18	0.00	1.04	0.38	0.32	0.00	2.17
Observations	432				1152			

Conservation Zones, Municipality specific pre and post periods

	Treated: pre				Treated: post			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Dln Value agriculture	0.08	0.46	-1.97	1.94	0.11	0.47	-2.56	2.48
Dln Value soy	0.31	0.98	-1.52	4.44	0.16	0.55	-2.27	2.15
Dln Value corn	0.09	0.73	-4.26	3.81	0.04	0.64	-3.97	3.14
Dln Value rest	0.06	0.54	-2.54	3.36	0.10	0.52	-2.56	2.70
Value agriculture (USD mn)	20.03	59.62	0.14	601.52	20.40	62.46	0.16	669.89
Value soy (USD mn)	9.31	40.53	0.00	414.74	8.14	41.61	0.00	430.07
Value corn (USD mn)	2.04	6.46	0.00	75.41	2.25	8.04	0.00	93.48
Value rest (USD mn)	8.67	18.91	0.13	271.29	10.01	18.76	0.12	181.19
Yield (V) agriculture	1,335.33	1,253.02	293.62	12,788.05	2,145.32	1,729.81	280.54	18,583.66
Yield (V) soy	1,013.38	333.73	248.98	1,804.87	1,333.19	432.43	440.71	3,546.20
Yield (V) corn	552.31	310.12	94.06	1,773.46	646.41	348.68	0.00	2,105.12
Yield (V) rest	1,582.15	1,339.19	305.95	12,842.60	2,719.44	2,197.72	301.26	20,996.96
Yield agriculture	6.27	7.56	1.49	66.15	6.91	4.55	0.91	61.07
Yield soy	2.69	0.39	1.20	3.50	2.89	0.33	1.50	3.60
Yield corn	1.88	1.02	0.35	5.81	1.97	1.09	0.03	6.01
Yield rest	7.62	8.06	1.36	68.11	8.81	5.34	0.91	62.36
P agriculture	254.03	112.48	37.07	586.72	320.72	153.31	38.31	1,502.68
P soy	375.80	113.64	135.81	654.24	459.69	134.49	198.16	1,182.07
P corn	308.04	94.04	85.53	626.69	346.35	109.99	0.00	779.77
P rest	251.42	137.37	34.73	1,389.69	324.58	173.58	35.69	1,590.78
DC outside (USD mn, at 50 USD/tCO2)	126.28	217.29	0.00	1,881.00	57.78	116.73	0.00	1,404.56
P level	1.31	0.31	0.90	2.45	1.84	0.32	1.08	2.43
Observations	493				948			

Note: Value refers to the total value of crop production, Yield (V) is the mean value of crop production per hectare, Yield is the mean quantity produced per hectare, P is the implicit average price, calculated as Value/Quantity. All variables measured at the municipality level. "agriculture" refers to aggregates across the ten crops used in this study. *Dln* refers to first difference of logs. See section 3 for more details on the data.

Table A.21: Effects on Value Creation in Agriculture and Carbon loss

		<i>CO<sub>2</sub> loss</i>										
Policy		$\beta$	$P_{pre}$	$P_{post}$	$\% \Delta P$	$\% \Delta CO_2^i$	$CO_2$	$CO_{2,cf}^i$	$\Delta CO_2$	$\% \Delta CO_{2,cf}$	$PV10 SEQ$	$PV10 CO_2$
Price	Off	0.93	1.10	1.72	56.4	52	46	31	16		0.27	16
Prio	Off	3.63	1.32	2.01	52.3	360		193				
Prio	On	2.38	1.32	2.01	52.3	172	114	42	-79	-40.9	-2.59	-81
SM	Off	0.15	1.16	1.84	58.6	7		28				
SM	On	0.34	1.16	1.84	58.6	17	31	26	3	9.2	0.10	3
CZ	Off	0.45	1.31	1.84	40.5	17		42				
CZ	On	1.36	1.31	1.84	40.5	59	58	36	15	36.2	0.45	16

*Production value in agriculture and local price of CO<sub>2</sub>*

		$\beta^i$	$P_{pre}$	$P_{post}$	$\% \Delta P$	$\Delta g^i$	$\frac{e^{\Delta g^{on} T_g}}{e^{\Delta g^{off} T_g}}$	$\bar{R}$	$R_{cf}$	$\Delta R$	$PV10 \Delta R$	$PV10 \Delta \Pi$	$PV10 CO_2$	$SCC_{estimate}^{local}$	$SCC_{plot-by-plot}^{local}$
Price		0.31	1.10	1.72	56.4	0.14	0.87	24	21	3.1	31	5	16	15	2.6
Prio	Off	0.50	1.32	2.01	52.3	0.21									
Prio	On	-0.91	1.32	2.01	52.3	-0.38	0.55	56	101	-45.1	-451	-68	-81	42	6.1
SM	Off	-0.47	1.16	1.84	58.6	-0.22									
SM	On	-0.12	1.16	1.84	58.6	-0.06	1.18	66	57	9.9	99	15	3	278	6.2
CZ	Off	-0.07	1.31	1.84	40.5	-0.02									
CZ	On	0.06	1.31	1.84	40.5	0.02	1.05	20	20	0.9	9	1	16	4	6.4

Note: Table provides treatment effects on the treated, with ( $i = on$ ) and without ( $i = off$ ) the policy.

Upper panel: identical calculations as Table A.4, where  $Y$  is carbon loss (measured in USD mn, at 50 USD/tCO<sub>2</sub>).  $PV10 SEQ$  is the present value of carbon sequestration, if the forest were standing.  $PV10 CO_2 = PV10 SEQ + \Delta CO_2$

Lower panel:  $R$  is production value of the ten crops included in this study (Value agriculture, USD mn).  $\Delta g^i$  gives the estimated difference in the growth rate:  $\Delta g^i = \beta^i \Delta \ln(P)$ .  $\frac{e^{\Delta g^{on} T_g}}{e^{\Delta g^{off} T_g}}$  gives  $R$  with the policy relative to  $R$  without the policy after  $T$  years. We set  $T=1$ .  $\bar{R}$  is the actual mean of Value agriculture in the treated municipality-years.  $R_{cf}$  is the counterfactual  $R$  with the price increase but without the policy.  $\Delta R = \bar{R} - R_{cf}$ .  $PV10 \Delta R = \Delta R / 0.10$ , i.e. the present value with a 10% discount rate and infinite horizon.  $PV10 \Delta \Pi = 0.15 PV10 \Delta R$ , i.e. we use a 15% profit margin.  $SCC_{estimate}^{local}$  is the local price of carbon based on the estimated effects:  $PV10 \Delta \Pi / PV10 CO_2 * 50$ .  $SCC_{plot-by-plot}^{local}$  is the local price of carbon when we use the raw data for production values.  $\beta^i$  estimates from Tables 5-6. The necessary descriptive statistics are from Tables A.19-A.20.