# Essays on Environmental and Resource Economics: Evaluation of Voluntary and Mandatory Policies

Von der Fakultät für Wirtschaftswissenschaften der Rheinisch-Westfälischen Technischen Hochschule Aachen zur Erlangung des akademischen Grades einer Doktorin der Wirtschafts- und Sozialwissenschaften genehmigte Dissertation

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Tag der mündlichen Prüfung: 2. Mai 2019

Der Aufsatz *Sourcing from Conflict Regions: Policies to Improve Transparency in International Supply Chains* ist im Jahr 2018 als Working Paper in der MAGKS Joint Discussion Paper Series in Economics als Nummer 38-2018 veröffentlicht.

Der Aufsatz *Protection and Profit: Empirical Evidence of Governmental and Market-Based Forest Policies* ist im Jahr 2019 als Working Paper in der MAGKS Joint Discussion Paper Series in Economics als Nummer 01-2019 veröffentlicht.

# Acknowledgement

Writing this dissertation was an exciting and challenging experience which contributed substantially to my personal development over the last years. This is to no minor part due to the help and support of several people to whom I want to express my sincere gratitude.

First and foremost, I thank my supervisor **Oliver Lorz** for his continuous support, for his profound advice and his constructive honesty at any point of my dissertation. I am deeply grateful that he gave me the opportunity to follow my research interests and for his faith in me and in my skills. Furthermore, I consider it a great honour and joy to work with him on our joint paper and learn from his research experience.

I am also hugely appreciative to my second supervisor **Thomas Lontzek** for bringing so much vitality into our office life and for sharing his inspiring views with me. I would also like to thank the other two members of my committee **Almut Balleer** and **Christian Grund** for their time and interest in my work.

A special thanks goes to **Torfinn Harding** who invited me to be part of the research group on *Tropical Deforestation* and who gave me the opportunity to work with him in Norway and Brazil. I thank my co-author **Karlygash Kuralbayeva** for being a great source of conceptual understanding and advice.

My collogues from the 5th floor have contributed immensely to my wonderful personal and professional time in Aachen. I thank them for their help and for their friendship. I am particularly indebted to **Morten Endrikat**, my office mate, with whom I had numerous discussions on my research and who helped me passing demanding phases with his humour and optimism. Similar profound gratitude goes to **Susanne Mohammad Zadeh** for her unconditional support which has gone far beyond the call of duty. I want to thank various friends and family members who encouraged and helped me at every stage of this dissertation.

I would like to express my deep gratitude and love to **José Omar Ruiz Ramirez** not only for his affection, patience and empathy but also for his smart ideas and comments which contributed to the successful completion of this thesis.

Finally, this thesis would not have been written without the tremendous support, confidence and love of my parents, **Matthias Herzberg** and **Gabriele Buck-Herzberg**, who raised me to always stay curious and who encouraged me in all my pursuits.

So many thanks to all of you.

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# Chapter I

# Introduction

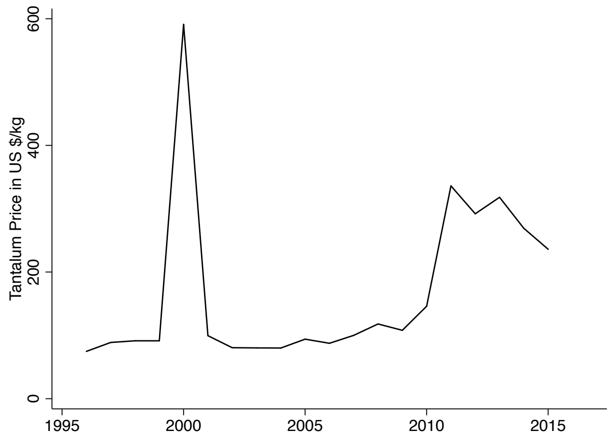
## I.1 Motivation

When we go shopping today, be it in a supermarket, in a clothing store, or in an electronics shop, we will rarely find any product which does not contain material from one or several foreign countries. A product's supply chain is often globalized and complex, such that it is difficult for the end consumer to trace the chain back to the first link. Consequentially, negative effects on the local population or on the environment, which are associated with the production of the good or its primary inputs, are not transparent and are only occasionally detected by international organizations or the media. Such issues become particularly visible in times of price booms, triggered by a higher demand or a shortage in the supply, which can lead to a rapid increase in production volume and in related social and environmental impacts.

This dissertation considers policy and market instruments that aim to increase transparency along the supply chain and to mitigate negative externalities of the primary production. Therefore, three primary sectors are put into focus: The mining industry, the agricultural industry and the forestry industry.

Considering the boom of the mineral sector during the past two decades, it can be easily traced back to the development of new high-technology which requires certain minerals as a fundamental raw material. The dissemination of electronic devices, such as smartphones or notebooks, and the envriomental necessity of electric cars and renewable energy plants are all developments which have augmented the demand for these minerals and are expected to push it to an even higher level in the future (Glöser et al., 2015). Some geological deposits of the so-called high-tech minerals and green tech metals are quite concentrated in some regions[1] of the earth. Access to these resources is especially important for high-tech production countries, such as Japan, Germany, or the US. Besides geological scarcity, a further concern of the sourcing countries is that mineral deposits are often located in countries with weak institutions, where investment is risky and a stable supply is not guaranteed (EU, 2017). Thus, several price peaks over the last decades could be observed due to the rapid development and diffusion of high-tech products on the one hand and the insecurity in supply on the other hand (Ali et al., 2017).

*Figure I.1: Tantalum Price*




Note: The right panel plots the price for one kg tantalum against time. The first peak in 2000 is due to a demand shock that was partly driven by the release of PlayStation 2 and the second peak coincided with the introduction of the Dodd-Frank-Act, which contained a Section on the prevention of raw material from the Democratic Republic of Congo and adjoining states. Data source: USGS (2015a)

As an example, figure I.1 plots the price for tantalum between 1995 and 2015. Anecdotal evidence connects the dramatic price increase between 1999 and 2000 to the release of PlayStation 2 in March 2000, which reached sales numbers above 150 million. Sony appeared to have trouble meeting consumer demand and ordered a large number of electric capacitors, which require tantalum as a main input. As a result, an “overnight”price explosion boosted prices up to 600$ per kilogram of tantalum. The price peak led to a rush on columbite-tantalite[2], which can be found in the Democratic Republic of Congo

[1]For instance, China produces around 90% of the world’s rare earth elements, which are essential inputs for renewable energy plants, such as wind turbines or solar panels (EU, 2017), and around 70 % of the world’s germanium, which is used in semiconductors and substrates in electronic circuitry and solar cells (USGS, 2016a). South Africa is the leading producer of the platinum-group metals, which find their main application in catalysts in the automotive sector, and holds about 91% of the reserves (USGS, 2016b). Besides coltan, the Democratic Republic of Congo also holds the largest reserves of cobalt, which is a component of battery electrodes that are important, e.g., in electric car production (USGS, 2015b). In Brazil, 95% of the global niobium can be found, a metal which is used in superalloy for rockets and wind turbines as well as in biodiesel production (EU, 2017).

[2]Columbite-tantalite or known as ”coltan” is an ore from which tantalum is extracted (USGS, 2014).

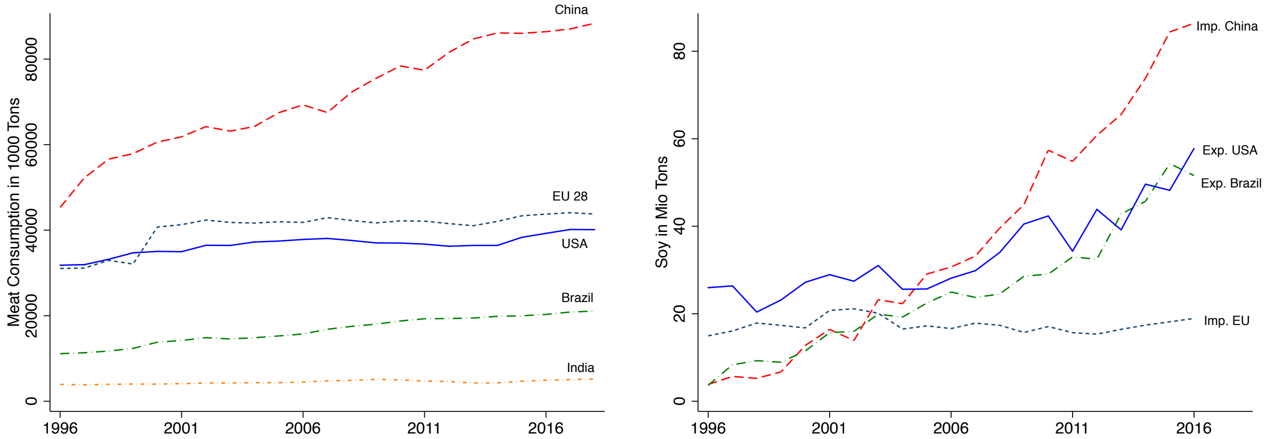
(DRC), Rwanda, and adjoining countries. Numerous armed rebel groups fought for control over the mines and forced civilians to extract coltan from the mines. These vicious fights between the different militias in the region have since been called the *Playstation War* (UN, 2003; Lasker, 2008). The peaks and increases in prices of minerals which are especially used in the high-tech industry in the 2000s are known as the *commodities supercycle* and are broadly associated with internal conflicts and enslavement of adults and children who are forced to work in the mines (Collier et al., 2004; Bazzi and Blattman, 2014; Berman et al., 2017).

While novel technologies drive up demand for certain materials, a general increase in the demand for consumption goods is induced by rapidly growing emerging countries. This new demand does not only accelerate the extraction of the world's natural resources but also often leads to unsustainable forms of extraction due to the lack of regulation on both sides of the supply chain.

As an example, the trade with illegally harvested tropical timber could be considered. Illegal logging is a widespread issue in the Peruvian Amazon, such that 70-80% of all harvested timber is estimated to stem from illegal sources (Goncalves, 2012; Osinfor, 2018) Tree species which deliver precious tropical timber, such as mahogany or cedar, have already been brought to the edge of extinction in Peru (National Geographic, 2013). The three main importers of Peruvian tropical wood are China, the US, and Mexico (UN Comtrade, 2018). While the United States, which has a legislation on timber imports, receive mainly wood with "clean documents", the lack of this legislation in China or Mexico means that an estimated 70% of all exports to these countries bear an unacceptable risk of having been logged illegally (Finer et al., 2014).

In Peru's neighboring country Brazil, the agricultural expansion in the Amazon region has lead to a loss of large pieces of forest during the past decades. This boom could also be linked to changing consumption patterns in emerging countries, as the habit of having meat in daily meals has pushed up the demand for meat products to an unknown scale. In China, the annual per capita meat consumption was around 35 kilograms in 1996 and increased up to 62 kilograms in 2013 (FAO, 2018). While China's per capita consumption is still lower than the per capita consumption in Germany (85 kg) and the US (115 kg), its total meat consumption exceeds that of any other country. The left panel of figure I.2 plots the total annual consumption of meat (in tons) of China, the US, the EU, Brazil, and India.

*Figure I.2: Meat Consumption and Soybean Trade*




Note: The left panel plots the annual meat consumption in 1000 tons against time. Data are published by OECD (2018). The left panel plots the soy import of the EU and China and the soy exports of the US and Brazil against time. Data are published by FAO (2018).

These increasing levels of meat consumption are especially challenging for the availability land resources and nutritious soils. Today, already 50% of the habitable land on earth is dedicated to agricultural purposes, of which about 88% is used to produce livestock or animal food.[3]

Due to their various beneficial characteristics, soybeans are one of the most popular plant-based animal foods. In 2016, trade volume of soybeans summed up to over 54 billion dollars (FAO, 2018), and thus it may not be surprising that China's importing of US soybeans is one of the main issues in the recent trade policy between these two countries (The Guardian, 2018).

The propagation of *bovine spongiform encephalopathy* (BSE) disease in the early 1990s in Europe led to an abandonment of protein-rich concentrate based on meat and bone meal. The shortage in protein-based food for animals boosted the price of soybeans, whose nutritional properties and high share of protein make it a highly suitable food for livestock production. Novel genetically modified seeds made cultivation under difficult climatic conditions in the region possible. Moreover, the upcoming Chinese economy was seeking to serve its increasing livestock production, and China finally became the largest importer of Brazilian soybeans during the 2000s. The right panel of figure I.2 plots the import volume of China and the EU and the export volume of the major producers: Brazil and the US.

Studies using geospatial data on land conversion show that the expansion of soybean

[3]More precisely, 77% of all agricultural land serves for livestock production, such as pasture and grazing land. About 23% of the agricultural area is dedicated to crop cultivation. Almost half of the crop harvest is used for animal feed (FAO, 2018). However, on the other half, plant-based food for human meals is grown and it delivers 82% of the global caloric supply, while only 18% of the caloric requirement is satisfied by meat and dairy products (Poore and Nemecek, 2018).

production is the main driver of the high deforestation rates in the Brazilian Cerrado (Gibbs et al., 2015b), the Paraguayan Amazon (Fehlenberg et al., 2017), and the Argentine Chaco dry forest (Gasparri and Grau, 2009). Such virgin forest lands do not only host a huge biodiversity but are also large storages of carbon. Accounting for these carbon emissions by land conversion, the production of each kilogram of soybeans is associated with the release of 0.6 kg $CO_2$ into the atmosphere, excluding any emissions caused by transport. In 2017, the area planted with soybeans worldwide reached a size equal to three times the area of Germany (FAO, 2018).

These examples illustrate that an everyday consumption good could be directly or indirectly related to a decrease in the welfare of another country, which is not immediately obvious to the consumer, especially if this welfare decline is associated to the primary production at the beginning of the supply chain. The question arises of how to regulate and control the production of commodities in a supply chain in order to reduce or eliminate negative effects on the environment and on humans. The advocates of a global solution, which requires agreements between most countries, aim to establish worldwide-valid agreements on standards of production and trade.

Critics of global regulations point out that such agreements will never work due to the lack of credible sanctions against countries which violate standards or exceed environmental limits. They request that regulative policy instruments should be found and implemented on a national level and enforced by the government on the legislative, executive and judicial level.

However, some people consider public policy interventions to be too weak and too slow. They argue that in countries where most regulation would be necessary (mostly developing countries), institutions are weakest and governmental instruments are rarely well established. A third possibility is seen in a market solution induced by responsible producers, conscious consumers, and engaged NGOs, who push companies to become transparent and ensure fair and environmental-friendly production at each stage of their supply chain. Companies could communicate their commitment via certificates, labels, or other forms of participation in transparency projects. This would provide more information for the consumer when choosing a product.

This thesis studies the effectiveness of governmental and market-based instruments in reducing ecological and social deterioration which is linked to the production and extraction of primary products. By using a theoretical approach as well as quasi-experimental empirical techniques, the three essays of this dissertation shed light on the effectiveness of various policy instruments and take a special focus on the robustness of these in periods of high commodity prices.

The first essay in chapter II provides a theoretical model which studies two unilateral policy options of manufacturing countries that source minerals from a resource-abundant

country with a weak institutional background. The research is motivated by demands for more transparency in global supply chains and increasing possibilities in tracking and tracing along the value chain in order to identify legally extracted minerals. It aims to deepen the understanding of the welfare effects of trade policies which ban an entire region or, alternatively, ban only those mines which are not proven to operate legally.
Chapter III empirically investigates the effects of governmental and consumer-driven standards in the tropical timber sector. The study is motivated by a lack of evidence on the effectiveness of market-driven sustainable forestry compared to governmentally implemented sustainable forest projects. The research gives evidence on the creditability of environmental-friendly labeled forest products and disentangles the factors which are decisive for the impact of these policies on deforestation.
In chapter IV, the impact of booming agricultural commodity prices on deforestation in Brazil is empirically analyzed and it is shown how different policy instruments affect this impact. Results show that a policy design that focuses on economic and institutional aspects in selected municipalities is superior to policies that target a single crop or puts a part of the forest under protection. The research is inspired by the agricultural price boom in the 2000s and, during the same time period, a massive reduction in deforestation rates in the Brazilian Amazon.
The following section summarizes central developments in the research around social conflicts and environmental damage connected to primary goods production. It is shown how insights from my own research, which are presented in this dissertation contribute to this literature.

## I.2 Literature Review and Contribution

### The Link between Civil war and Natural Resources

In contrast to what many politicians and civilians still believe, the discovery of large oil fields or precious minerals does not automatically result in higher living standards for the people living in the resource-rich country. The political and economic literature has studied the phenomenon of the so called *resource curse*, on both the theoretical and the empirical level.[4] The quality of a country's institutions, before a large resource discovery was made, is identified to be the key criterion that decides about whether natural resources increase a country's welfare (such as Norway or Botswana) or whether a country's economy slows down due to a dominant resource sector (such as in Venezuela or Nigeria). Countries where corruption is low, law and order are valid, inflows and outflows are transparent, and in which politicians have to justify their decisions are less endan-

[4]Examples for pioneering work on the resource curse are Sachs and Warner (1995) and Collier and Hoeffler (1998)

gered of falling into the resource trap.[5]

A mechanism that illustrates simply and clearly how productivity and development of the agricultural, industry, and service sectors could be reduced by a booming resource sector is the *rent-seeking* concept, which can be dated back to the work of Tullock (1967). It describes economic actors using part of their factor endowment, such as labor force or capital, to influence political decisions and change the allocation of rents for their own benefit. This creates a competition for the distribution of political rents and leads to a certain amount of factors which are diverted from productive activities to rent-seeking and thereby lower the output of goods and services in the country. Theoretical models by Tornell and Lane (1999); Torvik (2002); Wick and Bulte (2006) show that booms in natural resources, triggered by a discovery or by a price increase, are strong incentives to enter in rent-seeking activities and that productivity and growth in other sectors decline. In the context of natural resources, rent-seeking could also be interpreted as illegal extraction of resources. For instance, it is estimated that around 100,000 barrels of oil ($3.6bn) are stolen from pipelines every day in the Niger Delta (Nigeria), which often forces the extractive companies to shut down pipelines and lower their own extraction (Katsouris and Sayne, 2015). Similarly in Peru, illegal gold mining is estimated to be about $3bn worth, which is twice as much as the countrys drug trade (Asner et al., 2013). Natural resources are also a popular source of income for rebel and terroristic groups, such as the oil trade network of the Islamic State or the Hezbollah (Giraldo and Trinkunas, 2007). Thus, resource abundance makes a country not only prone to a large rent-seeking sector but also to civil conflicts (Ross, 2006). In a study covering the whole African continent, Berman et al. (2017) find that up to a quarter of the average level of violence on the continent could be explained by price booms of natural resources during the super commodity cycle in the 2000s.

In the theoretical model presented in chapter II, we consider such a situation which illegal operators in a mineral-rich country reduce public revenues not only via theft of the resources but also via government spending to defend and recapture the sovereignty over mines on public territory. Within this framework, we study how unilateral policies of another country sourcing minerals from this state could decline the incentives for rent-seeking and reduce the dead-weight lost in the country's welfare.

In international polices tariffs, sanctions, or embargoes are popular instruments to regulate trade with countries that face problems of international or internal conflicts over the sovereignty of resource extraction, Such policies are supposed to force upstream countries to comply with international standards, to execute geographical control, or to calm domestic consumers. In the case of minerals, a recent example of a legal act which

[5] There is a large literature on the link between the resource curse and institutions, started by the fundamental work by Mehlum et al. (2006) Other influential articles on this linkage are: Robinson et al. (2006); Arezki and van der Ploeg (2011); Ross (2001).

aims to increase the accountability of domestic firms is Section 1502 of the Dodd Frank Act. It requires that publicly traded companies sourcing any minerals from the DRC or adjoining countries to disclose their supply chain (SEC, 2010). In this case, especially tech-companies, such as Apple, Intel or, Microsoft are affected, which have to declare any risk of illegal components within their supply-chain. Studies have shown that such unilateral actions can only reduce violence related to resource extraction if investment into conflicts and rent-seeking is limited by binding constraints (Janus, 2012) and that a ban on certain minerals does not lead to a shift of illegal extraction towards lootable and unregulated minerals (Parker and Vadheim, 2017).

In the model in chapter II these findings are expanded by showing that the outcome of an embargo depends essentially on the relative resource endowment across the several extracting countries and the demand from countries which do not have any legislation on resource imports. An embargo against one country or region punishes not only illegal actors but also legal companies and workers, who face a decline in prices if demand from non-embargo countries is not strong enough. Analogously, the purchasing country will experience a decline in welfare if the supply via countries which are not sanctioned does not completely satisfy the demand or only with a drastic increase in prices.

Having seen how the extraction of raw material can cause social conflicts and economic losses, the next section considers the global issue of tropical deforestation as a consequence of increasing demands for timber and land.

### Deforestation and Trade from a Global Perspective

One of the most important developments in the research on global deforestation in the last decade has been the increase in the quality of satellite pictures and the diffusion of high-performance computers which have the power to deal with large amounts of data and which have the software to translate graphical information into data that can be used for empirical estimations. The most cited and applied data set within the scientific community is Global Forest Data published by Hansen et al. (2013), which offers a spatial resolution of 30 meters for the entire globe.[6] A recent study on change in global forest cover by Song et al. (2018), which uses these data, presents a surprising result: Global tree cover has actually increased over the last 35 years. Forest loss has been offset by intensive reforestation by about 2.24 million $km^2$, which is more than four times the size of France. The researchers explain that this tree cover gain is being driven by warmer temperatures that allow forests to grow in poleward regions, by agriculturally abandoned areas and by

[6]Besides Hansen et al. (2013), national systems exist which provide data on deforestation in domestic forests, e.g. the Brazilian Space Agency INPE (2017).

China's large "green wall"project.[7] In Europe, tree cover in 2018 even exceeds the tree cover of 100 years ago. Indeed, forest gain is mostly observed where human development is high and economies are developed (Kauppi et al., 2018). This effect is also known as the Environmental Kuznets Curve (EKC)[8], which predicts that while developing countries in their catching-up process increase environmental destruction until they reach an intermediate level of income, environmental outcome improves after further economic growth. However, this increase in forest cover is often only possible since these countries source wooden furniture, paper pulp, or agricultural goods from abroad. For instance, in a study on geographic displacement of forest-clearing across countries Meyfroidt et al. (2010) describe that strengthened environmental policies in Vietnam have led to a forest gain since the 1990s, made possible by large wood imports from neighboring countries, where deforestation rates have increased.

In a pioneering work, Foster and Rosenzweig (2003) offer another explanation for the appearance of the EKC phenomenon. Studying forest cover change in India, they argue that in a relatively closed economy, income growth leads to a higher demand for forest products and, consequentially, to an increase in forest land. From this perspective forest could be considered as a renewable resource, whose harvesting and replantation are driven by external market forces. However, this limits a forest's benefits to the simple timber value which could be extracted, and it neglects positive effects on climate, biodiversity, and human health, the so-called ecosystem services. The forests which deliver the highest amount of these ecosystem services are tropical forests. In contrast to temperate forests, which are mostly responsible for the net gain over the last 35 years, tropical deforestation has increased sharply up to a loss of 15% of all tropical dry forests on earth. The country which hosts the largest tropical forest area on earth is Brazil and it is also the country with the largest area of forest lost of 399,000 $km^2$ between 1982 and 2016, which is more than the combined loss of the next four countries in the ranking (Song et al., 2018). However, considering tropical deforestation in the 2000s, Hansen et al. (2013) detected that deforestation rates are tending to decline in Brazil and Peru, while increasing deforestation rates in Indonesia, the Democratic Republic of Congo, Paraguay, and Malaysia are offsetting these positive tendencies. In a recent follow-up study Curtis et al. (2018), identify five main drivers of forest loss in satellite images: wildfire, logging of tree plantations, large-scale agriculture, small-scale agriculture, and urbanization. The authors show that large-scale agriculture is identified to contribute most to global forest

[7]The Three-North Shelter Forest Programme is a large ecological reforestation program covering 13 Chinese provinces. The project aim is to stop desertification in middle China by replanting trees on an area of 350,000 $km^2$ until 2050.

[8]The original Kuznets curve is a concept that describes the U-shaped relationship between income and inequality in a country (Kuznets, 1955, 1959). Empirical evidence on the connection between income per capita and envriomental outcomes is provided by Grossman and Krueger (1995), who showed that $SO_2$ pollution increases until an income of \$5,000-\$6,000 per capita and declines afterwards.

lost, being responsible for the 27% of all deforestation. In the Brazilian Amazon, the share of forest cleared for agricultural purposes even lies at around 50% (Godar et al., 2014). In chapter IV of this thesis, an empirical estimation on the effect of booming agricultural prices on deforestation is presented, which finds that around 0.96 Pg[9] of carbon stored in biomass was lost between 2002 and 2013. In general, deforestation in the tropics accounts roughly for one tenth of the total anthropogenic carbon emissions in the atmosphere (Bebber and Butt, 2017).
Converting forest into crop fields, pasture, or plantation is classified as permanent land use change, due to the fact that once cleared, tropical forests tend not to revert to mature forests, when the land is used for large-scale agricultural cultivation and the soil is intensively prepared for this purpose (Lawrence et al., 2007). Such irreversible changes in land cover does not only have dramatic consequences for biodiversity but also decreases potential yields and lowers the carbon stored in tropical trees in a long time horizon. Results from studies on the disappearance of the Maya culture[10] in Middle and South America show that the collapse of this civilization could not only be attributed (to a large part) to a long-lasting drought caused by intensive deforestation of their environment (Cook et al., 2012) but also because the carbon-sink capacity of the soils[11], which they used for agriculture, has not recovered to pre-deforestation values by now (Douglas et al., 2018), which implies that also the current replacement of tropical forests by agricultural plantations will have long-lasting effects on soil fertility and carbon sinks. Moreover future harvests are jeopardized, since deforestation leads to a reduction in precipitation and a higher frequency of droughts[12], which could cause large crop failures (Lesk et al., 2016). In the Legal Amazon, continuous loss of biodiversity and carbon storage might reach a threshold, beyond which changes are irreversible and transform the tropical forest into a degraded savanna with unpredictable consequences for humans[13] and nature. The tipping point is estimated at a local temperature increase of four degree Celsius or when deforestation exceeds 40% of the forest area. At the end of 2017, around 20% of the Brazilian Amazon was deforested and the region has warmed about one degree Celsius

[9]One petagram is $10^{15}$ grams or one billion metric tonnes. For comparison, the carbon emissions caused by burning of fossil fuels are estimated to be about 9.9 PgC/yr in 2016 (Le Quéré et al., 2016).

[10]The preclassical period of the Maya civilization is dated at 2000 years BC, population and agricultural expansion peaked in the classical period around 250 AD and finally collapsed in 900 AD.

[11]Soil carbon is the largest terrestrial carbon reservoir, absorbing around 25% of the world's $CO_2$ emissions from the atmosphere (Scharlemann et al., 2014)

[12]As crops are light colored plants the agricultural land reflects more sunlight than dense dark-green forests, which absorb energy from the sun and makes water condense to create cloud and rainfalls. Deforested areas hold less water and reflect more sunlight, which results in less rain and even droughts (Wang et al., 2009; Cook et al., 2012)

[13]Health studies identify direct effects of deforestation as, for instance, a study by Olson et al. (2010) in the Brazilian Amazon, find that an increase of 4.3% in deforestation is associated with an increase in malaria incidence of 48%. Other tropical outbreaks of diseases such as yellow fever, and Lyme disease are also shown to correlate loss of forest cover in a region.

over the last 60 years (Nobre et al., 2016).
Due to the numerous negative externalities of deforestation, affected countries do implement national policies to alleviate deforestation and maintain local environmental benefits. On a national level, countries often implement command-and-control regulations, which are supposed to either control the processes that lead to the problem or to ameliorate the problem after it occurs (Holling and Meffe, 1996). Again, new technologies, such as a satellite-based alert system, help governments to detect illegal deforestation and to react immediately. Ideally, this alarm enables the (environmental) police to catch illegal loggers before they can escape and continue clearing in other parts of the forest. The dominant policy instrument in the combat against deforestation remains the implementation of protected areas (PAs), which are natural parks where human activity is restricted or completely prohibited. In 2015, already over 16% of forest lands worldwide were put under protection (Morales-Hidalgo et al., 2015). Bebber and Butt (2017) find that tropical PAs reduced carbon emissions by 4.88 PgC/yr compared with what would have been emitted by deforestation in this areas without protection. Overall, PAs are estimated to store 14.5% of global forest biomass carbon (Collins and Mitchard, 2017). However, what should not be neglected in the consideration of protected areas' effectiveness is that deforestation could be shifted to areas outside of the protected zone, such that the net effect of this policy is equal to zero, which has been shown in several empirical investigations (among others Aukland et al. (2003); Joppa and Pfaff (2009); Pfaff and Robalino (2017)). In chapter IV of this dissertation, novel evidence is provided on the appearance of leakage around protected areas and other forms of conservation zones, which is related to an increase in agricultural prices. Outcomes of the zoning policy are compared with two other anti-deforestation policies which allows the effectiveness of each policy to be calculated in terms of area deforested, carbon loss, and economic costs.
The empirical evaluation of sustainable forestry in chapter III shows that the appearance and the size of a leakage also depend on the governance form of a conservation zone.
In the next section, I introduce voluntary commitments as a market-based policy instrument of companies and industries which seek to improve social and environmental conditions. This is an overreaching topic that is an object of investigation in all three essays of this dissertation.

### Voluntary Commitments

Voluntary commitments are understood as a social or environmental-friendly action of companies that exceeds what the companies are legally obliged to do. Such commitments, which are often pushed by conscious consumers, could provide access to new markets, allow for a price premium or improve a company's reputation.
However, voluntary commitments are hard for costumers to observe, especially if they

are not implemented locally but at the stage of resource extraction, where transparency of production conditions and legal compliance are often the most necessary. For instance, the pure size and remoteness of the Brazilian Amazon as well as the lack of concentration of timber production makes the creation of a transparent market there challenging (McDermott et al., 2015). As a solution, credible certificates on the legal origin of the timber or other resources are required and translated into a product label which informs the customer that the product has been produced according to certain standards.

For the downstream-firm, this is a comfortable solution, since certification costs are first borne by the primary producer and could be passed on to the end-consumers. For small-scale primary producers, however, relatively high costs of certification and extensive paperwork could be an issue (Rametsteiner and Simula, 2003). New hope for better traceability of supply chains, with a sharp reduction in costs, is seen in the evolution of new technologies, such as RFID chips and the blockchain[14], which offer a decentral approach that generates a digital representation of the physical commodity and tracks it along all stations of the value chain (Westerkamp et al., 2018).

In chapter II of this thesis it is shown that a certification system which could be implemented free of charge, is beneficial for the economic and social outcome in the resource-abundant country and in a manufacturing country with conscious consumers. Based on a novel panel dataset, chapter III analyzis whether a label for sustainably harvested timber, such as the Forest Stewardship Council (FSC) certificate, reduces deforestation rates in the Brazilian Amazon. Moreover, in chapter IV, another form of industry commitment is considered, the so-called Soy Moratorium, in which soy producers and retailers in Brazil signed an agreement not to plant soy on recently deforested fields. It is show that such an industry-driven policy targeting only one crop is prone to leakage, which offsets the positive effect that the moratorium might have.

This thesis aims to improve the understanding of these environmental and resource policies on different levels. In three chapters it applies theoretical and empirical methods to analyze the implementation effect of policy instruments that are supposed to increase transparency in international trade and thereby decrease the number of products on the market which are linked to envriomental destruction or violence against humans.

[14]The blockchain technology was introduced by a Japanese person who calls himself Nakamoto. The principal idea is to store valuable information e.g. economic transaction without having a third party audit or a central control organization. This works by including the whole network as a control instance. This decentralized structure makes failures or hacks nearly impossible. Information and transaction are clustered into blocks and written to a digital ledger by powerful computer ("miners"), which are chosen by solving mathematical puzzles. This procedure makes a blockchain transparent and incorruptible, since all users are able to monitor the record of information and any updated version of it (Tapscott and Tapscott, 2016).

## I.3 Thesis Outline

Based on these motivational thoughts, this section outlines the overall structure of the thesis. The main part involves three interrelated essays focusing on the consequences of regulatory policies in primary goods production and trade from three different perspectives: from that of a downstream country that sources raw materials as inputs from countries with weak institutions, from the local population and companies which implement a sustainable management policy for timber and ecosystem services, and from the perspective of a government which aims to protect its native forests while simultaneously maintaining economic growth. The essays are presented in three separate chapters of this dissertation and can be read independently. The following paragraphs give a first overview on the research question and method, the data, and the central results of the three essays.

**Sourcing from Conflict Regions: Policies to Improve Transparency in International Supply Chains**

Chapter II presents the essay *Sourcing from Conflict Regions: Policies to Improve Transparency in International Supply Chains* in which we develop a theoretical model to study the effects of unilateral policies on prices and intranational conflicts. The paper is joint work with Oliver Lorz.

The model considers a world consisting of manufacturing countries in the North and resource-extracting countries in the South. The market for manufacturing goods is represented by a Dixit Stiglitz monopolistic competition framework. The Southern countries are endowed with minerals which are essential for the production of the manufacturing goods. In one of the two Southern countries, the government and illegally operating rebel groups contest the raw-materials. This illegal extraction is related to human-rights abuse or environmental destruction. Since consumers in the Northern countries are assumed to be altruistic, they prefer to consume manufactured goods which do not contain illegal resources. In our baseline scenario, without any political intervention, we find that consumers suffer a utility loss, since they cannot differentiate between products containing legal raw material and products which contain raw material from illegal sources. We compare this benchmark equilibrium with the effects of two policy interventions that an importing country may implement: First, a region-specific embargo which prohibits importing any raw material from a conflict-affected country and, second, the introduction of a certification system in this country that labels raw material from legal mines as "conflict-free" or "clean".

For the embargo, we find that the price for minerals from the conflict-affected country decrease and prices for minerals from the other Southern country increase. This change

in prices results in a decline in rent-seeking and conflict but also in a general decrease in income of the embargoed country. The consumer welfare in the North increases if the altruistic payoff from decreasing conflict in the South exceeds the welfare loss from higher prices for conflict-free resources.
In the case of a targeted sanction in the form of the auditing and labeling of legal mines, we find that the policy-implementing North country sources from verified mines in the South as well as from mines conflict-free Southern country. Resource prices for legal minerals increase, while the price for illegal resources further declines, making rent-seeking less attractive. The net welfare benefit of the certification policy is higher for the Northern as well as for the Southern countries compared to the embargo policy and the baseline scenario. These findings indicate that higher transparency of the production process can be beneficial for both sides of the supply chain.

### Protection and Profit: Empirical Evidence of Governmental and Market-Based Forest Policies

Chapter III *Protection and Profit: Empirical Evidence of Governmental and Marked-based Forest Policies* empirically examines the environmental effects of voluntary and mandatory sustainable forest management. It is a single authorship essay. Sustainable Forest Management (SFM), which allows restricted logging activities that do not endanger the forest ecosystem, is seen as a key instrument for slowing down deforestation in regions with high forest loss and is broadly supported by international initiatives, such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation). However, the literature on the environmental performance of sustainably managed forests and the economic incentives that might influence their effectiveness is quite thin. To the best of my knowledge the essay presented here is the first to draw a comparison between governmental implemented SFM and voluntarily implemented SFM based on high spatial resolution image analysis. For this purpose, the essay considers a novel dataset of 70 sustainable-use zones which are distributed over the Brazilian Amazon. I constructed the dataset by using audit reports, which provide geo-referenced information on the location of the certified forests, which are forest zones privately managed by communities or companies. I only include forests which have received the FSC (Forest Stewardship Council) label after being audited by a third-party agency. The governmentally implemented zones are extractive reserves managed by the local population but monitored and organized by public authorities. I consider a period over 13 years from 2002-2015. For the empirical examination, I employ a difference-in-difference estimator to detect discontinuities in the deforestation trend around the implementation of the zone in a spatial and a temporal dimension. I show that while private actors reduce forest loss significantly in the two years before the first audit of their forest, deforestation increases as soon as the forest-company has passed the audit and commercial production begins. Results for public zones indicate that these zones are established where deforestation rates were already low before the policy intervention. This means that monitoring costs are low and so is the effect of the zone itself in terms of a reduction in forest loss. I provide evidence that geographical characteristics, which are important for both type of zones to be economically valuable, play a major role in effectively decreasing deforestation in the region. I enhance the dataset by including international agricultural prices, timber prices, and prices for non-timber forest products (such as fruits, medicine or rubber) which are economically meaningful for sustainable forestry. I find evidence that both types of SFM zones have positive spillover effects on their neighborhood by reducing timber price pressures from adjoining forests. Moreover, high prices for non-timber forest products appear to be a particular incentive to protect plants and wildlife within public zones. Generally, the results indicate that more attention should be paid to micro- and macroeconomic determinants that drive the outcomes of sustainable forestry as a policy against deforestation.

**Environmental Regulation and Commodity Prices: Evidence from Deforestation in Brazil**

The essay in Chapter IV *Environmental Regulation and Commodity Prices: Evidence from Deforestation in Brazil* focuses on the effectiveness of policies to control and mitigate agricultural-driven deforestation by using a novel triple-difference approach that combines price shocks and the spatial and temporal heterogeneity of three deforestation policies. The essay was written in collaboration with Torfinn Harding and Karlygash Kuralbayeva.

In this essay, we focus on the Brazilian Legal Amazon, a region that is - in large parts - characterized by a transition process from native forests into an agricultural area. We study the effect of three regulatory policies on this process. These policies are: *blacklisting* (monitoring of and sanctions against the municipalities with the highest deforestation rates), *conservation zones* (protected areas which receive legal management and monitoring to achieve long-term conservation of natural assets) and the *Soy Moratorium* (a voluntary agreement of the soy industry to stop clearing the forest for new soy plantation). In our approach, we use international commodity prices to examine how an increase in prices increases the incentives for farmers to expand their fields onto forest land. We interact the prices with the three policies to study the latter's potential to decrease the price pressure on the forest and also to study potential channel of leakage. We further investigate the effects of these policies on economic outcome and on climate change by considering estimation results on the carbon stock and the municipal GDP.

Our basic dataset is a balanced panel of the 660 municipalities in the Legal Brazilian

Amazon over a period from 2002-2013. To depict annual deforestation and forest cover change, we use remote sensing satellite images. In order to disentangle the policy effects from other unobservable time trends and local predefined characteristics, we use a flexible triple difference method. We construct an index of international commodity prices and use it as an exogenous regressor in interaction with the three policy treatments.
Our results indicate that a boom in commodity prices increases deforestation in our period of observation by about 20,682 $km^2$. The blacklisting policy avoids 17% of agricultural deforestation, which would have occurred without the policy. In contrast, for the conservation zones we find evidence of a shift of deforestation activities onto the surrounding land. The Soy Moratorium only shows a mitigating effect on price pressure when separating out the soy price as a regressor. Considering also other agricultural prices reveals a leakage to other crops, such as corn, which is planted on newly cleared land instead of soy.
We extend our interpretation by showing that the policies do not have an effect on economic performance (GDP) apart from a small decline in the case of the Soy Moratorium which is due to the substitution of soy by less profitable crops. In the blacklisted municipalities, about 0.02 Pg carbon stored in the forest was saved by the policy. While the effect of agriculture prices on deforestation in the Legal Amazon has been studied before (Hargrave and Kis-Katos, 2013; Assunção et al., 2015), we are, to the best of our knowledge the first to use this identification strategy, which deals with the non-randomness of the policy implementation and accounts for the individual production structure of a municipality. We managed to solve empirical issues of prior studies (DeFries et al., 2010; Gibbs et al., 2015b) on the identification of the effect of the Soy Moratorium, and we provide evidence of a novel form of leakage related to it. Moreover, our estimation method allows us to compare and conclude on different forms of governmental and industry-driven environmental policies.

My contribution to the joint work included the construction of the dataset, the estimation of the triple-difference regressions, the design and estimation of the graphs and parts of the writing. The data set is organized on two levels: On the municipality level and in a 1 $km^2$ grid cell over the entire Brazilian Amazon, which contains satellite-based deforestation data and other geographical information. On the municipality level, I constructed a municipality-specific weighting of the price index based on the production area of the 10 most important export crops. In order to identify a causal relation between increases in the commodity prices and deforestation, a difference-in-difference estimator is used as a first approach. I enhanced the dataset by including policy variables and constructed a triple difference-in-difference estimator in order to account for non-parallel trends in the pre-treatment and control group.
On the grid level, I used geo-informational software and remote sensing processes to con-

struct subsamples for each policy. Thus, I gained information about the exact location of grid cells within or outside of a treated area and was able to compute the distance of non-treated cells to the closest grid cell which is affected by a policy. These data are necessary in order to run spatial discontinuity estimations which substantiate our results on the municipality level. Finally, I run several robustness estimations, for which I calculated the soil quality and fertility, the travel time, and the deforestation rates for each grid cell.

# Chapter II

# Sourcing from Conflict Regions: Policies to Improve Transparency in International Supply Chains

Julika Herzberg and Oliver Lorz[1]

**Abstract**

In this paper, we set up a theoretical model to study how unilateral policies aimed at improving transparency for consumers concerning the source of certain raw materials influence prices, illegal mining activities and welfare. The model distinguishes two regions in the world, North and South. Firms in the North import natural resources from the South to produce final consumption goods. In one of the countries, in the South, local groups attempt to access natural resources, which results in rent seeking conflicts with the government and illegal mining. We find that a unilateral embargo against the conflict country as well as certification of legal mines can reduce rent seeking and illegal mining with different welfare consequences in the countries involved.

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## II.1 Introduction

Access to precious minerals is essential to various industries in the modern economy (OECD, 2009). Many minerals as well as energy resources such as oil or shale gas can be found in resource-rich developing countries with rather weak political institutions. In these countries, the presence of natural resources may trigger and intensify conflicts and rent-seeking behavior. For example, using a high spatial resolution dataset that covers the entire African continent, Berman et al. (2017) find a substantially stronger effect of the recent commodity price boom on the likelihood of conflict in geographical areas with mining activities compared to those without.[2] Rebel groups and independence movements are flourishing in certain resource-rich regions, such as in Southeast Columbia (FARC), in Kivu, Eastern Congo, or in Mindandao, Southern Philippines (Moro Islamic Liberation Front). They fight for the control of mines against each other and against state forces and can use earnings from illegally exported resources for new weapons, which tends to prolong conflicts (Fearon, 2004).

Public pressure from NGOs and the civil society against the use of inputs from conflict regions have stimulated the implementation of national and international sanctions. A prominent example that started in the early 2000s is the Kimberly Process, a commitment of 54 member states to prevent the inclusion of conflict diamonds in the global supply chain (Kimberly Process, 2018). After the financial crisis, the United States implemented the Dodd-Frank Act, a federal law concerning Wall Street reform, in which section 1502 requires to disclose the use of the minerals tin, tantalum, tungsten, and gold originating from the Democratic Republic of Congo or adjoining countries. More recently, similar regulations on conflict minerals have been passed by the European Union (European Commission, 2016). Energy resources may also be subject to international measures such as embargoes against oil from Syria (e.g., European Council, 2016).

This paper aims to shed light on the consequences of unilateral sanctions on markets for raw materials as well as on downstream industries. It distinguishes two different policies that may be implemented in order to increase market transparency: first, an embargo by a resource importing country against an exporting country in which mines are contested by illegal operators, and second, the implementation of a certification system that enables customers to distinguish legal from illegal mines. These policies are analyzed in a North-South framework with vertically related industries. Two downstream countries in the North import raw materials from two countries in the South, of which one has an internal conflict for raw materials. The downstream countries produce final goods according to a Dixit-Stiglitz framework of monopolistic competition. A Tullock rent-seeking contest maps the situation in the conflict country in the South. In this framework,

[2]For surveys of the earlier literature, see Van der Ploeg (2011) and Nillesen and Bulte (2014).

we investigate the effects of stepwise removing the information asymmetry concerning the source of raw materials on equilibrium prices, industry structure, rent seeking, and welfare. Our main results are the following:

1. A unilateral embargo reduces the price of raw materials sourced from the conflict country while the price for raw materials from the conflict-free country increases. Rent seeking and the supplied quantity of illegal raw materials decline.

2. The embargo raises consumer welfare only if the resource endowment of the conflict free country in the South is sufficiently large compared to that of the conflict country.

3. The introduction of a certification system further reduces rent seeking and the number of illegal mines compared to the embargo.[3] Certification is also superior in terms of consumer welfare.

Our paper is related to several strands of the literature: First, various studies investigate the effects of product labels on the consumers' and the producers' side. For example, Podhorsky (2013) analyzes product certification in a two country model with endogenous product quality. In her model, foreign welfare increases if a certification system is implemented by the home country as foreign consumers benefit from the resulting increase in product quality. Bonroy and Lemarié (2012) study the effects of labels for genetically modified food on upstream and downstream suppliers. The authors identify conditions under which such labels reduce the price of genetically modified inputs. Moreover, our paper relates to studies on vertical product differentiation, such as Gervais (2015), who shows in a Melitz-type model that product quality may influence selection into the export market.

One feature of our model is that consumers are willing to pay an extra premium for product varieties that are produced from conflict-free resources. This is related to the willingness to pay for "fair trade" products. For example, in experimental auctions realized on Ebay, Hiscox et al. (2011) find that consumers pay a substantial premium for fair trade labeled goods. Similarly, according to a survey-based study of Campbell et al. (2015) consumers are more willing to accept a price increase if this is justified by commitments to fair trade standards than by higher taxes. There could be various reasons why people prefer ethical products even though they do not differ in terms of their actual quality compared to conventional produced counterparts: Psychological aversion to being (indirectly) involved in illegal or harmful operations and a willingness to contribute to social desirable goals may be strong motives. A recent neurological study by Enax et al.

[3]In practice, such certification systems can be designed as supply-chain auditing programs, such as the ITSCI (2018) initiative, or as projects aiming at the verification of origin, e.g., by using geological identification methods (as in the "Analytical Fingerprint" project of the BGR, 2018)).

(2015) reported that for people who decide for a product labelled as "fair trade" more activities in their ventral striatum could be measured, which is an important brain region for reward-processing and motivational salience.

Our paper also builds on related theoretical studies on conflicts and rent-seeking in resource abundant countries. Wick and Bulte (2006) and Butler and Gates (2012) analyze how the framework of a resource conflict – in particular, the shape of the contest success function – determines its intensity. In De Luca et al. (2018) conflicts for natural resource access can be influenced by an autocratic leader who may have an incentive to promote such conflicts in order to weaken the political opposition. Janus (2012) considers the implications of liquidity constraints for resource extraction and conflicts. In his model, an import embargo reduces conflict intensity only if a binding credit constraint limits the amount of capital that can be invested in the conflict. Otherwise, an export restriction shifts activities from resource extraction to resource conflicts and thereby raises conflict intensity. Similarly Parker and Vadheim (2017), who assume that rebel groups can either tax resource mines or loot civilians, find that a ban on certain minerals may shift conflicts to other (less affected) types of mines or may increase looting of civilians.

In the remainder of the paper, section II.2 introduces the the model and derives the baseline equilibrium without government intervention. In section II.3 we introduce a unilateral embargo and a certification policy, and analyze the welfare properties of these measures in section II.4. Section II.5 summarizes the paper and concludes.

## II.2 The Model

The world according to our model is composed of four countries, two in the "North" (indexed by $NE$ and $NW$) and two in the "South" ($SE$ and $SW$). Both countries in the North supply a continuum of varieties of a manufacturing aggregate $M$ in a standard monopolistic-competition industry and sell $M$ exclusively in the North. Production of manufacturing varieties entails certain raw materials sourced from a continuum of mines in $SE$ and $SW$ distributed over the unit interval. Each mine is endowed with one unit of the resource. Per unit of a manufacturing variety, firms in the North need one unit of raw materials, which they buy on a competitive market for a price of $c$. Two types of mines exist in the South: Legal ($L$) mines, which adhere to certain environmental and labor standards, and illegal ($I$) mines under the control of illegal operators, producing raw materials under poor and unregulated conditions. **Consumer Preferences:** We consider conscientious consumers who care about of the production conditions in the mining sector of the upstream countries. These consumers experience a utility loss if varieties contain materials, which are connected with conflict, child labour or other human rights abuses. For the sake of simplicity, we term such materials as illegal raw materials or sourced from “illegal”mines. The counterpart are “legal”raw materials or mines which follow certain standards and are “conflict-free”. Although buyers of manufactured varieties know whether an industry is affected by illegal mining in general, they cannot verify for each single variety whether it contains illegal primary resources or not. To model this setting, we assign a certain quality discount to manufactured varieties that corresponds to the average share of illegally mined resources.[4] The difference to a standard product quality context is the fact that quality is not determined by the physical properties of a good but instead by the conditions under which its ingredients are produced. In particular, we consider a representative consumer with the following utility specification:

$$U = M^{\alpha} A^{1-\alpha} , \quad \text{with} \quad M = \left( \int_{\omega \in \Omega} [x(\Theta(\omega)) \cdot q(\omega)]^{\rho} \, d\omega \right)^{1/\rho} . \tag{II.1}$$

$A$ is a freely traded agricultural good (the numéraire), $M$ is the manufacturing aggregate, $q(\omega)$ is the quantity of variety $\omega$, and $\Theta(\omega) \in [0; 1]$ stands for the share of legal raw materials contained in this variety. The function $x(\Theta) \equiv 1 - \mu [1 - \Theta]$ measures the utility impact of $\Theta$, with $\mu$ $(0 < \mu < 1)$ representing the marginal effect of increasing the share of illegal raw materials in an individual variety . Each country in the North is endowed with $\bar{L}$ units of labor, which can either be employed in manufacturing or to produce $A$ (with productivity normalized to 1). In manufacturing, each firm needs a fixed labor input of $f$. Consumers' budget is defined by the income generated on the labour market and the total consumer income is $2\alpha\bar{L}$. Products can be purchased from either country in the North. Maximization of utility with total expenditures of $2\alpha\bar{L}$ for $M$ yields the following expenditure levels for an individual variety ($\sigma = 1/(1 - \rho)$):

$$q(\omega)p(\omega) = 2\alpha\bar{L}\tilde{P}^{\sigma-1}\tilde{p}(\omega)^{1-\sigma} , \quad \text{with} \quad \tilde{P} = \left( \int_{\omega \in \Omega} \tilde{p}(\omega)^{1-\sigma} d\omega \right)^{1/(1-\sigma)} \tag{II.2}$$

as the corresponding price index. The term $\tilde{p}(\omega) = p(\omega)/x\,(\Theta)$ represents the adjusted price for variety $\omega$.

With a wage rate of 1 and a raw material price of $c$, production costs in manufacturing are $C(q) = f + cq$. Manufacturing firms set profit maximizing prices at a constant mark-up over marginal costs, i.e., $p(\omega) = c(\omega)/\rho$.

**Illegal Mining:** The two countries in the South differ with respect to the distribution of legal and illegal mines. More specifically, illegal mining only occurs in $SE$ whereas country $SW$ does not have this problem. The term $S$ $(0 \leq S \leq 1)$ denotes the share of legal mines in $SE$.[5] We assume that the total endowment with raw materials is $\bar{R}_W$

[4]Manufacturing varieties are modeled here as credence goods, comparable to settings with non-observable product quality (see Darby and Karni, 1973). As in Hallak (2006), we specify quality as a utility-shifter.

[5]We will determine this share endogenously in our model.

in country SW and $\bar{R}_E$ in SE, such that the aggregate worldwide supply of the raw materials is given by $\bar{R} \equiv \bar{R}_W + \bar{R}_E$.[6] The share of legal mines $S$ in $SE$ is determined by a contest between illegally operating extractors on the one hand and the state on the other. We use "state"here as a general term for several subregions in the $SE$ region, in which independent local governments are responsible for the mines within their territory. Therefore, each subregion is a price-taker and a local government cannot influence the resource price by its actions.

At each mine there is a local group that may try to get hold of the resources extracted there, whereas the state tries to protect the mine. In the rent seeking contest for the mine, the group spends $a$ for rent seeking activities and the state spends $b$ for protection efforts. Assuming a Tullock (1980) contest success function, each single mine can be seized with probability

$$\pi(a, b) = \frac{a}{a+b} \ .$$

The higher the group's, or the lower the state's effort, the more likely the mine will get hold of by the rent-seekers. In addition to the rent seeking effort, the local group has to spend a fixed cost $\gamma F$ to enter the contest. The term $F$ follows a uniform distribution on $[0; 1]$ representing differences between mines with respect to the accessibility for rent-seekers. For example, some mines may be located in a civil war zone and thereby may be more easily accessible for rebel groups than others. The slope term $\gamma$ can be interpreted as a measure for the general situation in the country (its "institutional quality"), which improves as $\gamma$ increases. Given the entry costs, we can determine a critical cut-off $\tilde{F}$ below which mines are contested by rent seekers.

Suppose, the price for raw materials is $c_L$ or $c_I$ depending on whether they originate from legal or illegal mines. Maximizing the expected income of rent seekers or the state, respectively

$$I_{rs} = \pi(a, b)c_I - a - \gamma F \quad \text{and} \quad I_s = [1 - \pi(a, b)]\, c_L - b$$

yields the following equilibrium rent seeking expenditures and the resulting success probability as functions of the price for legal and illegal resources:

$$a = \frac{c_L \, (c_I)^2}{(c_I + c_L)^2} \ , \quad b = \frac{c_I \, (c_L)^2}{(c_I + c_L)^2} \ , \quad \text{and} \quad \pi = \frac{c_I}{c_L + c_I} \tag{II.3}$$

[6]This means, we assume that on each point on the unit interval $\bar{R}_E$ mines exist in country $SE$ and similarly $\bar{R}_W$ mines in $SW$.

Inserting $\pi$ into $I_{rs}$ and setting $I_{rs} = 0$ produces the critical cut-off:

$$\tilde{F} = \frac{(c_I)^3}{\gamma (c_I + c_L)^2} \ . \tag{II.4}$$

$\tilde{F}$ increases in $c_I$, declines in $c_L$, and has increasing returns to scale. That is, if prices of legal and illegal raw materials rise proportionally, more groups engage in rent seeking. With the cut-off $\tilde{F}$ and success probability $\pi(a, b)$, the aggregate share of legal mines in $SE$ is

$$S(a, b) = 1 - \tilde{F} + \tilde{F} [1 - \pi(a, b)] \ .$$

Inserting (II.3) and (II.4) yields the following expression for the endogenous share of legal mines in $SE$:

$$S = 1 - \frac{(c_I)^4}{\gamma (c_I + c_L)^3} \ . \tag{II.5}$$

**Benchmark Equilibrium:** As benchmark, we consider the case in which the source of raw materials contained in the final product is completely non-transparent for consumers. Consumers cannot distinguish legal from illegal mines and also do not know the geographical origin of raw materials used in a certain variety. In this setting of world-wide pooling, there is one common world market for resources with a common price, i.e., $c_L^p = c_I^p = c^p$.[7] For the distribution of illegal materials on final good producers, we assume perfect symmetry: each manufacturing variety contains the same share of legal materials given by $\Theta^p = (1 + S^p)/2$. All firms charge the same price $p^p = c^p/\rho$, sell the same quantity $q^p$ and make the same revenue $r^p$. The revenue of an individual firm equals the ratio between total expenditures $2\alpha\bar{L}$ and the mass or "number" of active firms $\Omega$ in the market, i.e., $r^p = 2\alpha\bar{L}/\Omega^p$. With the zero profit condition $r^p = \sigma f$, we use this ratio to derive the equilibrium number of varieties in the pooling setting:

$$\Omega^p = \frac{2\alpha\bar{L}}{\sigma f} \ . \tag{II.6}$$

For the equilibrium quantities of imported raw materials, we set demand equal to supply, $q^p \cdot \Omega^p = \bar{R}$, yielding

$$q^p = \frac{\bar{R}\sigma f}{2\alpha\bar{L}} \ . \tag{II.7}$$

After inserting into $p^p = \sigma f / q^p$, we obtain for prices

$$p^p = \frac{2\alpha\bar{L}}{\bar{R}} \quad \text{and} \quad c^p = \frac{2\alpha\bar{L}\rho}{\bar{R}} \ . \tag{II.8}$$

The result suggests that the resource price in the pooling situation does not depend on

[7] The superscript $p$ stands for the pooling equilibrium.

the number of legal and illegal material in the market. This is due to our set up of the Dixit-Stigilitz utility function in which the price elasticity is independent of the quality parameter. Thus, the resource price here could be interpreted as an average price over illegal and legal resources.
The value of aggregate raw material imports of the North is $q^p c^p \Omega^p = 2\alpha\bar{L}\rho$, which is equal to the value of its agricultural exports.
Equilibrium rent seeking expenditures are equal for the state and for rent seekers, which results in a success probability of 1/2 for all mines that are contested:

$$a^p = b^p = \frac{c^p}{4} \qquad \text{and} \qquad \pi(a^p, b^p) = \frac{1}{2} \tag{II.9}$$

Considering the critical $\tilde{F}^p = c^p/(4\gamma)$, we find that the aggregate share of legal mines increases in the fixed rent seeking costs $\gamma$ and decreases in the resource price. We assume that $\gamma$ is sufficiently large relative to the equilibrium resource price such that an interior solution with $S^p > 0$ exists. Inserting from (II.5) determines the share of legal mines as a function of the model's parameters:

$$S^p = 1 - \frac{c^p}{8\gamma} = 1 - \frac{\alpha\rho\bar{L}}{4\gamma\bar{R}} \, . \tag{II.10}$$

These results characterize the market situation without any governmental intervention or transparency initiative. In the following we expand the basic model by two possible downstream policies.

## II.3 Resource Transparency

In this section, we consider two policy options to raise transparency with respect to natural resources: First, we introduce a unilateral embargo of $NW$ against $SE$. As a result of the embargo, $NE$ firms rely entirely on resources from legal mines (those from $SW$), whereas products supplied by firms of country $NE$ still contain illegally mined materials from $SE$. The embargo serves as a screening device and reduces the degree of consumers' uncertainty, as it discloses the geographical origin of raw materials.

Second, we study the possibility of providing full transparency for consumers by introducing certification of legal mines from $SE$ into the model. For example, it could be possible to distinguish legal ($L$) from illegal ($I$) mines in $SE$ by third-party auditing. This auditing provides consumers with full information about the type of the raw materials sourced for each individual variety. For simplicity, we do not consider auditing costs.[8]

**Embargo:** An embargo by country $NW$ against $SE$ discloses the origin of the re-

[8] As an alternative, we may assume that the audit is financed by the government of $NW$.

sources for consumers: All manufacturing varieties supplied by $NW$ contain legal resources from $SW$. If raw material prices of $SW$ exceed those of $SE$, i.e., for $c_W^e > c_E^e$, firms from country $NE$ have no incentive to purchase raw materials from $SW$ as they cannot verify the source of their materials. As a result, firms from $NE$ source raw materials entirely from $SE$. Since, by assumption, only legal mines exist in $SW$, the perceived quality is $\Theta_W^e = 1$ for varieties produced in $NW$. For varieties produced in $NE$, quality declines to $\Theta_E^e = S^e$, i.e., to the share of illegal mines in $SE$. Consumers draw a higher utility from varieties from $NW$ and are willing to pay a higher price compared to $NE$ varieties, i.e., $p_W^e \cdot x(S^e) = p_E^e$. Derivations in appendix section II.A show that the resource prices can be determined as

$$c_W^e = \frac{2\alpha\bar{L}\rho}{\bar{R}_W + x(S^e)\bar{R}_E} \quad \text{and} \quad c_E^e = \frac{2\alpha\bar{L}\rho x(S^e)}{\bar{R}_W + x(S^e)\bar{R}_E} . \tag{II.11}$$

Compared to the pooling equilibrium, the resource price declines in $SE$ and increases in $SW$, i.e., $c_E^e < c^p < c_W^e$, since $x(S^e) < 1$. The share of legal mines in $SE$ is given by (II.5) with $c_I = c_L = c_E^e$ and and is higher than in the pooling benchmark ($S^e > S^p$):

$$S^e = 1 - \frac{c_E^e}{8\gamma} = 1 - \frac{\alpha\rho\bar{L}x(S^e)}{4\gamma\left[\bar{R}_W + x(S^e)\bar{R}_E\right]} . \tag{II.12}$$

Figure 1 illustrates the equilibrium price and share of legal mines in country $SE$. The downward sloping dotted line depicts the share of legal mines $S$ as a function of the price of raw materials supplied by country $SE$ as determined by equation (II.12). This relationship is the same for the pooling and the embargo setting. The upward sloping dashed curve depicts the resource price $c_E^e$ in country $SE$, as determined in (A.9) for the embargo case. The price of raw materials from the embargo country $SE$ is lower than in the pooling case (solid horizontal line) and rises with the share of legal mines. The intersection between both curves determines the equilibrium allocation in $SE$.

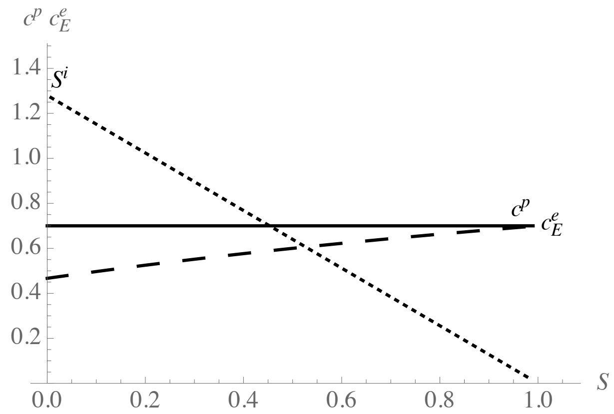



*Figure II.1: Equilibrium with Pooling and with Embargo*

We can use figure 1 to determine the effects of a change in exogenous parameters on the equilibrium. For example, an increase in the institutional quality in $SE$, i.e., an increase in $\gamma$, raises the slope of the $S^i$-line and results in less illegal mining and a higher equilibrium resource price in country $SE$. With an increase in the discount term $\mu$, the $c_E^e$ curve becomes less steep resulting in fewer illegal mines and a lower resource price in $SE$.

**Certification:** We now assume that the government in $NW$ allows its domestic firms to use raw materials from $SE$ if these are certified to be of legal origin. As in the embargo case, firms from $NE$ do not buy legal raw materials in this setting as they would have to pay a higher price than for illegal materials without being able to verify their source to consumers. That is, $\Theta_W^c = 1$ and $\Theta_E^c = 0$, and the perceived quality of varieties supplied by firms from $NE$ declines to $x(0) = 1 - \mu$.

The certification scheme raises the price for legal raw materials from $SE$ to the same level as for materials from $SW$, whereas the price for illegal raw materials is accordingly lower (see appendix section II.A for a derivation):

$$c_I^c = \frac{2\alpha\bar{L}\rho\,[1-\mu]}{\bar{R}_W + x(S^c)\bar{R}_E} \quad \text{and} \quad c_L^c = \frac{2\alpha\bar{L}\rho}{\bar{R}_W + x(S^c)\bar{R}_E}\ . \tag{II.13}$$

From these equations, we can infer $c_I^c < c_E^e$. Consequentially, the price for illegal raw materials under certification declines compared to the raw material price from $SE$ under the embargo. With certification, downstream buyers from $NE$ purchase only illegal materials from $SE$ compared to a mix of legal and illegal materials under the embargo. For the share of legal mines in $SE$ we obtain the following equation:

$$S^c = 1 - \frac{[1-\mu]^3\, c_I^c}{[2-\mu]^3\,\gamma} = 1 - \frac{2\alpha\bar{L}\rho\,[1-\mu]^4}{[2-\mu]^3\,\gamma\,\left[\bar{R}_W + x(S^c)\bar{R}_E\right]}\ . \tag{II.14}$$

Comparing (II.14) with (II.12) reveals that $S^c$ would exceed $S^e$ already for $c_I^c = c_E^e$. This is the case, since even if the rent-seekers would receive the same price as with the embargo implemented, the incentive for the local governments to invest in the provision of legal mines would be higher with the certification system implemented which follows from equation (II.13).
In addition, since the price for illegal raw materials $c_I^c$ declines compared to $c_E^e$ in the embargo case, the share of legal mines increases further. The inequality $S^c > S^e$ also implies $c_L^c < c_W^e$. That is, certification influences the price for legal raw materials via a supply effect by reducing rent seeking and thereby decreasing the number of conflict mines.

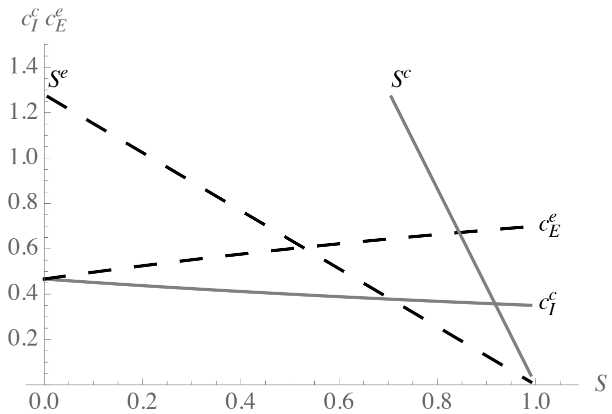



*Figure II.2: Equilibrium with Embargo and with Certification*

Figure 2 illustrates the equilibrium for the case of certification in comparison to the embargo equilibrium. The line $c_I^c$ depicts the price of illegal resources as determined by (II.13), and this line is declining in $S^c$. For $S^c = S^e = 0$, the resource price would be the same as in the embargo case. For every $S^c > 0$, the price of illegal resources $c_I^c$ is therefore lower than in the embargo case. The downward sloping line $S^c$ depicts the share of legal resources as a function of $c_I^c$ according to (II.14). This line is steeper than the $S^e$ line of the embargo case, with the same limit at $S^c = S^e = 1$ for $c_E^c = c_I^e = 0$. The intersection between the $S^c$ and $c_I^c$ lines determines the equilibrium.[9]

[9] As the $c_I^c$ line is strictly concave, we cannot rule out a priori that there are two intersection points, but we do not further consider this possibility of multiple equilibria here.

## II.4 Welfare Analysis

In this section, we evaluate all three settings in terms of consumer welfare in the North and aggregate income in the South countries. Welfare of the representative consumer in the North ($NE$ or $NW$) can be written as

$$V = 2\bar{L}\alpha^{\alpha}(1-\alpha)^{1-\alpha}\tilde{P}^{-\alpha} \ . \tag{II.15}$$

For the three scenarios considered, the utility based price index $\tilde{P}$ is

$$\tilde{P}^{p} = \frac{c^{p}}{x(S^{p})\rho}\Omega^{\frac{1}{1-\sigma}} \ , \quad \tilde{P}^{e} = \frac{c^{e}_{W}}{\rho}\Omega^{\frac{1}{1-\sigma}} \quad \text{and} \quad \tilde{P}^{c} = \frac{c^{c}_{L}}{\rho}\Omega^{\frac{1}{1-\sigma}} \ . \tag{II.16}$$

The number of varieties $\Omega$ is the same in all three settings. Compared to the pooling benchmark, the embargo lowers the price index and thereby raises consumer welfare in the North if and only if $c^{e}_{W} < c^{p}/x(S^{p})$, or $\bar{R}_{W} > x(S^{e})\bar{R}_{E}$ (see appendix). Thus, it could well be that the embargo lowers consumer welfare. This may happen, if resource supply from $SW$ is rather low compared to resource supply from $SE$ such that the embargo raises the price for legal resources from $SW$ above the quality adjusted price in the pooling setting. Certification is superior to the embargo from the view of consumers, as $c^{c}_{L} < c^{e}_{W}$.

Aggregate resource income in $SW$, $V_{SW} = \bar{R}_{W}c_{W}$, is highest under the embargo, since $c^{e}_{W} > c^{p}$ and $c^{e}_{W} > c^{c}_{L}$. For income (net of rent seeking efforts) in $SE$ we obtain

$$\begin{aligned} V^{p}_{SE} &= \left[1 - \frac{5c^{p}}{32\gamma}\right] c^{p}\bar{R}_{E} \ , \\ V^{e}_{SE} &= \left[1 - \frac{5c^{e}_{E}}{32\gamma}\right] c^{e}_{E}\bar{R}_{E} \quad \text{and} \\ V^{c}_{SE} &= \left[1 - \frac{(5-\mu^{2})\,(1-\mu)^{3}c^{c}_{I}}{2\gamma\,(2-\mu)^{4}}\right] c^{c}_{L}\bar{R}_{E} \ . \end{aligned} \tag{II.17}$$

Comparing $V^{e}_{SE}$ with $V^{c}_{SE}$, we first note that $c^{c}_{L} > c^{e}_{E}$. Equation A.13 proves that the term in $V^{c}_{SE}$ exceeds the one in $V^{e}_{SE}$ and thus the country $SE$ benefits from certification compared to the embargo. The term in squared brackets in (II.17) reveals that in $SE$ the aggregate welfare falls short of the resource rent because of the wasteful rent seeking efforts in the conflict for raw materials, which is also present in the certification case. However, we also show in this study that the effect of the embargo compared to the benchmark equilibrium without policy intervention could be ambiguous. As rent seeking becomes less attractive under the embargo, the declining resource price in $SE$ not necessarily reduces aggregate income in the conflict country. Instead, it may be the case that the rent-seeking effect outweighs the declining resource price such that the net income in $SE$

increases with the embargo against this country.[10]

Taking both countries $SE$ and $SW$ together, aggregate income under certification exceeds aggregate income under embargo, which in turn exceeds aggregate income in the pooling case.

$$V_{SE}^p + V_{SW}^p = 2\alpha\bar{L}\rho - \frac{5\left(c^p\right)^2 \bar{R}_E}{32\gamma} < \tag{II.18}$$

$$V_{SW}^e + V_{SE}^e = 2\alpha\bar{L}\rho - \frac{5\left(c_E^e\right)^2 \bar{R}_E}{32\gamma} < \tag{II.19}$$

$$V_{SW}^c + V_{SE}^c = 2\alpha\bar{L}\rho - \frac{(5-4\mu+\mu^2)(1-\mu)^2\left(c_I^c\right)^2 \bar{R}_E}{2\gamma(2-\mu)^4} . \tag{II.20}$$

The inequalities follow from $c^p > c_E^e > c_I^c$ and the fact that $(5-4\mu+\mu^2)(1-\mu)^2/(2-\mu)^4 < 5/16$ (see appendix section II.A).

# II.5 Summary and Conclusion

In this paper, we have analyzed unilateral policies aimed at improving transparency about the origin and the legal status of imported natural resources. In our framework, an embargo against a conflict country is comparable to a mandatory disclosure of origin. It lowers the equilibrium price of raw materials from the embargoed country and thereby reduces resource rents and rent seeking activities there. Consumers in the downstream countries benefit from the embargo if and only if the relative supply of resources from the conflict-free country is sufficiently large. Raising transparency further by a mandatory certification of legal resources is superior in terms of consumer welfare in the downstream countries as well as in terms of aggregate income of the resource exporting upstream countries. Compared to an embargo, rent seeking further declines which leads to more "clean products" on the market.

Our model can be extended in various directions to provide further insights into the implications of conflict resource policies: First, instead of assuming costless certification, one may explicitly account for such costs and their implications as barriers to entry for downstream suppliers. Second, the model may incorporate additional forms of illegally extracted rents, such as contraband to neighbouring states or taxation of the local population. This may allow for leakage, which appears to be important empirically.[11] Third, barriers for trading final product varieties between downstream countries may be considered. Unilateral measures to improve transparency would then affect domestic consumers

[10] Note that this rent dissipation effect differs from the sectoral allocation effect in Torvik (2002), where rent seeking crowds out entrepreneurial activities in a modern sector.

[11] See the empirical results on the effects of the Dodd-Frank-Act by Parker and Vadheim (2017) and Stoop et al. (2018).

differently compared to those in other downstream countries. Further asymmetries between downstream countries may result from consumer or firm heterogeneity. Promising extensions in this respect would be to distinguish between more and less ethical consumers, more and less productive firms and differences between countries in this regard. Finally, supply of natural resources could also be endogenized, such that policies that influence demand and prices also affect the total quantity of natural resources supplied.

# II.A Appendix

## Embargo Equilibrium

Maximizing utility

$$M = \left( \int_0^{\Omega_W} q(\omega)^\rho d\omega \quad + \int_0^{\Omega_E} \left[ x(S) \cdot q(\upsilon) \right]^\rho d\upsilon \right)^{1/\rho} \tag{A.1}$$

yields the following spending levels for varieties from $NW$ (indexed by $\omega$) and from $NE$ (indexed by $\upsilon$):

$$q(\omega)p(\omega) = 2\alpha\bar{L}\tilde{P}^{\sigma-1}\tilde{p}(\omega)^{1-\sigma} \qquad \text{and} \qquad q(\upsilon)p(\upsilon) = 2\alpha\bar{L}\tilde{P}^{\sigma-1}\tilde{p}(\upsilon)^{1-\sigma} \ , \tag{A.2}$$

with

$$\tilde{P} = \left( \int_0^{\Omega_W} \tilde{p}(\omega)^{1-\sigma} d\omega + \int_0^{\Omega_E} \tilde{p}(\upsilon)^{1-\sigma} d\upsilon \right)^{1/(1-\sigma)} \quad , \quad \tilde{p}(\omega) = \frac{c_W^e}{\rho} \quad \text{and} \quad \tilde{p}(\upsilon) = \frac{c_E^e}{\rho x(S)}$$

as corresponding price index and profit maximizing prices.

From the zero profit condition and (A.2) we can infer $\tilde{p}(\omega) = \tilde{p}(\upsilon)$, i.e., adjusted prices have to be equal in the world equilibrium. For this to hold, manufacturers have to pay a premium for raw materials from $SW$:

$$c_E^e = x(S^e) \cdot c_W^e \ . \tag{A.3}$$

Given that quality adjusted prices are equalized, we obtain for quantities from (A.2)

$$q_W^e = x(S) \cdot q_E^e \ . \tag{A.4}$$

With an aggregate number of varieties $\Omega = \Omega_W + \Omega_E$, the price index can be written as

$$\tilde{P}^e = \frac{c_W^e}{\rho} \cdot \Omega^{1/(1-\sigma)} \ . \tag{A.5}$$

The equilibrium aggregate number of varieties can be determined from the free entry condition as

$$\Omega^e = \frac{2\alpha\bar{L}}{\sigma f} \ . \tag{A.6}$$

Inserting into (A.2) yields

$$\Omega^e \cdot q^e_W = \frac{2\alpha\bar{L}\rho}{c^e_W} \quad \text{and} \quad \Omega^e \cdot q^e_E = \frac{2\alpha\bar{L}\rho}{c^e_E} \ . \tag{A.7}$$

Using $\Omega^e_W \cdot q^e_W = \bar{R}_W$, $\Omega^e_E \cdot q^e_E = \bar{R}_E$ and (A.3) yields (A.8) for the number of varieties in both countries and (A.9) for equilibrium resource prices.

$$\Omega^e_W = \frac{\bar{R}_W}{\bar{R}_W + x(S^e)\bar{R}_E} \cdot \Omega^e \ , \quad \Omega^e_E = \frac{x(S^e)\bar{R}_E}{\bar{R}_W + x(S^e)\bar{R}_E} \cdot \Omega^e \ , \tag{A.8}$$

$$c^e_W = \frac{2\alpha\bar{L}\rho}{\bar{R}_W + x(S^e)\bar{R}_E} \quad \text{and} \quad c^e_E = \frac{2\alpha\bar{L}\rho x(S^e)}{\bar{R}_W + x(S^e)\bar{R}_E} \ . \tag{A.9}$$

## Certification Equilibrium

Firms in $NW$ have the possibility to purchase certified legal minerals from $SE$ or $SW$. Consumer utility is then

$$M = \left( \int_0^{\Omega_L} q(\omega)^\rho d\omega \ + \int_0^{\Omega_I} [x(0) \cdot q(\upsilon)]^\rho \, d\upsilon \right)^{1/\rho} .$$

with varieties made from legal raw materials indexed by $\omega$ and varieties using illegally mined resources by $\upsilon$. Utility maximization leads to a spending pattern of

$$q(\omega)p(\omega) = 2\alpha\bar{L}\tilde{P}^{\sigma-1}\tilde{p}(\omega)^{1-\sigma} \quad \text{and} \quad q(\upsilon)p(\upsilon) = 2\alpha\bar{L}\tilde{P}^{\sigma-1}\tilde{p}(\upsilon)^{1-\sigma} \ ,$$

with corresponding prices

$$\tilde{P} = \left( \int_0^{\Omega_L} \tilde{p}(\omega)^{1-\sigma} d\omega + \int_0^{\Omega_I} \tilde{p}(\upsilon)^{1-\sigma} d\upsilon \right)^{1/(1-\sigma)} \ , \quad \tilde{p}(\omega) = \frac{c_L}{\rho} \quad \text{and} \quad \tilde{p}(\upsilon) = \frac{c_I}{\rho x(0)} \ .$$

Using the zero-profit condition, we again obtain $\tilde{p}(\omega) = \tilde{p}(\upsilon)$ and thus

$$c^c_I = x(0) \cdot c^c_L \quad \text{and} \quad q^c_L = x(0) \cdot q^c_I \ .$$

As in the embargo case, we can derive equilibrium resource prices (A.10) and the equilibrium number of varieties (A.11) from these equations. Hereby we also employ the relationship $x(S^c) = S^c + x(0) \cdot (1 - S^c)$ that follows from the linear specification of $x(\cdot)$.

$$c^c_L = \frac{c^c_I}{1-\mu} \quad \text{and} \quad c^c_I = \frac{2\alpha\bar{L}\rho(1-\mu)}{\bar{R}_W + x(S^c)\bar{R}_E} \ . \tag{A.10}$$

$$\Omega_W^c = \frac{\bar{R}_W + R_L}{\bar{R}_W + x(S^c)\bar{R}_E} \cdot \Omega^c \quad \text{and} \quad \Omega_E^c = \frac{x(0) \cdot R_I}{\bar{R}_W + x(S^c)\bar{R}_E} \cdot \Omega^c , \tag{A.11}$$

with $R_L = S^c \cdot \bar{R}_E$, $R_I = (1 - S^c) \cdot \bar{R}_E$ and

$$\Omega^c = \frac{2\alpha \bar{L}}{\sigma f} .$$

For the equilibrium price index, we obtain

$$\tilde{P}^c = \frac{c_L^c}{\rho} \cdot \Omega^{1/(1-\sigma)} . \tag{A.12}$$

## Welfare Effects

With regard to welfare in the North, comparing (II.8) with (II.11) reveals that $c_W^e < c^p/x(S^p)$ if $\bar{R}_W + x(S^e)\bar{R}_E > x(\Theta^p)\bar{R}$. Inserting for $\Theta^p$ and for $x(\Theta)$ yields the condition $[1 - S^p]\,\bar{R}_W > [1 + S^p - 2S^e]\,\bar{R}_E$, or, after inserting for $S^p$ and $S^e$, $\bar{R}_W > x(S^e)\bar{R}_E$. If this inequality is satisfied, the embargo raises consumer welfare.

Welfare in $SE$ is equal to resource rents in $SE$ minus the costs of rent-seeking, i.e.,

$$V_{SE} = \left[c_L - \pi(c_L - c_I)\tilde{F} - (a + b)\,\tilde{F} - 0.5\gamma\tilde{F}^2\right] \cdot \bar{R}_E .$$

Inserting yields

$$\begin{aligned} V_{SE}^p &= \left[1 - \frac{5c^p}{32\gamma}\right] c^p \bar{R}_E , \\ V_{SE}^e &= \left[1 - \frac{5c_E^e}{32\gamma}\right] c_E^e \bar{R}_E , \quad \text{and} \\ V_{SE}^c &= \left[1 - \frac{(5-\mu^2)\,(1-\mu)^3 c_I^c}{2\gamma\,(2-\mu)^4}\right] c_L^c \bar{R}_E . \end{aligned}$$

To compare certification with the embargo, we first note that $c_E^e < c_L^c$, $c_I^c < c_E^e$ and $1 - \mu < 1$. Therefore, sufficient for $V_{SE}^c > V_{SE}^e$ is

$$\frac{(5-\mu^2)(1-\mu)^2}{(2-\mu)^4} < \frac{5}{16} \quad \text{or} \quad f(\mu) \equiv 56 - 72\mu + 21\mu^2 > 0 . \tag{A.13}$$

The term $f(\mu)$ declines in $\mu$ for all $\mu \leq 1$ and and it is positive at $\mu = 1$. Condition (A.13) is satisfied and $V_{SE}^c > V_{SE}^e$.

For aggregate welfare with certification, we obtain from the budget constraint of consumers $2\alpha\bar{L}\rho = \bar{R}_W c_L^c + (1 - S^c)\bar{R}_E c_I^c + S^c \bar{R}_E c_L^c$. Inserting $c_L^c = c_I^c/(1-\mu)$ and $S^c$

yields

$$V_{SW}^{c} = c_L^c \bar{R}_W = 2\alpha\bar{L}\rho - \frac{c_I^c \bar{R}_E}{1-\mu} + \frac{\mu(1-\mu)^2}{(2-\mu)^3\gamma}\left(c_I^c\right)^2 \bar{R}_E \ .$$

Adding $V_{SE}^{c}$ leads to

$$\begin{aligned}
V_{SW}^{c} + V_{SE}^{c} &= 2\alpha\bar{L}\rho - \frac{c_I^c \bar{R}_E}{1-\mu} + \frac{\mu(1-\mu)^2}{(2-\mu)^3\gamma}\left(c_I^c\right)^2 \bar{R}_E + \left[1 - \frac{\left(5-\mu^2\right)(1-\mu)^3 c_I^c}{2\gamma\left(2-\mu\right)^4}\right]\frac{c_I^c \bar{R}_E}{1-\mu} \\
&= 2\alpha\bar{L}\rho + \frac{\mu(1-\mu)^2\left(c_I^c\right)^2 \bar{R}_E}{(2-\mu)^3\gamma} - \frac{\left(5-\mu^2\right)(1-\mu)^2\left(c_I^c\right)^2 \bar{R}_E}{2\gamma\left(2-\mu\right)^4} \\
&= 2\alpha\bar{L}\rho - \frac{(5-4\mu+\mu^2)(1-\mu)^2\left(c_I^c\right)^2 \bar{R}_E}{2\gamma(2-\mu)^4} \ . \qquad \text{(A.14)}
\end{aligned}$$

Since $5 - 4\mu + \mu^2 < 5 - \mu^2$, (A.13) also implies $(5-4\mu+\mu^2)(1-\mu)^2/(2-\mu)^4 < 5/16$, i.e., $V_{SW}^{c} + V_{SE}^{c} > V_{SW}^{e} + V_{SE}^{e}$.

# Chapter III

# Protection and Profit: Empirical Evidence of Governmental and Market–based Forest Policies

Julika Herzberg

**Abstract**

In this paper, I study the effectiveness of privately managed FSC certified forests and public sustainability reserves distributed over the entire Brazilian Amazon from 2002-2015. The paper uses high-resolution data on forest cover derived from satellite images and organized in a grid of 1 $km^2$ cells. Using a difference-in-difference estimator in a regression discontinuity environment, I find an increase in deforestation of an annual area of 8,057 ha in FSC forests after the certification. Public sustainability zones' impact on deforestation is also positive but declines over time. The effectiveness of both type of zones improves if they are located closer to (export) markets or existing infrastructure.

## III.1 Introduction

Tropical forestlands are gaining increasing attention due to their various beneficial characteristics, especially the manifold environmental aspects associated with forests such as biodiversity, water regulation or sequestering carbon. However, economic development close to forests is often related to environmental damage and illegal deforestation due to the extension of agriculture, mining and infrastructural projects. Conservation policies face the challenge of simultaneously achieving deforestation reduction and poverty alleviation. Moreover, local forest policies are at risk of leakage since in large forest areas deforestation activities could be shifted to other spots which are less monitored. One integrative solution is seen in Sustainable Forest Management (SFM), which is a concept involving social, economic and environmental principles in the management of forest resources. The implementation of this concept could be politically or economically motivated. While the former is realized by governmental control and management support, the latter is voluntarily adapted by firms or communities and is often motivated by an expected pay-off on environmental-conscious markets. The empirical literature provides quite mixed results on the effectiveness of both governmental and private, certified SFM projects. [1] However, to the best of my knowledge, a comparison between the two, based on a geo-referenced panel data analysis, has not been studied before.

This paper argues that for the identification of the effects of such conservation projects, various aspects such as spatial and temporal trends have to be taken into account. I provide evidence on how these parameters influence the policy outcome of the SFM zones and furthermore consider geographical heterogeneity and economic incentives by using international commodity prices. To do so, a data set is used consisting of 70 governmental and private-run sustainable-use zones distributed over the entire Brazilian Amazon from 2002-2015. As public zones[2] I consider extractive reserves (*Reservas Extravistas, RESEX*), which are implemented as part of the Brazilian conservation policy. These public reserves are dedicated to traditional populations, who generate a basic income mainly from small agriculture and the extraction of non-timber forest products (NTFP).

As private zones, certified forest management units are studied, which have to comply to sustainability standards prescribed by the Forest Stewardship Council (FSC)[3] in order

[1]See on the success of sustainable forest management among others: Bacha and Rodriguez (2007); Blackman (2015); Rico et al. (2018).

[2]For the sake of simplicity "public zone" will be used for extractive reserves reserves and "private zone" for describing FSC certified forests. However, this should not disguise the fact that not all FSC zones are private properties but are also managed by local communities. Table III.A.2 gives an overview of the tenure of the FSC certified zones.

[3]Competing systems of forest certification exist. Some are industry driven (e.g. PEFC) or state organized (e.g. Malaysian Timber Certification Council, CFLOR), others are developed by NGOs (e.g. FSC). The FSC label is the best known label (on the consumer side) and is present in over 80 countries. Comparing the FSC and PEFC system reveals that FSC has stricter rules on banning pesticides and on the introduction of exotic species (Rametsteiner and Simula, 2003)

to pass a regular third-party audit. Promoted as a non-regulatory conservation tool, forest certification marks forest products extracted in a sustainable manner. The label provides information to conscious consumers about the compliance of the company to certain management standards that guarantee the preservation of the forest.

Existing studies on the production side of FSC zones are often limited to specific cases (Rockwell et al., 2007; Kalonga et al., 2016; Rico et al., 2018) or based on qualitative data (Ulybina and Fennell, 2013; Araujo et al., 2009). Studies implementing a quasi-experimental approach are e.g. Nordén et al. (2016), considering forest certification in Sweden, and Blackman et al. (2018), studying the outcomes of FSC certified areas in Mexico. Both studies use a propensity score matching method and both find very small or insignificant effects of certificated zones on deforestation. In this paper I argue that propensity score matching has a number of shortcomings which impede the estimation of the total effect. Since the control group is formed by units of forests distributed all over the country and matched by a limited number of covariates, propensity score matching is quite weak in capturing local effects such as spillovers to areas close to the certified forest units.

In contrast to strictly protected conservation zones, sustainable-use zones are affected by human activity and are by definition part of the economic system in the region. Therefore, it is essential to take local heterogeneity, time and market trends as well as spillover effects into account to evaluate their effectiveness in reducing deforestation.

This paper uses a novel geo-referenced panel data set for FSC zones in the Brazilian Amazon. For the empirical estimation, I use two variants of a difference-in-difference method in a regression discontinuity environment. The advantage of this approach is that it deals with the non-randomness nature of the treatment and that it accounts for direct and indirect spillovers on adjacent forests. Additionally, I offer a conceptual framework which highlights theoretical mechanisms of localization, institutional ownership and economic incentives of sustainable-use forests on the variable of interest i.e. the deforestation rate. The results provide evidence that certification of private zones significantly increases deforestation in the certified forest, which leads to additional 8,057 ha per year deforested area. The time trend model shows that this increase in deforestation rates is especially high in the first 5 years after the certification date and that around 3-4 years before the main audit deforestation rates decline sharply. This result is robust to all specifications in this study. Accounting for local heterogeneity reveals that the increase in deforestation rates is driven by FSC zones located further away from markets and infrastructure. Moreover, I find evidence that under high timber prices the deforestation on the surrounding areas decreases.

Regarding the public zones, deforestation increase as well but at a lower rate. The spatial estimations do not show a significant treatment effect at the border of the zone and suggest that in the long term trend deforestation rates decrease. Higher prices for non-timber forest products further reduces deforestation activities in this extractive reserves. The results allow to draw several conclusions. First, whether the zone is governmental or privately established, its location plays an important role. If a SFM zone is established where the forest industry has not arrived yet, its implementation could open up access into intact forest lands which might finally increase overall deforestation. Second, private sustainable forest management organizations such as the FSC should ensure that firms do not increase deforestation after the successful certification and that financial incentives do not overlap envriomental principles. Finally, governments are supposed to take overall effects on the region into account and could increase the effectiveness of extractive reserves by supporting the production of non-timber forest products.

The paper contributes to the literature in several ways. While there exists a range of studies examining the acceptance of ecolabels on the consumer side [4], evidence on the producer side is very thin. One reason for this is the lack of available data on FSC certified zones which incorporate time and spatial dimensions. This paper helps filling the gap by studying the deforestation in the presence of voluntary and mandatory conservation policies, by (i) using data at a high spatial resolution; (ii) covering the entire Brazilian Amazon; and (iii) by disentangling the effect with respect to various determinants. The paper also contributes to the broader literature of evaluating conservation zones and forest certification in consideration of heterogeneous effects within regions. Finally, it also provides new evidence for the growing literature on the relationship between environmental degradation and increasing commodity prices.

The paper is structured as follows. Section III.2 discusses findings of the existing literature and elaborates a conceptional framework that underpins the empirical analysis. Section III.3 provides data resources and pre-tests on geographical and political parameters in the control and treatment group. Section III.4 states the empirical strategy. Section III.5 presents the estimation results on the effect of certification and designation of SFM zones on deforestation rates and how it varies with local characteristics and volatility in exogenous prices. Finally, section III.6 presents the conclusion.

## III.2 Existing Evidence and Conceptual Framework

While in the last decade of the 20th century small-scale settlers, gold diggers and a dominant timber industry were the main drivers of deforestation in the Brazilian Amazon, nowadays the largest threat is the transformation of forest into pasture (Margulis, 2004), soy fields (Morton et al., 2006; Nepstad et al., 2014), and other crops (Harding et al.,

[4] D'Souza et al. (2006); Aguilar and Vlosky (2007); Atkinson and Rosenthal (2014) provide experimental and empirical evidence on consumer preferences for *eco-labeled* products.

2018). Since the early 2000s, the Brazilian government launched a battery of different conservation policy tools to decrease deforestation rates dramatically. One of the most impressive interventions is the establishment of new conservation zones which now cover over 44% of the legal Amazonian territory (Verissimo et al., 2011).

### III.2.1 Conservation Zones

In contrast to the Brazilian zoning policy in the 1970s and 1980s, when most zones were centrally administrated top-down policies with only restrictive access for the local population or tourism, a large part of the recent implemented zones are decentrally-managed sustainable-use projects. The Convention on Biological Diversity[5] defines sustainable use as:
*"...the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations."*(CBD, 2018)

The effectiveness of the implementation of sustainably managed forestry compared to strictly protected areas or compared to no policy intervention, has been discussed in an ongoing debate over many years. An argument for the denying of human activity in protected forests is a higher level of biodiversity and less degradation of primary tropical forests (Zimmerman and Kormos, 2012). Opponents of strictly protected parks that completely prohibit any human use of forest resources, would argue that the reduction of deforestation is more probable if local communities are involved in the decision-making and monitoring process (Ostrom, 2010). They could efficiently contribute with their knowledge about local resource management to the conservation of the forest lands (Hayes, 2006).
A recent discussion about the effects of SFM zones was induced by a study by Brandt et al. (2016) on deforestation rates in the Congo Basin after the implementation of a new SFM law. According to the study, deforestation in forests with a sustainable management plan stayed the same or even increased in the six concessions of their study. The main reason for this is seen in the extension of the road network and increasing settlements close to SFM zones, which further increase deforestation. In Karsenty et al. (2017) a group of 20 researchers comments on this article. Besides pointing on methodological shortcomings and limitations of the data used, the researchers emphasize that sustainable forestry projects are coming with a long time horizon. Thus, for a valid evaluation, longer observation periods are necessary and time trends have to be taken into account.

[5]The Convention on Biological Diversity was founded at the 1992 Rio Earth Summit and signed by 150 states. It is dedicated to promote sustainable development and to elaborate practical tools to realize the principles of Agenda 21.

Nevertheless, a related study on the development of roadless space in Congo's forests, by Kleinschroth et al. (2017), concludes that within FSC certified concessions roadless space has been continuously lost. The only forests without a loss of roadless space are found in strictly protected national parks.
An empirical study by Pfaff et al. (2014) assesses public conservation zones in the Brazilian state Acre and finds that although forest loss is higher in SFM zones compared to strictly protected areas, the impact in the reduction of deforestation is larger as well. The authors attribute this result to the fact that sustainable use zones are in average located closer to human settlements and roads. This seems to be rational since the production of sustainable timber is reliant on infrastructure that makes transport to domestic and international markets possible.
Another point researchers consider as important for the evaluation of SFM projects is their economic purpose. Naturally, if economic considerations overlap ecological principles, deforestation increases as soon as it pays off for the forestry managers or owners. For instance, Rasolofoson et al. (2015) compare different forms of forest management and find that only in those without permission of commercial timber extraction deforestation is significantly reduced.

A further important determinant of the effectiveness of zones in reducing overall deforestation rates are spillover effects. This refers to the policy effect on the non-treated areas. In principle the effect can have three potential outcomes: First, no spillover effects could be detected, which means that the policy did not influence the deforestation patterns outside of the area targeted by the policy.
Second, spillover effects can be positive, which means deforestation rates outside the treated area are reduced. By the implementation of sustainable-use zones monitoring efforts in the region could increase in general and thereby also decrease deforestation rates in forests outside of the protected zone. Anecdotal evidence suggests that sustainable forestry increases the awareness of intact forests as an economic and social value in the affected regions (Schelhas and Pfeffer, 2005).[6] The presence of SFM projects could also create new jobs and increase financial stability in a municipality and therefore decrease illegal activities in the forest (Bacha and Rodriguez, 2007). Moreover, if they are economically successful and demand is high enough, SFM practices could diffuse throughout the entire sector and have effects on the overall compliance of the industry (Foster and Gutierrez, 2013).
Finally, spillovers could be negative or the policy could come with leakage. Literature shows that the construction of new roads other infrastructure in forest areas is highly correlated with deforestation (Mertens et al., 2002; Pfaff et al., 2007). Thus, if the imple-

[6] Moreover forests systems themselves have numerous positive externalities: Fertile soil, climate and rainfall regulation, provision of nutrition and medical plants (Sims and Alix-Garcia, 2017).

mentation of SFM zones is connected with the extension of the road network in a region, it reduces opportunity costs of deforestation and opens access for illegal deforestation as well (Brandt et al., 2016; Kleinschroth et al., 2017).

Forms of leakage could be observed when the decrease in deforestation in a country, region or municipality leads to an increase in deforestation in neighbouring forests, as for instance shown by Alix-Garcia et al. (2012). Channels for leakage are multiple. It could be that lumbers who are operating -or who would operate in the future- in the protected area shift their activity to land outside of the conservation zone (Aukland et al., 2003). Moreover, leakage is especially observed where alternative land uses are present and deforestation pressure is high. If the establishment of a conservation zone leads to a restriction of land available for agriculture, then deforestation on unprotected land accelerates (Armsworth et al., 2006; Fisher et al., 2011; Delacote et al., 2016). Finally, restriction of the timber production due to the limited harvest rates in sustainable forestry, may increase prices. This motivates new firms to enter the market leading to an increase in deforestation

The effectiveness of sustainable-use zones may also be different if the introduction of sustainable management practices is a voluntary adoption by individual firms or communities or if it is a obligatory requirement by the state. Since this is one of the main focuses of this paper, the conceptual differences are elaborated in the following subsection.

### III.2.2 Governance in Sustainable Forestry

Sustainable-use zones implemented by the government are usually supported and monitored by public institutions. Thus, not surprisingly the effectiveness of such anti-deforestation policies is correlated with institutional quality and the executive power of a state (Arcand et al., 2008; Culas, 2007). Blackman (2015) emphasizes that the lack of effectiveness of conservation zones is nonetheless due to the limited governmental enforcement and monitoring of strictly protected areas in (developing) countries.

However, it is also mentioned by several studies that the limited success in reducing deforestation might be a result of not locating them at the hot spots of deforestation, close to the large agriculture companies and farms, but rather to remote areas, where they do not impede economic growth (e.g. Joppa and Pfaff (2009); Nolte et al. (2013)).

In contrast to state-owned and controlled SFM zones, the certification of forests is widely considered as a market-based instrument for lowering deforestation rates. The aim of ecolabelling forest products is to increase the value of timber production, which is in line with environmental goals, and to encourage the market to financially appreciate sustainably produced wood. With this approach, private certification generally goes beyond or around governmental regulation, taking consumer responsibility into account (Sundstrom and Henry, 2017).

Product labelling is often considered as a tool to deal with asymmetric information on the market. The lack of information about a company or a production process yields inefficiencies for the consumer (search costs, adverse selection etc). To solve these issues a label has to provide valuable and credible information. This means that a consumer should be familiar with the production criteria associated with a certain label and that the assessment of a firm has to be executed by an independent agency (Roe et al., 2014). Researchers have identified at least four reasons why participating in a voluntary environmental program in the forest sector could be beneficial for private agents.[7]

First, the *signalling mechanism* of the label could generate economic advantages if the costumer values the extra effort the firm takes to comply to environmental standards, and is willing to pay a higher price for the product.[8] Second, the signalling effect could also be positive for a firm's public reputation as it shows awareness of environmental responsibility (Overdevest and Rickenbach, 2006). A better image of a firm is, in turn, associated with higher sales figures, less marketing costs and easier access to capital. Third, in a survey among FSC certified companies in Brazil, Araujo et al. (2009) find that the main motive to apply for a certificate does not lie in a possible price premium, but in the access to knowledge and technology transfer. This *learning mechanism* corresponds to the expectation that certification comes with a technology transfer for ecological production provided by the NGO or monitoring agency (Overdevest and Rickenbach, 2006). Finally, especially for developing countries, access to environmentally conscious international markets in Europe or the US is an important incentive for firms to participate (Rico et al., 2018).

It is sometimes argued, especially by firms from developing countries, that ecolableing is used as an entry barrier to markets in developed countries or as a strategic instrument to decrease their competitiveness. Indeed, the presence of certificated forests is higher in developed countries in the northern hemisphere than in tropical regions, where forests are biologically most valuable. Reasons for this gap often lie in problems with land tenure, high cost of certification and the small demand from domestic markets for certified products (Sierra, 2001). Especially for small-scale producers, it is also a lot of paperwork and difficulties to get licenses for their land. Moreover, additional costs for the audit and the transformation of the production process have to be covered by extra market benefits. As a consequence only those firms with the lowest compliance costs, which mainly are already close to sustainable management, apply for the certification. This selection process into the voluntary environmental programs reduces their overall effect in the combat

[7] This could be farmers, communities, local companies for timber or paper products, or large often multinational companies. Klooster (2010) finds that most of the FSC certified areas are owned by large forest management operations

[8] There is no fixed price paid for certified timber as it is, for example, for *fair trade* products. Estimations of average on price premia are mixed. Clark (2011) reports a 10-30 % higher producer price, while Yuan and Eastin (2007) only find a 1.5 -6% for China.

against deforestation (Foster and Gutierrez, 2013).
In general, the effectiveness of voluntary certification programs could be measured by taking the number of participants times the average effect per participant plus the spillovers the program has on other non-participating firms (Potoski and Prakash, 2005). This also applies for the evaluation of governmental programs with the difference that the number of participants (or here, forest area protected) is not exogenous but can be determined by the state. In the voluntary case, the number of participants will result from the direct and indirect costs of the participation and how harmful consumers' sanctions for non-participating are. The average effect depends on the label's criteria, the firm's willingness to comply and the frequency of the audits. Theoretical models show that voluntary environmental programs can dominate mandatory programs if governmental monitoring expenditures are higher than costs to incentivise a voluntary participation (Wu and Babcock, 1999) or if the market demand for products that meet environmental standards is high (Karl and Orwat, 1999).

The above stated facts and insights show that the final success of SFM projects in reducing deforestation depends on various parameters, which might also differ between voluntary and mandatory implemented conservation zones. The analysis in this paper considers the following aspects in regard to the effectiveness of sustainable-use policies:
*Where* is the SFM zone located? If a sustainable-use zone is located where deforestation and human activity is low, the implementation might be accompanied by an expansion of infrastructure which opens access into virgin forests and increases deforestation there.
*Which* effects does a SFM zone have beyond its borders? If overall monitoring around the zone is augmented, deforestation rates could decrease even on unprotected forest lands. Implementation could also result in higher deforestation rates if deforestation activity is simply shifted to forest lands outside of the zone. *Who* does implement sustainable-use practices and who does monitor and control the timber harvest in the zones? A community or forest company, which already uses quite long rotation rates in their management plans, might have less opportunity costs to comply with SFM certification standards or governmental requirements of sustainability, but will also make a smaller change to overall deforestation by joining the certification program. Subsequentially, if a reasoned monitoring plan is missing or consequences of misbehaviour are not clearly communicated, full compliance to SFM regulations cannot be expected.
*Why* is the SFM zone implemented? If a SFM project has mainly commercial ends and mainly produces for export markets, it will be more vulnerable to volatilities in price and demand than if the priority lies on conservation and poverty alleviation.
In the following sections, all these parameters will be carefully analysed to examine if the SFM zones substantially and statistically significant reduce deforestation rates.

## III.3 Data

This section describes the data sources and explains the data preparation. Geographical and socio-economic covariates are pre-tested to illustrate parallels and differences between treatment and control group.

### III.3.1 Data Sources

*Deforestation rate and Remaining Forest* — My main dependent variable is the annual deforestation rate in a grid cell of 1 $km^2$ size. The deforestation rate is defined as:

$$df_{rate} = \frac{fr_{t-1} - fr_t}{fr_{t-1}} \tag{III.1}$$

where $fr_t$ is the remaining forest in year $t$ and $fr_{t-1}$ is the remaining forest cover in the previous year. In order to calculate the annual change in remaining forest, I use data based on NASA satellite images which have been processed at the Brazilian National Institute for Space Research (*INPE (2017) - Instituto Nacional de Pesquisas Espaciais*). The data cover the entire legal Amazon, an area of about 5 million $km^2$. The data are organized into 1 $km^2$ grid cells and to each such cell the annual deforestation is assigned. For the control group, I use grid cells located outside the conservation zone within different buffers where the largest is 60 km.
The forest data are coded from August to July. This means that deforestation in year 2002 actually measures forest loss from August 2001 to July 2002. To account for the timing of the deforestation data, I adapt the zone's dataset by counting zones establishes from September to December in year $t$ as being established in year $t+1$. In order to have at least one year before and one year after the implementation date of a zone, I include only zones that where implemented after July 2002. An overview over the certification dates and size of the FSC zones is given in table III.A.2 and for the implementation date of the RESEX zones in table III.A.3. I further restrict the sample by excluding all grid cells without any forest cover left in 2002. Cells that are part of a protection zone of another type than RESEX or FSC zones are excluded from the sample to avoid a bias in the dependent variable. Geographic covariates are used to check for systematic differences between treatment and control group. For instance, these covariates are: distance to the next river, road, municipality borders and cities. A detailed overview of dimension and source of all variables used in this paper is available in table III.A.1.

*Public Zones RESEX Data* — The first RESEX zone was implemented in 1990 in memorial to the famous resistance fighter and rubber collector Chico Mendes. Their primary objective is to clear property rights distribution over the land and serve local communi-

ties as a protected habitat. These communities are not indigenous but have traditional knowledge on the extraction of non-timber forest products, such as fruits or rubber, as well as substantial agriculture production. The central idea behind the implementation of these zones is that traditional forest users may have the most responsible interaction with the resource their livelihood depend on. Thus, extractive reserves are only designated to those local populations that can exhibit a history of sustainable forest use (Da Silva, 2004). In this spirit, more and more extractive reserves were designated such that 92 exist until today; 35 in my period of observation, 53 before and additional 4 in 2018. The establishment of RESEX zones comprise three principal steps. First, a formal request of the local population is necessary, which has to contain descriptions of the social, economic and environmental conditions of the area where the zone should be implemented. This first request is often accompanied and supported by an environmental NGOs (Koziell, 2002). Thus, their placement is not a top-down decision but requires a bottom-up request by the communities themselves. Second, the Brazilian Envriomental Institute (IBAMA) has to approve the request and elaborate a plan for the sustainable use of the resources of the area. Finally, the plan has to be translated into action and should be steadily improved to guarantee long-term efficiency (Da Silva, 2004).
Data on implementation date, localization and size of the RESEX areas are acquired from the Brazilian ministry of environment, *Ministerio do Meio Ambiente* (MMA, 2017). The sample contains 35 RESEX zones, where the smallest is about 28 square kilometres and the largest is about 12887 square kilometers. Table III.A.3 lists all RESEX zones contained in the sample and gives information about size and the municipalities in which they are located. Figure III.A.7 maps the location of the zones and shows the proximity to agricultural frontier, the so called arc of deforestation[9] and, thus, illustrating the distance to the forest which is probably most affected by recent deforestation.

*Private Zones FSC Data* — The Forest Stewardship Council is a non-governmental organization that was founded in 1993 with the objective of establishing a voluntary system for sustainable production and of providing a market-based solution to the timber industry.[10] Since then, the number of certificates and the size of the area certified have increased steadily.

[9]The arc of deforestation describes a region at the southern edge of Brazil's Amazon, where most of the deforestation takes place and the frontier between cleared land and dense forest is located. Each year it moves further into the forest, revealing a boom and bust pattern (Rodrigues et al., 2009).

[10]Initially, the label mainly addressed the timber industry and commercial lumber companies. For small-scale loggers and communities it is much more complicated to receive the certificate due to economies of scale and often less experience in commercial forestry. However, in 2013 the Smallholder Fund was found by the FSC to financially help smallholders with the certification costs and with other obstacles in the certification process.

The main concept is to limit the annual maximum yield in a clearly defined area: a so-called Forest Management Unit (FMU). The certification is executed by a third-party audit agency at the level of those FMUs. Usually, there is one main audit at the beginning of the certification followed by reassessments every 5 years if the firm applies for an extension of the certificate. Additionally, a short audit report is provided by the agency each year to confirm the compliance with the FSC standards. Beyond regulations on harvesting and regeneration of forests, the FSC imposes formal principles to ensure a socially beneficial, economically viable and environmentally sustainable management plan (FSC, 2015).

For the FSC zones, there is no data set available that gives information about the exact geographical localization, the size, the operating company, and the duration of the certificate. Documents on this first assessment (to obtain the certificate) are available from the FSC webpage (info.fsc.org) and they provide information on GPS coordinates, size of the certified areas, maps, timeline and report changes in the scope of certification. By using the Brazilian land register (CAR, 2017), where private agents have to register their land since 2012, it was possible to identify the areas. Careful examination and comparison of companies' maps and the CAR shape file made it possible to get the exact geo-referenced location and border of the certified area. The detailed process of the creation is described in III.A. Furthermore, I run several sensitivity tests with variation of years in the pre- and post-treatment period in order to increase reliability.

It is important to notice that many of the FSC certified forests could not be part of the sample, since they are secondary forests[11] or plantations. However this is a form of reforestation and thus, not the objective of this investigation. After these adjustments, my data set contains 35 FSC zones with geographic references in 28 municipalities. The smallest zone is 12 $km^2$ and the largest is 8777 $km^2$. A list of all certified FSC zones is given in the appendix III.A.2.

There are several limitations of the FSC data sets that should be taken into account for the interpretation of the results. First the geographical allocation was not possible for all FSC certified forests in the Amazon due to missing documents or a lack of information in the documents. Timber harvest in FSC certified forests is supposed to follow a management plan which divides the area into parcels that are harvested in one year and fallowed for several years afterwards in order to give nature time for recover. I do not have information about which parcels are harvested in which year but only know location

[11] Secondary forest is forest that is re-grown on woodland that was once cleared and hence differs in its biodiversity. While natural forests contain many species, re-grown forests usually have only one or two species, commonly fast growing ones like e.g. eucalyptus, with rotation cycles as low as 7 years for paper and pulp production. Thus, rules for the management of native forests are more stringent than those for plantations (Blaser, 2011).

and certification dates for the entire zone.[12] This could be an issue when harvesting is systematically higher or lower close to a zone's border, which could specially bias the results of the spatial estimation and regression discontinuity figures. There is no reason to assume that deforestation should be higher or lower closer to the border on average. However, to meet this concern, I run the regression with different distances to the border within and outside the zone.
Several FSC zones are located in public forests for which the certification holders possess a license for forest use. Therefore, I cannot completely rule out that these areas are additionally supported or monitored by governmental forces. However, the decision to certificate their land, the cost of certification and the income from the sold timber are solely determined by private agents.

*International Prices* — As basis for the construction of the price index of corn and cattle, I use annual commodity prices by the World Bank (2017). Figure III.A.15 shows the development of these prices from 2002 to 2015. Especially the price for corn increased about 2.5 times between 2010 and 2013 and declined rapidly afterwards.
For timber, I use tropical sawnwood prices published by the International Tropical Timber Organization (ITTO, 2018) which collects the data on tropical timber prices and production in collaboration with the FAO and the World Bank. The organization also provides data on plywood and roundwood, but I use sawnwood here due to two main reasons. First, because in terms of tropical timber, sawnwood is the product with the highest export figures in Brazil in the regarded period. It makes about 67 % of all tropical timber exports from Brazil. Second, sawnwood exports are mainly delivered to environmentally conscious markets such as Japan, the US and the EU-28, which are the target markets for sustainable produced timber (Blaser, 2011).
Furthermore, I consider the three most important non-timber forest products: rubber, açaí and brazil nuts. Rubber is the only commodity of those three for which the international price is available, again published by the World Bank. For Açaí and Brazil nuts I take average prices from South Brazilian states, which do not produce them but are often a stopover to international markets. For each of the commodities, prices are normed on the year 2002. These prices are the time-varying component of the price index. Cross-sectional variation is achieved by using the heterogeneity of the economic importance of a commodity in a municipality since each grid cell is located in a municipality, the commodity weights of the municipalities are automatically attributed to the grid cell. The

[12] Similarly to the data Blackman et al. (2018) use in their paper on FSC certified areas in Mexico, the data which do not provide information on which part of the zone is deforested in which year.

weight $w$ for the price index is calculated as follows:

$$w_{j,i,2002} = \frac{v_{j,i,2002}}{\sum_{j=1}^{n} v_{i,2002}} \tag{III.2}$$

where $v_{j,i,2002}$ is the output value of commodity $j$ in municipality $i$ in the year 2002. This value is divided by the aggregated value of all agricultural and forest commodities produced in municipality $i$ in the initial year 2002. The output value of the commodities are published in the annual report *Produção Agrícola Municipal* and the *Produção da Extração Vegetal e da Silvicultura* at the Brazilian Statistical Institute (IBGE, 2017).

Figure III.A.11-III.A.14 presents a map that shows how each price intensity is distributed over the Amazonian municipalities. While timber intense municipalities seem to be smoothly distributed over the whole area, there are two regions to highlight: First, the south of the Amazon, mostly the state of Mato Grosso, where timber intensity is low, agricultural business is large, and not much forest is left. Second, the north east of the Amazon, where municipalities with high timber intensity cluster. Municipalities there, for instance are Paragominas or Dom Eliseu in northern Pará, which are located close to big harbors like Belém or São Luiz, from which timber can be exported to the US, Europe or China. At the same time the conversion into agricultural land there is not at the same advanced stage as it is in the south. However, in the southern part there is hardly any production of NTFP, which is most intense in the northern parts where forest is more dense and intact than in areas close to the agricultural frontier. I control for these clusters by including robustness checks, which account for spatial autocorrelation.

### III.3.2 Covariates

This section examines whether geographical and socio-economic covariates are significantly different in the treatment and the control group before the zones are implemented. Different pre-trends of the dependent variables are tested separately in section III.4.3.
A critical assumption for a difference-in-differences(DD) estimation with a geographical threshold (here the borders of the zones) is that the subjects of observation (grid cells) do not differ systematically around this threshold, such that the only fact which makes them different is the implemented policy. For an assessment of this smoothness around the border the upper panel of table III.1 compares geographical characteristics at the grid level and focuses at a 10 kilometer buffer around a zone's border. All variables are either measured before 2002 (Distance to Sawmill, City and Road) or are time invariant (Non-Forest Area, Soil Quality and Distance to River). Since data on socio-economic covariates are only available on the municipality level, the lower panel compares these characteristics between municipalities which host a SFM zone and non-affected neigh-

bouring municipalities.

*Table III.1: Pre-test on Covariates*

| | Private (FSC) | | | Public (RESEX) | | |
|---|---|---|---|---|---|---|
| | Inside | Outside | tStat | Inside | Outside | tStat |
| | | | *Geographical Variables* | | | |
| Non-Forest Area (%) | 0.02 | 0.07 | (-1.08) | 0.08 | 0.09 | (-1.03) |
| Soil Quality (1-5) | 1.82 | 1.76 | (0.20) | 1.40 | 1.53 | (-0.54) |
| Distance to Sawmill (km) | 122.98 | 108.21 | (0.30) | 218.56 | 216.43 | (1.52) |
| Distance to City (km) | 65.08 | 62.78 | (1.01) | 82.1 | 76.8 | (1.91*) |
| Distance to River (km) | 21.39 | 21.66 | (-1.26) | 14.56 | 15.19 | (-1.03) |
| Distance to Roads (km) | 24.51 | 19.27 | (0.48) | 66.12 | 60.7 | (1.67) |
| Observations | 14,126 | 19,218 | | 212,135 | 206,476 | |
| | | | *Municipality Variables* | | | |
| Deforestation ($km^2$) | 58.5 | 80.9 | (0.87) | 57.6 | 51.9 | (-0.38) |
| Population 2000 | 40130 | 43688 | (0.16) | 46823 | 30893 | (-1.06) |
| GDP per capita (in Tsd R$) | 4.3 | 4.1 | (-0.31) | 3.6 | 4.1 | (1.30) |
| Extraction Fuelwood (m3) | 31426 | 24089 | (-0.77) | 30083 | 20804 | (-1.62) |
| Extraction Acai (tons) | 185.8 | 748.1 | (0.98) | 245.9 | 564.2 | (1.05) |
| Extraction Brazil Nuts (tons) | 271.8 | 106.5 | (1.96*) | 145.6 | 52.02 | (2.16**) |
| Extraction Rubber (tons) | 32.7 | 19.3 | (0.37) | 22.3 | 7.5 | (2.23**) |
| Accessibility | 3.19 | 3.31 | (0.98) | 3.44 | 3.19 | (1.99*) |
| Cattle (heads) | 71182 | 97987 | (1.00) | 57283 | 82753 | (1.73*) |
| Corn (in Tsd R$) | 1095 | 671 | (-1.12) | 621 | 826 | (0.70) |
| Observations | 40 | 110 | | 108 | 165 | |

Note: Upper panel compares average values of geographical variables on the grid level for the first 10 km around a zone's border and documents a t-test for the difference between these values in brackets. All variables are time invariant. *Non-Forest Area* gives the % of area that is naturally not covered by trees (rocks, mountains etc.). *Soil quality* is a FAO measure giving the restriction of the soil with respect to agricultural fertility: 1= very low restrictions and 5=high restrictions. The lower panel reports average values of the year 2002 for socio-economic an geographical variables on municipality level. The population data stem from the demographic census in 2000 that is published every 7-10 years. Units of measure given in brackets.

Column (1) reports the mean value of geographical variables for grid cells in a FSC zone and column (2) does the same for grid cells outside the zone. Column (4) shows values of grid cells within a RESEX zone and column (5) shows the values for the adjoining grid cells. Columns (3) and (6) show the t-statistic for the difference between them. Column (6) reveals that the only statistically significant difference on the grid cell level

lies at a slightly higher distance to the closest cities in the RESEX sample. Note that when comparing public and private zones it becomes evident that private zones are in average located about 100 km closer to sawmills, almost 20 km closer to cities and over 40 km closer to roads than public zones.
Another assumption for geographical-based DD is that zone borders are not following a specific intention but are rather randomly drawn. About 4% (7%) of borders of the public (private) conservation zones are identical to the administrative borders such as municipality or state borders. About 11% (5.8%) are defined by main rivers. Those are of great importance in the Brazilian Amazon because they serve as a main transport system, especially for timber. About 1.4% (4.2%)of the zone borders follow roads or highways. Only 9% (24%) of the borders are straight, which implies that the majority of the zone borders are defined by natural geography such as small rivers, mountains etc. rather than designed on a drawing board. Since the Brazilian Amazon is very humid and rich in all kinds of water bodies, borders following small rivers are less of a concern.
Additionally, figures III.A.8 and III.A.9, which plot several geographic characteristic 10 km inside and outside of the zones in 2002, illustrate that around the border variable values pass quite smoothly. This and the insignificant t-tests in table III.1 indicate that systematic differences in geographical covariates between treated and non-treated grid cells cannot be rejected.

As described above, the lower panel compares average values of socio-economic variables on a municipality level in the year 2002, before the zones are established. In columns (1) and (4) municipalities which host a SFM zone are regarded and in columns (2) and (4) average values for the neighbouring municipalities are shown. Again, columns (3) and (6) report results of the t-test which examines if differences are significant. The private zone sample shows that a higher amount of *Brazil nuts* is collected in treated municipalities, which indicates high extractive activity. All other variables do not significantly differ in the FSC sample.
As expected, extracting activity in RESEX municipalities is higher in respect to *Brazil Nuts* and *Rubber*, due to the traditional populations which are supposed to live in these municipalities. Moreover, the variable *Accessibility* measures the mean travel time from the municipality center to the closest city with more than 50,000 inhabitants. It is coded in an interval from 1 to 5. An accessibility value of 1 means that the travel time is less than 1 hour and a value of 5 corresponds to travel times of more than 24 hours. This value is significantly higher for RESEX municipalities than for their neighbours and also higher than in FSC municipalities. This fact, together with the larger distances to roads and sawmills, suggest that access to formal markets, especially export markets, is more limited for inhabitants of extractive reserves than for private forestry companies. Finally, fewer *cattle* is kept in the RESEX municipalities, indicating fewer agricultural activities.

These values are particularly interesting in regard to the examination of the commodity price effect on deforestation in section III.5.4. The individual weighting of the prices, which is explained in section III.3.1 ensures that the differences in the production volume of agricultural and extractive goods, which are shown here, do not bias the estimation results.

## III.4 Empirical Strategy

In general, the empirical evaluation of conservation zones has to take into account that they are not randomly assigned but that their location could be chosen intentionally or systemically, which makes it difficult to identify the real cause of any change in the outcome. In other words, one cannot simply compare treated with non-treated areas, since it is not possible to disentangle effects of the policy from other unobservable differences between the two. To deal with this challenge, quasi-experimental designs are a popular approach to study conservation zone polices. Their advantage is that they aim to select an adequate control group for the treated units to ensure an unbiased estimator.

This paper uses a difference-in-difference estimator in the spirit of a regression discontinuity design (RDD) to estimate the policy effect of sustainably managed forests on deforestation rates. This means that control groups are formed by the directly adjoining forests in different buffers around the zones. The analysis is based on the assumption that grid cells which are located close to each other are not only similar in terms of geographical characteristics and administrative and political parameters but also in unobservables which cannot be captured by controls or fixed effects in the regression. Following Ahlfeldt et al. (2017) the standard model is adapted to capture spatial heterogeneity and differences in time trends between treatment and control group. As baseline, I start with with a simple difference-in-difference model which estimates the average treatment effect for grid cells within a sustainable-use zones before and after the implementation. Grid cells located within 30 km outside the zone are used as a control group. However, I run various robustness checks including different specification of the control group. The baseline regression for is the following:

$$df_{it} = \alpha_j + \gamma_t + \beta_1 I_i + \beta_2 T_{it} + \beta_3 (I_i \times T_{it}) + \beta_3 X_i + \epsilon_{it}, \tag{III.3}$$

where the outcome variable $df_{it}$ is the deforestation rate in grid cell $i$ in year $t$. Zone fixed effects are captured by $\alpha_j$ and year fixed effects by $\gamma_t$. The inside dummy $I_i$ is indicating whether a grid cell is located within a zone. The time dummy $T$ is one if a year is equal to or higher than the year of the implementation of the zone to which grid cell $i$ belongs. Note that for the FSC zones, the certificate either automatically expires after 5 years (if it is not extended) or it is suspended before the end of this period due to environmental

or social misbehavior. For years following the termination of the certificate, the time dummy $T$ becomes 0 again.
The coefficient of interest is $\beta_3$ which measures the effect for the forest belonging to a grid cell that is located after a zone was successfully implemented. $X_i$ is a vector of different time invariant geographical control variables which differ between the grid cells. $\epsilon_{it}$ is an error term, which is assumed to be independently and equally distributed.
To account for potential spillover effects the second specification of equation III.3 takes grid cells located within 10 km around the zone as a second treatment group into the equation:

$$df_{it} = \alpha_j + \gamma_t + \beta_1 I_i + \beta_2 T_{it} + \beta_3 (I_i \times T_{it}) + \beta_4 O_i + \beta_5 (O_i \times T_{it}) + \beta_6 X_i + \epsilon_{it}. \quad \text{(III.4)}$$

The model is analogous to the first one but includes a dummy $O_i$ which equals one for all grid cells located with a maximum distance of 10 km around a zone's border. $\beta_4$ captures the intercept of possible spill-over effects on close neighbor cells of the zone after the designation. Note that for the main model used in this paper $\eta_i$ is included in order to account for cell fixed effects, which excludes all variables without between variation; in this case $I_i$, $O_i$ and $X_i$.

### III.4.1 Spatial Difference-in-Differences

An RDD approach in a geographical context assumes that political boundaries (cut-off point) split units into treatment and control areas (Keele and Titiunik, 2015). Analysts suppose that right at the cut-off point, characteristics between the units of observations do not differ systematically and could be used as a quasi experiment. Compared to the standard case where the selection into treatment and control group is based on whether their value for numeric rating falls above or below a certain threshold (Lee and Lemieux, 2010), the geographical boundary creates the threshold in the case of the spatial estimation. This basic assumption is translated to this study. The focus is taken precisely to those grid cells that are located close to a zone's border, since the probability that there is a systematic difference between the cells on both sides of a border becomes smaller (see table III.1).
The spatial empirical model estimates the treatment effect of the implementation of a zone at different distances from the zone border as well as a possible discontinuity in deforestation rates around the border. The spatial DD model is estimated with the following regression form:

$$\begin{aligned} df_{it} = \eta_i + \gamma_t + \beta_1 T_{it} + \beta_2 (I_i \times T_{it}) + \beta_3 (I_i \times D_i \times T_{it}) + \beta_4 (O_i \times T_{it}) + \\ \beta_5 (O_i \times D_i \times T_{it}) + \beta_6 (D_i \times T_{it}) + \epsilon_{it}, \end{aligned} \quad \text{(III.5)}$$

again $df_{it}$ is the deforestation rate in grid cell $i$ at time $t$, $\eta_i$ accounts for cell fixed effects and $\gamma_t$ for time fixed effects. $D_i$ measures the distance of cell $i$ to a zone's boundary. In this specification $\beta_2$ gives the intercept of the treatment effect at the border and $\beta_3$ measures how it changes with respect to the distance from the border. In the full model of this specification, I also include interactions with an outside dummy $O_i$ that measures the external effect of the treatment within the first 10 km outside of the border. Here $\beta_4$ captures the intercept of possible spill-over effects on close neighbor cells of the zone and $\beta_5$ shows whether these effects are changing with higher distance to the border (e.g. due to lower monitoring). The coefficient $\beta_6$ reports the effect the treatment has on grid cells which are located with higher distance from the zone, beyond the first 10 km after the border. Implementation of the zones occurred in different years during the sample period. The first year of official recognition as a RESEX zone counts as the first year of treatment. Equally, for the FSC zones, the first year of certification confirmation by the audit agency is the first year of treatment.

### III.4.2 Time Difference-in-Differences

The spatial model described above assesses the effect of political or private protection effort on a pre-defined area and possible spillovers on the environment. However, it does not account for potential pre-trends in preparation of the treatment or changes in the effectiveness during the post-treatment years. Especially in the case of certification, the adoption of FSC standards is expected to start before the first audit that decides whether a zone will be certified or not. To address these limitations, the time trend DD model focuses on trends in the years before and after the first year of certification or governmental protection, respectively. It takes the following regression form:

$$df_{it} = \alpha_i + \gamma_t + \beta_1 T_{it} + \beta_2(I_i \times T_{it}) + \beta_3(I_i \times YT_{it}) + \beta_4(I_i \times YT_{it} \times T_{it}) + \beta_5(O_i \times T_{it}) \\ + \beta_6(O_i \times YT_{it}) + \beta_7(O_i \times YT_{it} \times T_{it}) + \beta_8(YT_{it} \times T_{it}) + \epsilon_{it}, \tag{III.6}$$

where the number of years before the implementation (negative values) of a zone and afterwards (positive values) are captured by $YT$. The year of implementation itself takes the value 0. The $YT$ variable is interacted with the inside dummy to control for specific trends, which differ between treatment and control group, analogously, for the external treatment dummy $O_i$. In order to control for general post-treatment trends, an interaction between $YT$ and $T$ accounts for trends in deforestation that changes in the control group after the the zone was implemented. Taking these unobserved trends into account puts the functional form in a regression discontinuity environment with a time running variable (Anderson, 2014). Unobserved trends that may affect deforestation are assumed to behave smoothly around the year of implementation since the only change in this specific date is the implementation of the SFM zone. Thus, a significant $\beta_2$ can be entirely attributed to the treatment and allows the identification of the changes in deforestation trends which are induced by the treatment captured by the coefficient $\beta_4$.

### III.4.3 Sensitivities

In order to increase confidence in my estimates, I provide a sensitivity analysis for each result presented in this paper, concerning different potential threats to identification.
A first evident test is to include several definitions of the *dependent variable*. My main specification is the deforestation in a grid cell normed on the remaining forest cover in that grid cell. The advantage of this definition is that it accounts for the simple fact that where more forest is left, more deforestation is physically possible. Thus, the effect in grid cells with a lot of remaining forest would be overestimated. However, if one is only interested in the total area of avoided deforestation, due to a specific treatment, the dependent variable has to be measured in levels. For that matter, I use the deforestation in hectare per grid cell in a year. Moreover, I provide estimations on the probability that any deforestation may occur in the grid cell.
Table III.2 presents estimations on deforestation trends measured in the several forms described above. While the dependent variable in a difference-in-difference estimation is allowed to differ in levels between treatment and control group, a pre-condition for a valid estimation is that the trends are parallel in both groups.

*Table III.2: Pre-test on Dependent Variables*

| | Private (FSC) | | | | Public (RESEX) | | | |
|---|---|---|---|---|---|---|---|---|
| | Df % | Df ha | Df 1/0 | Fr | Df % | Df ha | Df 1/0 | Fr |
| L.Inside × Trend | 0.074 | 0.022 | 0.514* | 0.387 | 0.096 | 0.057 | 0.239 | -0.017 |
| | (0.083) | (0.048) | (0.260) | (0.249) | (0.080) | (0.055) | (0.220) | (0.279) |
| Observations | 0.688m | 0.688m | 0.688m | 0.688m | 2.75m | 2.75m | 2.75m | 2.75m |

Note: Dependent variables are deforestation in percentage of remaining forest cover $Df\%$ , deforestation in hectare *Df ha*, the probability of deforestation $Df1/0$ and the remaining forest cover $Fr$ in a grid cell. Pre-trends before the policy implementation is measured by an interaction term $Inside \times Trend$. Not shown in the table but included in the regression are the subterms of the interaction term, namely $Inside$ and $Trend$ as well as year and municipality fixed effects. Standard errors are in parentheses and clustered at the municipality level.

The interaction term $Inside \times Trend$ combines a dummy that indicates if a grid cell is located within a zone and a trend variable that indicates the number of years before the policy treatment. This interaction term estimates if differences between treatment and control group are significant in respect to the development of the dependent variables over time before the treatment was implemented. As the coefficients of the interaction term are insignificant, the hypothesis of parallel trends could not be rejected. An exception is the coefficient on the probability of deforestation *Df 1/0* in the private zone's sample, which is significant on the 10% level. Thus, the following results in regard to this variable should be interpreted carefully.

Another concern is that results could be biased by a specific choice of the buffer size around the zone, which defines the *control group*. Therefore, I repeat each table with different definitions of the control group, by mainly increasing the baseline definition of 30 km to 60 km or to narrow it down to 10 km.

In my main specification I implement the RD Design by using a parametric model. It is stated by Gelman and Imbens (2017) that regression discontinuity designs of higher polynomial order are prone to noisy estimates and sensitive to the degree of the polynomial chosen in the regression. Moreover, it is claimed that designs above the second polynomial degree cover confidence intervals incompletely. However, as Lee and Lemieux (2010) suggest, checking *nonparametric* specifications of the model provide more flexible estimates of the regression function. One straight forward way to implement a nonparametric model is to simply include polynomials of the assignment variable as regressors. Therefore, I include robustness by adding the second polynomials of the time variable, in order to relax the assumption of linearity in my models.

A further concern which emerges when using RD Designs regressions, especially if it is run at a geographical border (Keele and Titiunik, 2015), is that variables may be *spatially correlated*. Similar values could either appear near to each other or dissimilar ones could be located closely to each other. Both cases would bias results. I control for this by clustering the standard errors at the municipality level in all regressions and run further robustness that cluster the standard errors at the municipality-year level and at the state-year level. Further robustness which are specific to the regression form of each result table are explained in detail in the following results section III.5.

## III.5 Empirical Results

This section empirically analyses the relationship between deforestation and the public and private zoning policy, assessing whether the level and form of deforestation changed significantly after the area was officially established as a sustainable-use zone. As a baseline I start with a simple difference-in-differences model which estimates the average treatment effect for grid cells within sustainable use zones before and after the designation. In a second step, I further disentangle the effect in its spatial and temporal dimension, which provides insights in the deforestation dynamics within and outside the protected area.

*Table III.3: Baseline FSC*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 1.293*** | 1.361*** | 0.717*** | 0.715*** | 5.337*** | 4.870*** |
| | (0.368) | (0.288) | (0.186) | (0.164) | (1.280) | (1.145) |
| Inside | -1.795*** | | -0.890*** | | -6.839*** | |
| | (0.350) | | (0.176) | | (1.188) | |
| T | -0.659** | -0.673** | -0.385** | -0.385** | -1.600 | -1.499 |
| | (0.299) | (0.304) | (0.160) | (0.167) | (0.982) | (1.014) |
| Total Effect | -1.16 | 0.69 | -0.56 | 0.33 | -3.10 | 3.37 |
| Control Group | 30km | 30km | 30km | 30km | 30km | 30km |
| Fixed Effects | Year& Zone | Year& Grid | Year& Zone | Year& Grid | Year& Zone | Year& Grid |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-squ | 0.04 | 0.17 | 0.04 | 0.15 | 0.07 | 0.27 |
| Inside × T | 1.325*** | 1.360*** | 0.730*** | 0.696*** | 5.536*** | 5.009*** |
| | (0.380) | (0.289) | (0.191) | (0.159) | (1.330) | (1.201) |
| Outside × T | 0.131 | -0.002 | 0.054 | -0.064 | 0.785 | 0.471 |
| | (0.164) | (0.227) | (0.103) | (0.137) | (0.713) | (0.850) |
| Inside | -1.885*** | | -0.932*** | | -7.239*** | |
| | (0.359) | | (0.179) | | (1.235) | |
| Outside | -0.325** | | -0.152** | | -1.455*** | |
| | (0.123) | | (0.061) | | (0.488) | |
| T | -0.696** | -0.673** | -0.401** | -0.366** | -1.825* | -1.638 |
| | (0.298) | (0.312) | (0.158) | (0.168) | (0.960) | (1.046) |

Note: The dependent variables are the percent deforested in cell $i$; area deforested in grid cell $i$ in hectare; and whether or not a grid had any deforestation. *Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal 1 as soon as a zone is certificated or officially established, respectively. The internal treatment effect is measured by $(Inside \times T)$. Variable $D$ measures the distance to the border in $km$. *Outside* is a variable that is one if a grid cell is located within the first 10 km outside of the border. The external treatment effect is measured by $(Outside \times T)$. Upper panel includes only internal treatment regressors and lower panel additionally includes external treatment regressors. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

Table III.3 documents the main treatment effect for three measures of deforestation: Deforestation in relation to remaining forest cover in columns (1) and (2), the area of deforestation in hectare in columns (3) and (4), and the probability of deforestation in column (5) and (6). The upper panel considers only the internal treatment effect and the lower panel also includes the external treatment. Columns (1), (3) and (5) include zone and year fixed effects. This makes it possible to compare the effect of of the policy

$Inside \times T$ to the general effect that the location has on the grid cell $Inside$. I find that deforestation rates before the treatment are in average about 1.8% lower than in the control group what corresponds to a 0.89 ha less deforestation. The probability of deforestation is 6.8% lower than in the control group. Columns (2), (4) and (6) include grid cell fixed effects and thus the *inside* term is captured by the fixed effects. The coefficient of the interaction term $Inside \times T$ shows how deforestation changed after the zone gets the certification. The coefficient is positive and significant on the 1% level for all deforestation measures and for all regression models in table III.3. Coefficients between the grid cell fixed effects model and the zone fixed effects model are equal in significance and polarity, moreover, similar in size which indicates that the pre-differences between grid cells in the treatment or the control group are well captured by cell fixed effects. After the certification, deforestation rates increase by 0.69%[13], which is a considerable number in comparison with the an average deforestation of 1.55% in the sample. Column (3) shows that this corresponds to 0.33 hectare per grid cell, which sums up to 8,057 ha for the entire certified forest per year after the certification. Finally, column(6) exhibits that the probability for deforestation raises about 3.4%. The lower panel additionally provides information on potential spillover effects of the treatment. Generally, deforestation rates are 0.33% lower in grid cells that are located close to the zones' border compared to grid cells located further away from the border. However, the treatment itself does not change the deforestation rates in the adjoining forests, since the interaction term $Outside \times T$ stays insignificant over all specifications.

[13]Total effects in the *zone fixed effects* model are calculated by: $\beta^{Inside \times T} + \beta^{Inside} + \beta^{T}$. Total effects in the grid fixed effect model is: $\beta^{Inside \times T} + \beta^{T}$

*Table III.4: Baseline RESEX*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 0.229*** | 0.238*** | 0.083** | 0.081*** | 0.893*** | 0.940*** |
| | (0.064) | (0.054) | (0.038) | (0.030) | (0.245) | (0.217) |
| Inside | -0.347*** | | -0.143* | | -1.344*** | |
| | (0.116) | | (0.076) | | (0.433) | |
| T | 0.136** | 0.133** | 0.051 | 0.052 | 0.336* | 0.321* |
| | (0.053) | (0.053) | (0.032) | (0.034) | (0.174) | (0.166) |
| Total Effect | 0.02 | 0.37 | -0.01 | 0.13 | -0.12 | 1.26 |
| Control Group | 30km | 30km | 30km | 30km | 30km | 30km |
| Fixed Effects | Year& Zone | Year& Grid | Year& Zone | Year& Grid | Year& Zone | Year& Grid |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-sq | 0.02 | 0.13 | 0.01 | 0.11 | 0.03 | 0.21 |
| Inside × T | 0.288*** | 0.302*** | 0.109** | 0.110*** | 1.106*** | 1.178*** |
| | (0.082) | (0.069) | (0.047) | (0.037) | (0.300) | (0.261) |
| Outside × T | 0.168*** | 0.184*** | 0.074*** | 0.083*** | 0.602*** | 0.681*** |
| | (0.056) | (0.056) | (0.028) | (0.030) | (0.185) | (0.178) |
| Inside | -0.412*** | | -0.169** | | -1.595*** | |
| | (0.128) | | (0.080) | | (0.474) | |
| Outside | -0.180*** | | -0.072*** | | -0.691*** | |
| | (0.056) | | (0.024) | | (0.202) | |
| T | 0.078 | 0.070 | 0.025 | 0.023 | 0.128 | 0.086 |
| | (0.060) | (0.059) | (0.034) | (0.035) | (0.206) | (0.192) |

Note: The dependent variables are the percent deforested in cell $i$; area deforested in grid cell $i$ in hectare; and whether or not a grid had any deforestation. *Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal 1 as soon as a zone is certificated or officially established, respectively. The internal treatment effect is measured by ($Inside \times T$). Variable $D$ measures the distance to the border in $km$. *Outside* is a variable that is one if a grid cell is located within the first 10 km outside of the border. The external treatment effect is measured by ($Outside \times T$). Upper panel includes only internal treatment regressors and lower panel additionally includes external treatment regressors. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

Table III.4 is analogous to table III.3 but it considers the RESEX sample. Variable $T$ is a dummy indicating the date of establishment of a zone and all years after. This is different to the FSC sample where $T$ can become 0 again if a certificate is suspended by the FSC or if firms do not extended their certificate. In contrast to table III.3, the coefficient for $T$ is positive in all specifications and significant in three of them. As in the FSC sample the inside dummy is negative and significant, showing that deforestation is generally lower inside of a RESEX zone than outside of it. However, the official acknowledgement as a protected zone increases deforestation, which results in a total effect that is close to zero for deforestation measured in percent of remaining forest in columns (1) and(2) and for deforestation measured in hectares in columns (3) and (4). Including fixed effects in columns (2) and (4) shows that the treatment increases deforestation about 0.37% within the zone which corresponds to an increase of 0.13 hectares. In columns (5) and (6) the probability for any deforestation is the dependent variable and exhibit that the probability of deforestation increase 1.26% after implementation. In contrast to the FSC case, the lower panel reports significant significant spillover effects to the neighbouring forests where deforestation also increases after the implementation of the zone.

Comparing the magnitude of the effect of both types of forest zones reveals that the certification date increases deforestation rates more than twice as much as the implementation of the governmental conservation zone. Moreover, the area of deforested and the probability of deforestation is almost three times higher in the case of private zones.However, considering the total effects also reveals that the probability of being affected by deforestation grows by 3.4 % for grid cells located in a certified area after passing the first assessment audit.

Deforestation rates are still 3.1% lower for grid cells within the certified zones than in grid cells which surrounds them. For public zones the probability of deforestation increases only by 1.26 % after designation. Nevertheless, the total effect of for a grid cell to be located within a public zone decreases the probability of deforestation only by 0.12% compared to the control group. Thus, considering the total effect a grid cell within a private zone is better protected than a grid cell within a public zone. However, in private zone they also lose more of their effectiveness after implementation.

Tables III.A.4 and III.A.5 repeat column (1) of tables III.3 and III.4, which include zone fixed effects, geographical controls and remaining forest cover as control variables. Results stay robust to the inclusion of these additional controls. Decreasing the control group and the treatment group to grid cells located not further than 10 km from the border, located inside and outside the zone, table III.A.6 and III.A.7 show that results are robust but coefficients decrease in size. Extending the control group by including a 60 km buffer, table III.A.8 and III.A.9 present evidence that treatment effect stays robust and increases in size. Finally, table III.A.10 and III.A.11 control for spatial autocorrelation. Results remain equal in size and significance in the case of private zones, shown in table III.A.10. For public zones, however, the specification in column (3) and (4) in table III.A.11, where deforestation in hectares is the dependent variable, loses significance.

### III.5.1 Spatial Trends

Figure III.1 plots the $\beta$s of the treatment at a zone's border. The graph focuses on the first 30 and 50 kilometers around the border. Negative values indicate distances to the border within the zone and positive values describe distances to the border from outside the zone. These graphs make it possible to observe the increased pressure from outside the zone before the implementation as well as spillovers to the forest plots outside the zone after the treatment.

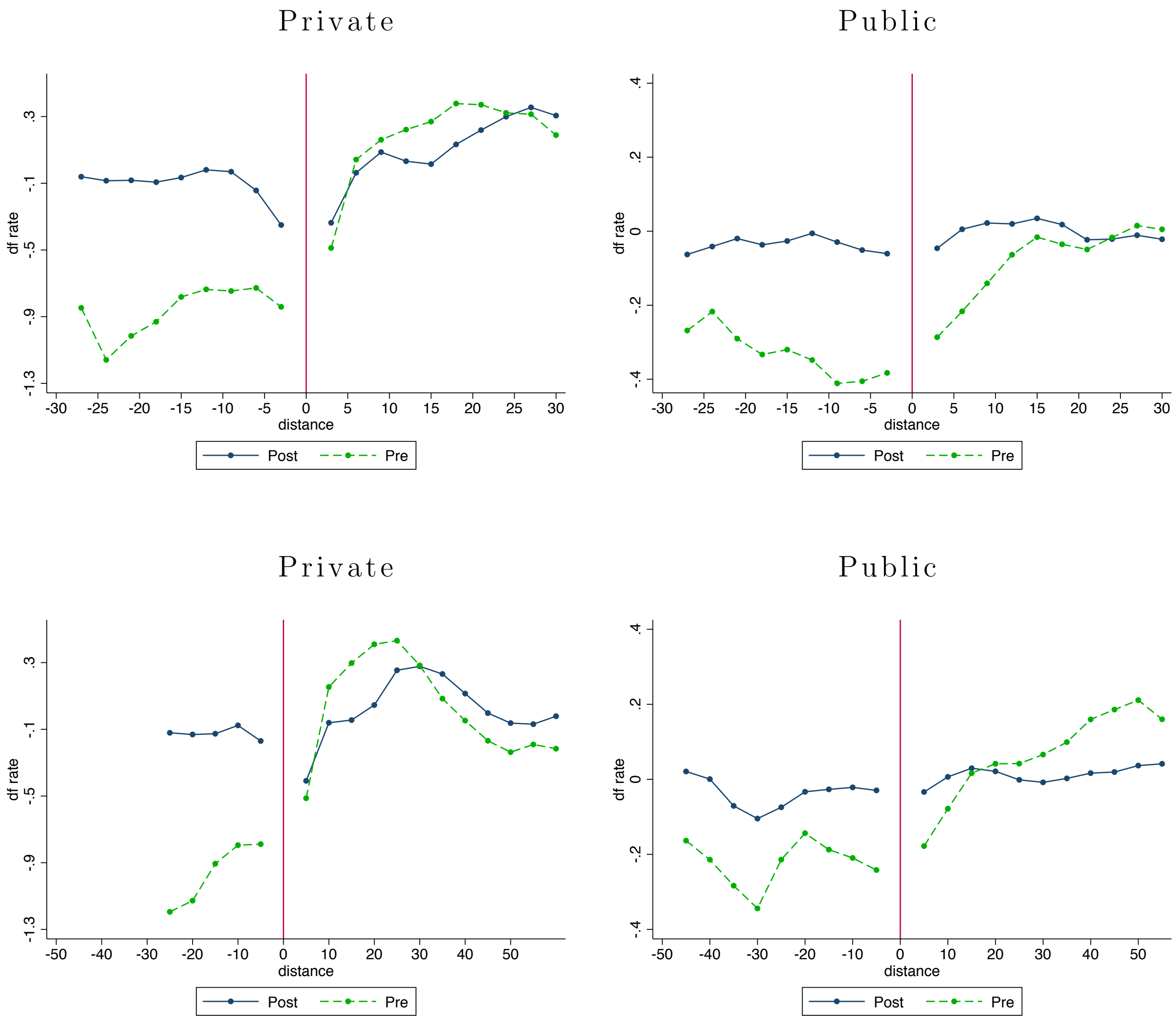



*Figure III.1: Diff-in-diff Spatial*

Note: The figure plots the $\beta$ coefficients of the treatment on deforestation against the distance to the zone border of FSC zones (left panel) and RESEX zones (right panel) for each kilometer within a buffer of 30 km (upper panel) and 50 km (lower panel).The regression, which is subject to this graph, is identical to equation III.5 but replaces the $D \times T$ variables with full sets of distance-to-the-border effects and includes a dummy variable for each bin shown in the figure. The bins have a size of 3 km (in the 30km panel) and of 5 km (in the 50 km panel). Negative distances indicate that the grid cell is located inside a zone and positive distances are for grid cells outside. The dashed green line plots the predicted relation between the two variables *before* the zone was established and the solid blue line the values *after* the implementation.

The green dashed line shows deforestation rates before certification and the solid blue line illustrates their course after the zone's implementation. The left and the right panel

consider the situation around FSC certified zones and around RESEX zones, respectively. The upper figures include the first 30 km around the border and the lower figures zoom out to 50 km around the border. Note that for the FSC panel the maximum distance from a center to the closest border is 40 km. Hence, the inside distance to the FSC zones is limited to 30 km here in order to keep results comparable. Figure III.A.10 in the appendix provides a closer look to within a 10 km buffer around the border.
In the FSC panel the increase in deforestation after certification is clearly visible by the gap between the blue line and the green dashed line. For the control group, grid cells outside the zone, post-treatment deforestation is lower between kilometre 6 and kilometer 27 and slightly higher close to the border and with larger distances. Thus, a clear spillover effect is not visible.
The upper graph on the right side reveals that inside of public SFM zones, deforestation rates after the designation (solid blue line) also jumped above the pre-treatment level (dashed green line) on both sides of the border. Both post-designation curves remain on an equal level and appear to be quite stable around the zero-line. Interestingly, the pre-treatment curve shows lower level close to the border and increases steadily with higher distances to the border while exceeding the post-line around kilometre 25. This indicates increasing pressure from the neighbourhood on the forest area, which is treated. This becomes even more visible in the lower 50 km graph, where the pre-treatment begin to increase sharply, right outside of the border.
In summery, the graph revealed that, in case of private zones, deforestation rates between inside and outside grid cells rather approximate after the certification and the discontinuity at the border, which could be seen before, almost vanishes. Similarly, a discontinuity in case of public zones is not found after implementation of the policy and differences between the inside and outside level of deforestation rates, which could be observed before the treatment, are offset afterwards.

Table III.5 presents the results from an estimation of the spatial DD equation III.5. The first part of the table, columns (1)-(3) show the results of the FSC sample and columns (4)-(6) show the estimations of the RESEX sample. Each column includes cell and year fixed effects, to take unobserved time-invariant and location-invariant variables into account. Columns (1) and (4) use the full sample, including all grid cells which are located within 60 km around the border. The rest of the columns include only cells within 30 km distance from the border, where location characteristics are assumed to be more similar. In columns (1), (2), (4) and (5) the treatment group are all grid cells that fall within a zone. In columns (3) and (6) I further control an external treatment effect by including the first 10 km outside of the zone. The remaining outside cells form the control group. In the three columns of the FSC panel, the coefficient of the interaction term $Inside \times T$,

*Table III.5: Spatial Difference-in-Differences*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 1.285*** | 1.304*** | 1.757*** | 0.086 | 0.059 | 0.153 |
| | (0.358) | (0.396) | (0.513) | (0.068) | (0.059) | (0.122) |
| Inside × D × T | 1.673 | 2.233 | 0.181 | 1.067*** | 1.225** | 0.789 |
| | (1.095) | (1.764) | (2.185) | (0.408) | (0.508) | (0.671) |
| D × T | 1.135 | 1.001 | 3.052 | -0.932*** | -1.156*** | -0.719* |
| | (0.780) | (1.498) | (1.978) | (0.237) | (0.328) | (0.435) |
| T | -0.682* | -0.833** | -1.286** | 0.416*** | 0.307*** | 0.213** |
| | (0.392) | (0.395) | (0.513) | (0.091) | (0.071) | (0.104) |
| Outside × T | | | 0.599 | | | 0.158 |
| | | | (0.429) | | | (0.144) |
| Outside × D × T | | | -2.833 | | | -1.368 |
| | | | (4.227) | | | (1.282) |
| Total Effect | 0.60 | 0.47 | 0.47 | 0.50 | 0.37 | 0.37 |
| TE Distance | 1.43 | 1.42 | 1.42 | 0.53 | 0.38 | 0.38 |
| Control group | 60km | 30 km | 30(-10)km | 60km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 3.026m | 1.42m | 1.42m | 17.3m | 11.9m | 11.9m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.13 | 0.13 | 0.13 |

Note: The dependent variable is the deforestation rate in a grid cell. *Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal 1 as soon as a zone is certificated or officially established, respectively. The dependent variable is the percent deforested in a grid cell. The internal treatment effect is measured by $(Inside \times T)$. Variable $D$ measures the distance to the border in $km$. *Outside* is a variable that is one if a grid cell is located within the first 10 km outside of the border. The external treatment effect is measured by $(Outside \times T)$. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

which accounts for the treatment effect close to the border, is positive and significant. The triple interaction term $Inside \times T \times D$ includes the continuous variable $D$ which measures the distance of a grid cell to the border. The coefficients are positive but not significant suggesting that the deforestation rates further increase closer to a zone's centre.

Columns (3) include interactions with the *outside* dummy that indicates grid cells located within the first 10 km outside of a zone's border. The intention here is to capture the external effect of the treatment and to control for possible spillover effects to the neighbouring grid cells. The coefficient of $Outside \times T$ is positive but not significant, while the coefficient of $Inside \times T$ is robust to the inclusion of the additional interaction terms and slightly higher than in columns (1) and (2). The coefficient of the triple interaction term $Outside \times T \times D$ is negative which corresponds to the lower levels which could be seen in figure III.5. However, due to the high variance the result cannot be statistically verified.

For the RESEX panel, the coefficients of the treatment interaction term become insignificant compared to results in the baseline table III.4. The triple interaction term has a positive and significant coefficient which indicates that timber production is taking place closer to a zone's centre than to the border. The interaction term $D \times T$ is negative and significant, describing a decrease in deforestation within a certain distance to the border. However, considering the total effect *TE Distance* of the treatment with higher distance to the border and the total treatment effect *TE* at the border, it is visible that they are almost equal in size, although the later is not significant.

The results of the spatial examination of the sustainable forest management policy showed, on the one hand, that for the public zone's the deforestation levels outside and inside the zone approximated after the establishment of the zone. Thus, for the public zones, the establishment of the zone seems to have a rather general effect on the whole region by stabilizing deforestation rates, which might be due to more monitoring efforts or better organized logging.

However, outside of private zones, deforestation rates close to the border remained stable over the certification process and afterwards. They exhibit a tendency to increase. The inside deforestation rates jumped to the level of the outside deforestation close to the border after certification. The results here suggest that the effect of the certification could be rather detected within the treated zone and does not influence deforestation on the outside.

Taking deforestation in hectare as a dependent variable, table III.A.12 exhibits that in the private zones deforestation close to the border increases just by 0.27 ha per $km^2$, while with higher distance to the border deforestation increases by even 0.82 ha per $km^2$. However, this is only significant for the large sample, which includes all grid cells within 60 km around the border. The treatment effect of the public zones becomes completely insignificant. Furthermore, results are robust to a nonparametric specification shown in table III.A.13 and to different buffer sizes around the border, which is shown in table III.A.14.

### III.5.2 Time Trends

Besides the investigation of discontinuities at the border of a zone, a discontinuity at the temporal threshold, the year of implementation, underpins the existence of a treatment effect. Moreover, trends in deforestation rates before and after the treatment occurs, allows one to distinguish long-term from short term effects of the policy.

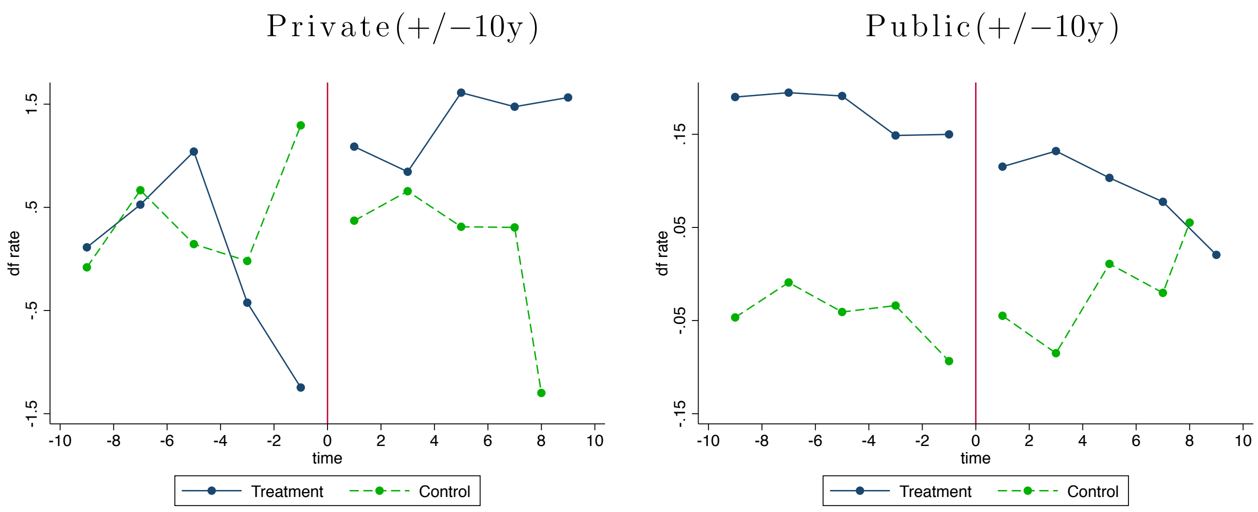



*Figure III.2: Diff-in-diff Time Trends*

The figure plots the $\beta$ coefficients of the treatment on deforestation against the years before and after the date of implementation of FSC (left panel) and RESEX (right panel) zones for each year before and after the date of the treatment. The regression, which is subject to this graph, is identical with equation III.6 but replaces the $YT \times T$ variables with full sets of years-since-destination effects as well as includes a dummy variable for each bin shown in the figure. Negative years indicate that years before the implementation date and positive values years afterwards The dashed green line plots the predicted relation between the two variables for *non-treated* grid cells and the solid blue line the values of ever *treated* grid cells. The panel estimates deforestation rates in a two-year rhythm for a 20-year period; 10 years before and 10 years after. Bin sizes are two years. The regressions follow specification given in equation III.6, including dummies for each possible year before and after the treatment.

Figure III.2 plots deforestation against time. Negative values indicate years before the implementation and positive values years after the implementation of the zone. The blue solid line shows estimated deforestation rates for the treated grid cells and the green dashed line for grid cells in the control group. The graphs on the left are estimations of the FSC certified zones. While trends in deforestation rates inside and outside the FSC zones appear parallel between ten to six years before the first audit, deforestation begin to decrease around five years before the certification audit. Three years before deforestation rates fall below the outside level. This suggests that certificate holders reduce deforestation on their land before the audit, probably in order to increase the chances to of acquiring the certificate. The data are limited in terms of information about the ownership and change of the ownership of the area. Thus, the cut-off point

here is when the firm and its forest has successfully passed the third-party audit. It appears, that this leads to a clear jump of the blue solid line at the border, indicating a rapid increase of deforestation rates after the firm received the certificate.
The right panel of figure III.1 plots the estimation results for the public zones. In contrast to the private zones, the deforestation rates after the designation of the zone are lower and show a tendency to decrease further the longer the time they are designated as a conservation zone. Outside curves appear to stay quite stable with a slight trend to decrease over time.

*Table III.6: Time Diff-in-Diff*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 1.349*** | 2.521*** | 1.416*** | -0.297*** | -0.084 | -0.298*** |
| | (0.358) | (0.742) | (0.399) | (0.076) | (0.069) | (0.092) |
| Inside × YT | -0.094** | -0.607*** | -0.110** | 0.188*** | 0.118*** | 0.213*** |
| | (0.044) | (0.210) | (0.050) | (0.041) | (0.038) | (0.049) |
| Inside × YT × T | 0.216** | 0.683*** | 0.229*** | -0.180*** | -0.129*** | -0.205*** |
| | (0.084) | (0.223) | (0.084) | (0.047) | (0.049) | (0.055) |
| YT × T | -0.085 | 0.092 | -0.097 | 0.123** | -0.027 | 0.147*** |
| | (0.073) | (0.203) | (0.077) | (0.049) | (0.061) | (0.055) |
| T | -0.663** | -1.354*** | -0.731** | 0.356*** | 0.061 | 0.357*** |
| | (0.321) | (0.455) | (0.354) | (0.100) | (0.092) | (0.112) |
| Outside × T | | | 0.249 | | | -0.011 |
| | | | (0.275) | | | (0.084) |
| Outside × YT | | | -0.061 | | | 0.073** |
| | | | (0.043) | | | (0.037) |
| Outside × YT × T | | | 0.047 | | | -0.074* |
| | | | (0.083) | | | (0.038) |
| Total Effect | 0.69 | 1.17 | 0.69 | 0.06 | -0.02 | 0.06 |
| TE Over Time | 0.72 | 1.33 | 0.71 | 0.19 | -0.06 | 0.21 |
| Sample | 10 years | 5 years | 10 years | 10 years | 5 years | 10 years |
| Control group | 30km | 30 km | 30(-10)km | 30km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 1.497m | 0.859m | 1.497m | 11.9m | 7.216m | 11.9m |
| R-sq | 0.17 | 0.25 | 0.17 | 0.13 | 0.22 | 0.13 |

Note: The dependent variable is the deforestation rate in a grid cell. *Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal to one as soon as a zone is certificated or officially established, respectively. The dependent variable is the deforestation rate in a grid cell. The internal treatment effect is measured by $(Inside \times T)$. Variable $YT$ measures the number of years before (-) or after (+) the treatment date. *Outside* is a variable that is one if a grid cell is located with in the first 10 km outside of the border. The external treatment effect is measured by $(Outside \times T)$. All columns include grid and year fixed effects. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on municipality fixed effects. ***, **, *=significant at 1, 5 and 10 % level.

Table III.6 estimates equation III.6 for both type of zones with including 5 years around the treatment date in columns (2) and (4), and 10 years in the other columns. Columns (3) and (6) include spillover effects on grid cells located within 10 km around the zones. Table III.6 confirms first graphical impressions since the internal diff-in-diff

parameter $Inside \times T$, which measures the direct effect of the treatment around the certification date, is significant and positive in all three specifications estimated in the FSC panel. The coefficient is larger in size and significant at a higher level in the case of the shorter 10 years range around the treatment date compared to the longer 20 years period. The interaction $Inside \times YT$ describes the time trend of deforestation within the zone before the certification. In line with the results presented in table III.2, the coefficient is negative and relatively large in the 5 years before the audit. The triple interaction of $Inside \times YT \times T$ estimates the development of the effect in the years after the treatment. This coefficient is positive and significant for all specifications, but about 3 times higher in the shorter time period in column (2). These results combined with the graphical illustration in figure III.2 yield to the conclusion that until one year before the first audit, which is the most extensive and detailed audit, forest owners keep deforestation particularly low[14] and relax this strict behaviour after a successful certification process, which explains the increase in deforestation afterwards.
For the public zones, the coefficient of interest of the interaction term $Inside \times T$ turns negative and is significant in the sample of the large period. Interestingly, the situation in the public zones is quite the opposite to what we see for the private zones; an increase in deforestation before the designation of the zone, a drop in deforestation rates afterwards and a continuously decreasing trend over time, while deforestation in the control group show some evidence to increase. While the total effect of the policy is very similar or identical to the baseline specification for the private zones, it is close to zero for the public zones. Thus, for public zones pressure on the forests seem to have been increasing before the designation and appear to be controlled afterwards.
Table III.A.15 again takes deforestation in level as the dependent variable and provides quite similar results. The total effect remains equal over time for the certificated zones and is close to zero for the public zones. Including a the second polynomial in table III.A.16 does not change the results of the treatment effect. Changing the number of observations by increasing the buffer zone around the border to 60 km in table III.A.17 and limiting it to 10 km in table III.A.18 does not change the significance and sign of the coefficients but slightly increases and decreases the effect in size, respectively.

Up to here, the results have shown that private forests which are certified for SFM practices increase their deforestation rates once they have passed the audit. Results for public zones suggest that forests there experienced increasing pressure before the designation of the zone and significantly lower deforestation rates when controlling for time trends. The next chapters further examines the effectiveness of the sustainable-use zones by splitting up the heterogeneity of their microeconomic location and macroeconomic

[14]This could happen via better monitoring to combat illegal deforestation or via lower harvesting rates.

drivers. To capture this, first the focus lies on the geographical location of the zone and its environment, which differs between the zones but is fixed over time. Second, it is estimated how changes in commodity prices, which may lower or increase the opportunity costs of deforestation, change the outcome of the SFM polices. Prices are considered as exogenous shocks which change over time.

### III.5.3 Local Heterogeneity

With an area larger than 5 million $km^2$, the Brazilian Amazon demonstrates quite heterogeneous patterns in terms of infrastructure fertility and accessibility to markets or to the processing industry. Consequently, the pressure on the forest also differs substantially over the whole region. As suggested in model by Pfaff et al. (2014), the probability of the forest being cleared depends on the rent that the land provides. If a conservation zone is implemented at a place where the land rent is zero or below zero (due to clearing costs), the policy will not be effective since land conversion is unlikely even in the absence of protection. The importance of the positioning of conservation zones towards places with human activity to actually prevent deforestation is highly debated in the literature. For instance, in a study across 147 nations PA networks Joppa and Pfaff (2009) find that the majority of protected areas over all countries are located with high distance to roads and cities, which reduces their effectiveness remarkably. In this subsection, I study the effects of four local characteristics on the effectiveness of private and public sustainable-use zones in reducing deforestation rates, following an approach by Dell (2015).
The location of sustainable-use zones plays a twofold role for the effectiveness of the zone since it could influence both the pressure on the forest and the prospects of the SFM project. First, the distance to the closest city is important as a potential sales market or a hub for further transport to export markets. Apart from that, land rents close to cities are usually higher than in rural areas, which makes clearing there more probable. Second, low distance to roads are important for a direct transport of harvested timber but also provides easier access to the forests for illegal operators. Third, I take distance to the closest sawmill as a proxy for access to the proceeding industry which again could save transaction costs for SFM producers but also gives incentives for higher deforestation in the surrounding of the mill. Finally, I use the distance to the closest navigable river as an alternative form of transportation for extracted forest products and timber. In the legal Amazon, rivers are a common way of shipping timber from one place to another. It is the most cost saving form for long distance transports (Barros and Uhl, 1995). Especially for traditional populations and forest communities, the access to a river can be essential to reach markets in remote cities or harbours, since they often lack motorized vehicles.

*Table III.7: Local Characteristics: Private Zones (FSC)*

| | (1) City | (2) City | (3) Roads | (4) Roads | (5) Sawmill | (6) Sawmill | (7) River | (8) River |
|---|---|---|---|---|---|---|---|---|
| Inside | -1.136** | -1.242*** | -0.536* | -0.629** | -0.446* | -0.546** | -0.773** | -0.867*** |
| | (0.429) | (0.414) | (0.281) | (0.310) | (0.239) | (0.262) | (0.307) | (0.324) |
| Inside × Dist. Site | -1.343*** | -1.381*** | -2.027*** | -2.084*** | -2.115*** | -2.153*** | -1.678*** | -1.756*** |
| | (0.390) | (0.357) | (0.586) | (0.623) | (0.525) | (0.549) | (0.542) | (0.550) |
| Inside × T × Dist. Site | 0.035 | 0.137 | 0.621 | 0.612 | 0.606 | 0.440 | 0.534 | 0.678 |
| | (0.527) | (0.596) | (0.684) | (0.736) | (0.545) | (0.574) | (0.620) | (0.686) |
| Inside × T | 1.031** | 0.940* | 0.449 | 0.429 | 0.499* | 0.566* | 0.548 | 0.466 |
| | (0.455) | (0.515) | (0.318) | (0.350) | (0.298) | (0.323) | (0.483) | (0.523) |
| T | -0.202 | -0.133 | 0.249 | 0.256 | 0.269 | 0.198 | -0.205 | -0.145 |
| | (0.288) | (0.316) | (0.295) | (0.287) | (0.275) | (0.267) | (0.269) | (0.278) |
| T × Dist. Site | -0.359 | -0.429 | -1.135** | -1.109** | -1.096*** | -0.934*** | -0.368 | -0.464 |
| | (0.270) | (0.321) | (0.434) | (0.451) | (0.274) | (0.269) | (0.333) | (0.357) |
| Outside | | -0.262 | | -0.219 | | -0.306 | | -0.164 |
| | | (0.195) | | (0.227) | | (0.191) | | (0.219) |
| Outside × T × Dist. Site | | -0.033 | | -0.112 | | 0.019 | | -0.259 |
| | | (0.446) | | (0.345) | | (0.264) | | (0.303) |
| Outside × Dist. Site | | 0.217 | | -0.039 | | -0.578 | | 0.449 |
| | | (0.568) | | (0.477) | | (0.367) | | (0.462) |
| Outside × T | | -0.195 | | -0.025 | | 0.290 | | -0.227 |
| | | (0.293) | | (0.282) | | (0.219) | | (0.284) |
| Post Dist< 0.5 | -1.97 | -2.11 | -2.38 | -2.52 | -2.28 | -2.43 | -1.94 | -2.09 |
| Post Dist > 0.5 | -0.11 | -0.30 | -0.09 | -0.20 | 0.05 | 0.02 | -0.22 | -0.40 |
| Pre Dist < 0.5 | -2.48 | -2.62 | -2.56 | -2.71 | -2.56 | -2.70 | -2.45 | -2.62 |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Observations | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m |
| R-sq | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |

Note: The dependent variable is the deforestation rate in a grid cell. *Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal 1 as soon as a zone is certificated or officially established, respectively. The dependent variable is the deforestation rate in a grid cell. The internal treatment effect is measured by $(Inside \times T)$. The external treatment effect is measured by $(Outside \times T)$. *DistSite* is a dummy variable that is one if the grid cell belongs to the 50% of grid cells (based on the entire sample) with the shortest distance to the geographical characteristic considered. These geographic characteristics are: Distance to the next urban space (city), distance to the closest road, distance to the closest sawmill and distance to the closest navigable river. Post Dist. > 0.5 and Post Dist < 0.5 give the computed total treatment effects for grid cells belonging to the 50% further away from the site and the total effect for those grid cells which are located closer to the site, respectively. Pre Dist < 0.5 reports the total effect before the treatment for gird cells located closer to the local characteristics reported in the table. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

Tables III.7 and III.8 examine whether patterns of heterogeneity in the data are consistent with the hypothesis that the placement of zones determines their effectiveness. Columns (1),(3),(5) and (7) focus merely on the treatment effect and columns (2),(4), (6) and (8) take spillovers into account. The basis for the specifications here is column (1) of the baseline model in table III.3. Additionally, a triple interaction term including the distance to each local characteristic is included to account for heterogeneity in the effect. I chose the model with *zone fixed effects* instead of *grid fixed effects* here to be able to include the interaction $Inside \times Dist.Site$ and the variable $Inside$, which makes it possible to calculate the pre treatment effect of a zone being located close to one of the geographical characteristics studied in this chapter.

The *Dist.Site* is an indicator that equals one if the median distance from a zone to the closest city, road, sawmill or navigable river is lower than the median distance of all zones. Table III.7 exhibits the results for the private (FSC certified) zones.
Over all geographical characteristics the table show that being inside a forest that will be certified in the future reduces deforestation rates independently if the forest is relatively close to a place with human activity or not, this is shown by the negative sign of the coefficient of $Inside$ and $Inside \times Dist.Site$. However, the reductive effect is larger in size and significance if the forest is located closer to a city, road, sawmill or river. The treatment variable that shows the effect of the certification on deforestation in a grid cell is not significant for zones closer spots with economic activity or infrastructure. The treatment effect for zones far away from cities and sawmills is positive and significant. This suggests that FSC zones are increasing deforestation especially in remote places where commercial forestry and deforestation in general was very low before the FSC zone appeared. Moreover, it implies that they are more effective if access to markets and the processing industry is given. Another explanation could be that those zones, which are located closer to the markets, are economically more successful and can therefore afford better monitoring systems, which reduce illegal deforestation within their borders.
The total effects at the bottom of table III.7 show that average deforestation rates for a grid cell being within the zone is about 2.5% lower if the zone is located closer to spots with higher forest pressure. As known from the results in table III.3 and figure III.2, deforestation rates are lower *inside* than *outside* before the implementation of the policy and this effect is reduced after the certification. By just comparing the reduction of the effect of a zone after certification, it is revealed that a zone close to a city loses about 21% of its effectiveness while zones far away from cities lose about 90% of their effectiveness.[15] This pattern is solid for all characteristics and shows that the augmenting effect certification has on deforestation is driven by those zones located further away from places with economic activity. The external treatment effect is insignificant for all geographical characteristics.

[15]This numbers are calculated as follows. For zones with high distance to cities the pre-effect before the certification was -1.136 and post-effect -0.11. Thus, the effect is: $\frac{-1.136-(-0.11)}{-1.136} = 0.903$ smaller than without the certification. Analogue for zones close to cities: $\frac{-2.48-(-1.97)}{-2.48} = 0.205$.

*Table III.8: Local Characteristics: Public Zones (RESEX)*

| | (1)<br>City | (2)<br>City | (3)<br>Roads | (4)<br>Roads | (5)<br>Sawmill | (6)<br>Sawmill | (7)<br>River | (8)<br>River |
|---|---|---|---|---|---|---|---|---|
| Inside | -0.154 | -0.249* | -0.338*** | -0.430*** | -0.345*** | -0.403*** | -0.236 | -0.274 |
| | (0.145) | (0.150) | (0.062) | (0.080) | (0.081) | (0.097) | (0.165) | (0.172) |
| Inside × Dist. Site | -0.315* | -0.263 | 0.069 | 0.123 | 0.110 | 0.101 | -0.143 | -0.191 |
| | (0.164) | (0.165) | (0.191) | (0.192) | (0.145) | (0.139) | (0.171) | (0.178) |
| Inside × T × Dist. Site | -0.031 | -0.055 | -0.056 | -0.068 | 0.124 | 0.136 | 0.192 | 0.242* |
| | (0.109) | (0.123) | (0.113) | (0.124) | (0.092) | (0.097) | (0.118) | (0.128) |
| Inside × T | 0.232*** | 0.304*** | 0.261*** | 0.325*** | 0.165*** | 0.209*** | 0.129 | 0.156 |
| | (0.068) | (0.088) | (0.063) | (0.076) | (0.057) | (0.073) | (0.082) | (0.103) |
| T | 0.234** | 0.166 | 0.231** | 0.162 | 0.324*** | 0.282*** | 0.282*** | 0.247*** |
| | (0.101) | (0.109) | (0.098) | (0.098) | (0.098) | (0.106) | (0.070) | (0.079) |
| T × Dist. Site | -0.131 | -0.106 | -0.152 | -0.139 | -0.351*** | -0.365*** | -0.247*** | -0.294*** |
| | (0.119) | (0.131) | (0.109) | (0.110) | (0.129) | (0.132) | (0.079) | (0.083) |
| Outside | | -0.362*** | | -0.407*** | | -0.121* | | 0.009 |
| | | (0.071) | | (0.084) | | (0.070) | | (0.080) |
| Outside × Dist. Site | | 0.346*** | | 0.487*** | | -0.104 | | -0.354*** |
| | | (0.093) | | (0.119) | | (0.138) | | (0.126) |
| Outside × T × Dist. Site | | -0.268** | | -0.356*** | | 0.113 | | 0.363*** |
| | | (0.112) | | (0.116) | | (0.103) | | (0.117) |
| Outside × T | | 0.309*** | | 0.333*** | | 0.094 | | -0.030 |
| | | (0.076) | | (0.073) | | (0.071) | | (0.092) |
| Post Dist< 0.5 | -0.17 | -0.20 | 0.01 | -0.03 | 0.03 | -0.04 | -0.02 | -0.11 |
| Post Dist> 0.5 | 0.08 | 0.06 | -0.08 | -0.10 | -0.18 | -0.19 | -0.11 | -0.12 |
| Pre Dist< 0.5 | -0.47 | -0.51 | -0.27 | -0.31 | -0.24 | -0.30 | -0.38 | -0.46 |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Observations | 11.9m | 11.9 | 11.9m | 11.9m | 11.9 | 11.9m | 11.9m | 11.9 |
| R-sq | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |

*Inside* is an indicator equal to one if a grid cell is located in the zone and $T$ is equal 1 as soon as a zone is certificated or officially established, respectively. The dependent variable is the deforestation rate in a grid cell. The internal treatment effect is measured by $(Inside \times T)$. The external treatment effect is measured by $(Outside \times T)$. $DistSite$ is a dummy variable that is one if the grid cell belongs to the 50% of grid cells (based on the entire sample) with the shortest distance to the geographical characteristic considered. These geographic characteristics are: Distance to the next urban space (city), distance to the closest road, distance to the closest sawmill and distance to the closest navigable river. Post Dist. $> 0.5$ and Post Dist $< 0.5$ give the computed total treatment effects for grid cells belonging to the 50% further away from the site and the total effect for those grid cells which are located closer to the site, respectively. Pre Dist $< 0.5$ reports the total effect before the treatment for gird cells located closer to the local characteristics reported in the table. All columns include zone and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

Table III.8 shows the results for the public zone sample and reveals that a general lower deforestation rate before the implementation of the zone is only significant for zones in remote areas, since the coefficient of *Inside* is always negative. The only exception are zones close to cities, however, only if the external effect is not taken into account. The treatment effect is negative if the zone is located far away from cities, roads and

sawmills and positive but not significant for zones with larger distances to rivers. For public zones the location effect appears to be even larger than for private zones. For instance, considering zones, which are located with high distance to roads, the area loses about 97% of the effectiveness it had before its designation as an extractive reserve.
For zones close to rivers a positive effect could be detected in column (8). In general, table III.8 confirms that the establishment public zones has a higher effect on the surrounding area than private zones.
The external effects in column (2) and (4) show that after the designation of zones next to cities and roads, the deforestation decline significantly 10 km around the zones. However, deforestation rates increase in neighbouring forests of zones in more remote areas. These results are in line with the hypothesis that sustainable-use zones are effective when they are sited where the pressure on the forest is already large. However, if they are placed into the interior of a tropical forest, starting any timber production there will increase deforestation.
The external effects are not significant in the case of sawmills but positive if a zone is located close to a river. As mentioned above, for those public zones which are not connected to cities and harbours via roads, rivers become the only possibility to transport goods and people. Thus, it is probable that in grid cells close to rivers (within and outside of the zones) deforestation increases after the designation of the zone, since access to the river-transportation network is created in order to let the inhabitants of the reserve participate in the trade with sustainable products. Results are robust to the larger control group of 60km, which is shown in tables III.A.19 and III.A.20. The total negative effects are slightly smaller than in the main specification. Moreover, tables III.A.21 and III.A.22 include grid fixed effects and reveal that the discrepancy between zones in high- and low-pressure locations is larger for private forest plots than for public reserves.
Summarizing the above, it could be seen that the effectiveness of private zones located close to economic centres, to the proceeding industry and to transport systems is higher than the effectiveness of public zones, while the spillovers on the surrounding area are negligible. The public zones could have an attenuating influence on deforestation in their neighbourhood if located at a spot close human activities. However, within their borders deforestation appears to significantly increase after designation as further the zone is located from infrastructure and cities.

### III.5.4 Exogenous Price Shocks

In this section, an additional aspect contributing to the effectiveness of sustainable-use conservation zones is studied; the changes in international commodity prices.
The intuition behind this link is that the opportunity costs of deforestation decreases when commodity prices are high due to the fact that expansion of crop fields and pasture

becomes more profitable and deforestation itself becomes more feasible (Angelsen and Kaimowitz, 1999). From the empirical point of view, the advantage of including international prices into the estimation is that they are equal and exogenous for the entire Amazon and obviously also for the conservation zones. In contrast to strictly protected zones, sustainable-use zones do not only experience higher commodity prices as an increase of the land value and, therefore, as higher pressure on the forest, but also as a potential increase of their own income. This, however, depends on the production structure of the zone and of the commodity whose price increases. In this study, I use the prices of four commodities of which two are agricultural commodities, produced outside of the zones, and two are commodities, which are also produced inside the zones. First, I consider the production of the most land intensive good in the Brazilian Amazon, which is cattle. A strong correlation between cattle ranching and recent deforestation is suggested, since crops tend to be planted on previously used pastures and not directly on newly deforested area. For instance, Barona et al. (2010) and Morton et al. (2006) find that increasing soy production shift cattle ranching further north, where agriculture has not arrived yet. Carriquiry et al. (2016) confirm that especially states located at the agricultural frontier are likely to have increasing number of cattle ranching. For instance, in the state Rondônia, 30% of the total territory is covered by pasture at places where has been closed forest a few years before. Similarly, the expansion of crop fields, especially soybeans and corn, reached remarkable dimensions in the recent years.[16] Consequentially, the relationship between rising commodity prices and decreasing forest cover in the Amazon is subject of various studies, from which I want to emphasize three here:

In a panel data set including over 300 municipalities in Southern Amazon states, Assunção et al. (2015) find that deforestation is responsive to agricultural prices, such that deforestation declines when agricultural prices are low. However, anti-deforestation policies, such as the establishment of new conservation zones, implemented between 2004 and 2008 significantly reduced deforestation, even in times of commodity price booms. Their results are in line with those presented in a broader study by Hargrave and Kis-Katos (2013), covering the entire Amazon over a longer time period. The authors conclude that the remarkable decrease in deforestation in the 2000s could be partly attributed to the implementation of monitoring and control policies while higher agricultural prices and lower timber prices had an opposite effect. Finally, Harding et al. (2018) ,who disentangle the single policies, show that the conservation zone policy is related with leakage to unprotected land when commodity prices increase.

Ideally, conservation zones could reduce the pressure of high commodity prices on the forest as they form a blockade which stops the agricultural frontier to move further into

[16]According to numbers published by the IBGE (2017) soy fields increases by 69503 $km^2$ and corn fields by 31140 $km^2$ between 2002 and 2015.

intact forest land.
Next, I take a look at timber, which is the main product of the FSC certified zones and is also important for the economy in the RESEX zones. Compared with the agricultural sector, the timber sector nowadays plays a smaller role in the deforestation of the Brazilian Amazon.[17] Nevertheless, it indirectly supports agriculture expansion by opening up new paths into the forest, since for species traded with high enough prices, the construction of new roads can be economically beneficial (Chimeli et al., 2012).
Higher timber prices also increase the value of sustainably produced timber and sustainably managed forest land (Damette and Delacote, 2011). Thus, higher prices could have a twofold effect on the envriomental outcome of sustainable-use zones. On the one hand, they could make investment in the extension of the production area more attractive, if opportunity costs of illegal harvesting and the benefits from sustainable production are high enough. On the other hand, they could be an incentive for sustainable foresters to increase production and overharvest the forest in years when timber prices peak. Still, one of the main principles of sustainable forest management are fixed, pre-determined harvest rates which should not be exceeded to maintain the ecological system. Thus, the expected outcome for effective SFM zones are smooth deforestation rates over periods of timber price fluctuations.
The fourth price index I include is an index for non-timber forest products like rubber, fruits, and nuts. I take the three main NTFP products Açaí (*Euterpe oleracea*), Brazil nuts (*Bertholletia exclesa*), rubber (*Hevea brasiliensis*)[18] produced in the Brazilian Amazon and weight them according to their production value in 2002. The NTFP production is seen as a conservation strategy that supports traditional livelihoods and increases the value of forests. In the extractive reserves this production is used for both; own consumption and market sale. In the FSC zones, the production is quite limited. Only 3 of 35 FSC zones are documented to extract other forest products but timber, which might be due to their lower economic value. In a theoretical model on rubber collection, Jaramillo-Giraldo et al. (2017) estimate that in the Amazonian state of Acre, a potential average yield of 0.36 kg/ha/year is realistic, which is not sufficient to secure the livelihood of a rubber collector without governmental subsidies. Similarly, a study by Shone and Caviglia-Harris (2006) finds that the harvest value from the collection of NTFP is around US$35/ha/year, while at the same time the income from a crop yield is

[17]While it was the most important sector in the region in the region from the 1970s to the early 2000s, it lost significance in recent years due to a strict policy change and the high profits offered in large scale agricultural business.

[18]In the 19th and at the beginning of the 20th century, when natural rubber began to be an essential material for the production of tires, planes and military equipment, thousands of people migrated to the Amazonian region where the material has its natural origin. This boom ended suddenly when the British biologist Henry Wickham took 70,000 seeds of *Hevea brasiliensis* to plant them in Sri Lanka, Malaysia and Singapore in order to establish large plantations. Nowadays about 90% of the natural rubber production comes from Asia.

US$143/ha/year.[19] This small revenue is often due to a lack of local markets for these products and a limited access to the large and well-paying export markets.
In contrast to the three other commodities, the relationship between deforestation and an increase in the price of these forest products is expected to be negative, at least for those zones that actively produce them. Naturally, the more forest is lost, the less can be extracted.

The estimated model of table III.9 is analogous to baseline model presented in column (2) of tables III.3 and III.4 but extended by each commodity's price index. I interact the price index with the treatment interaction term $Inside \times T$ and, consequentially, with all subterms of it.

[19] Other studies find a range of US$17- 6330 ha/year (Arets and Veeneklaas, 2014), while one has to be careful to in differentiate between potential, realistic and actual harvest quantity.

*Table III.9: Price Effects on Deforestation: FSC*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.932** | 0.974** | 1.091** | 0.866** | 1.006** | 1.304** | 1.211*** | 1.192*** |
| | (0.346) | (0.382) | (0.404) | (0.392) | (0.443) | (0.481) | (0.329) | (0.350) |
| Inside × T × Price Index | 6.094 | 5.825 | 1.196** | 1.894*** | 0.482 | -0.054 | 0.126 | 0.363 |
| | (4.703) | (5.421) | (0.496) | (0.554) | (0.860) | (0.881) | (2.260) | (2.212) |
| Inside × Price Index | 5.501 | 4.497 | -1.823*** | -2.360*** | 1.232 | 1.365 | -0.654 | -0.980 |
| | (19.155) | (20.325) | (0.501) | (0.701) | (1.535) | (1.788) | (3.481) | (3.492) |
| T × Price Index | -8.533** | -8.251* | -1.519*** | -2.205*** | 0.070 | 0.593 | 0.493 | 0.258 |
| | (3.550) | (4.118) | (0.539) | (0.595) | (0.722) | (0.781) | (2.218) | (2.165) |
| Price Index | 8.361 | 9.289 | 1.479** | 2.017*** | -0.889 | -0.996 | 2.216 | 2.538 |
| | (9.384) | (11.940) | (0.544) | (0.678) | (1.382) | (1.655) | (2.429) | (2.418) |
| T | -0.195 | -0.239 | -0.043 | 0.181 | -0.676 | -0.966* | -0.724* | -0.706 |
| | (0.399) | (0.419) | (0.523) | (0.533) | (0.482) | (0.508) | (0.419) | (0.443) |
| Outside × T | | 0.162 | | -0.665** | | 0.925*** | | -0.067 |
| | | (0.198) | | (0.325) | | (0.223) | | (0.270) |
| Outside × Price Index | | -4.449 | | -1.779*** | | 0.417 | | -1.202 |
| | | (11.701) | | (0.643) | | (1.412) | | (0.961) |
| Outside × T × Price Index | | -1.060 | | 2.102*** | | -1.772*** | | 0.827 |
| | | (3.563) | | (0.593) | | (0.544) | | (0.982) |
| In. PI Effect Post | 0.87 | 0.82 | 0.26 | 0.06 | 1.24 | 1.31 | 0.48 | 0.44 |
| In. PI Effect Pre | 0.60 | 0.60 | -0.13 | -0.13 | 0.18 | 0.19 | 0.20 | 0.20 |
| Ex. PI Effect Post | | -0.68 | | -1.18 | | -0.43 | | -0.79 |
| Ex. PI Effect Pre | | 0.21 | | 0.09 | | -0.30 | | 0.17 |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.4m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |

Note: The dependent variable is the deforestation rate in a grid cell. *Inside* is a dummy indicating all grid cells within a zone and *Outside* is a dummy indicating all grid cells within the first 10 km outside the zone. $T$ is a dummy which is one for all years the area receives the treatment. Column(1)-(2) includes the price index for cattle, (3)-(4) includes the price index for corn, (5)-(6) include the price index for Non timber forest products. The price index is based on the year 2002 and weighted by a municipality-specific commodity intensity. Column (2), (4), (6) and (8) additionally include controls for the external treatment effect. Total Effects of the price on the deforestation rates before and after the treatment are given at the bottom of the table. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

Table III.9 shows that the positive treatment effect $Inside \times T$ is robust to the inclusion of any price index. The triple diff-in-diff interaction term $Inside \times T \times PI$ describes the the treatment effect at the time of high commodity prices. A positive value would indicate that higher prices increase deforestation even more within a certificated zone. A negative sign of its coefficient would indicate that deforestation rates are lower within the treated

zone when prices are high, compared to the contrafactual. The only commodity for which the coefficient of the triple interaction term is significant is corn in column (3) and (4). The positive coefficient indicates higher deforestation after certification in the presence of high corn prices, which is not the expected outcome for a well-working SFM zone, such as described above. Taking a look at the coefficient of $Inside \times PI$, which provides information about deforestation rates before the certification shows a negative sign and therefore indicate lower deforestation rates before. Computing the total effects results in an increase of 0.39%[20] what corresponds to additional 0.17 ha per $km^2$.
Regarding the external treatment effects in column (4) of table III.9 shows that there are no spillover effects of the sustainable forestry zone which would prevent to forests in the neighbourhood from higher deforestation, motivated by high cattle prices. The opposite is true for timber prices. Here the treatment effect is positive but turns negative when timber prices are high. This indicates that the presence of FSC certificated forestry projects in a region decrease conventional or illegal logging in the direct neighbourhood. In times of high timber prices, managers of certified zones might be more willing to invest, prepare and protect the surrounding areas for being included in the certified zone in the future.
In general, the total effects in the bottom line show that after certification high prices of any commodity included in this study increase deforestation within the zone, however only significantly in the case of corn. Deforestation in the neighbouring forests is lower in the presence of the private zone and with high prices, which could be interpreted as a sign of higher protection efforts to forests nearby, especially when pressure on these forests increases.

[20] Note that total effects in tables III.9 and III.10 are calculated by: $\beta^{Inside \times T} + \beta^{PI} \cdot \overline{PI} + \beta^{Inside \times T \times PI} \cdot \overline{PI} + \beta^{Inside \times PI} \cdot \overline{PI}\ \beta^{T \times PI} \cdot \overline{PI} + T =$ *In. PI Effect Post* and $\beta^{PI} \cdot \overline{PI} + \beta^{Inside \times PI} \cdot \overline{PI} =$ *In. PI Effect Pre*

*Table III.10: Price Effects on Deforestation: RESEX*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.245*** | 0.299*** | 0.216*** | 0.272*** | 0.045 | 0.077 | 0.190*** | 0.262*** |
| | (0.070) | (0.088) | (0.075) | (0.092) | (0.056) | (0.076) | (0.063) | (0.087) |
| Inside × T × Price Index | 0.277* | 0.338* | 0.029 | 0.035 | -0.070*** | -0.084*** | -0.061*** | -0.059** |
| | (0.160) | (0.183) | (0.033) | (0.040) | (0.021) | (0.025) | (0.021) | (0.027) |
| Inside × Price Index | -0.304 | -0.374 | 0.005 | 0.005 | 0.149*** | 0.172*** | 0.094** | 0.081* |
| | (0.243) | (0.288) | (0.044) | (0.051) | (0.036) | (0.045) | (0.038) | (0.043) |
| T × Price Index | -0.434** | -0.496*** | -0.029 | -0.035 | 0.014 | 0.028 | 0.069** | 0.068* |
| | (0.165) | (0.187) | (0.030) | (0.037) | (0.016) | (0.020) | (0.028) | (0.035) |
| Price Index | 0.065 | 0.135 | -0.006 | -0.007 | -0.032 | -0.054 | -0.077* | -0.064 |
| | (0.301) | (0.346) | (0.034) | (0.041) | (0.040) | (0.044) | (0.044) | (0.051) |
| T | 0.123 | 0.071 | 0.123 | 0.068 | 0.193** | 0.161* | 0.139* | 0.069 |
| | (0.085) | (0.092) | (0.084) | (0.093) | (0.076) | (0.087) | (0.075) | (0.080) |
| Outside × T | | 0.165** | | 0.169** | | 0.090 | | 0.203** |
| | | (0.074) | | (0.072) | | (0.069) | | (0.079) |
| Outside × Price Index | | -0.234 | | -0.005 | | 0.069 | | -0.033 |
| | | (0.195) | | (0.037) | | (0.043) | | (0.043) |
| Outside × T × Price Index | | 0.222** | | 0.027 | | -0.044** | | 0.000 |
| | | (0.110) | | (0.030) | | (0.018) | | (0.027) |
| Inside High PI | -0.03 | -0.03 | 0.34 | 0.34 | 0.30 | 0.30 | 0.35 | 0.36 |
| Inside Low PI | 0.37 | 0.37 | 0.34 | 0.34 | 0.24 | 0.24 | 0.33 | 0.33 |
| Outside High PI | | -0.14 | | 0.22 | | 0.25 | | 0.24 |
| Outside Low PI | | 0.24 | | 0.24 | | 0.25 | | 0.27 |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Observations | 11.9m | 11.9 | 11.9m | 11.9m | 11.9 | 11.9m | 11.9m | 11.9 |
| R-sq | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |

Note: The dependent variable is the deforestation rate in a grid cell. *Inside* is a dummy indicating all grid cells within a zone and *Outside* is a dummy indicating all grid cells within the first 10 km outside the zone. $T$ is a dummy which is one for all years the area receives the treatment. Column(1)-(2) includes the price index for cattle, (3)-(4) includes the price index for corn, (5)-(6) include the price index for Non timber forest products. The price index is based on the year 2002 and weighted by a municipality-specific commodity intensity. Column (2), (4), (6) and (8) additionally include controls for the external treatment effect. otal Effects of the price on the deforestation rates before and after the treatment are n at the bottom of the table. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

For extractive reserves, table III.10 presents results of the analogues model used in table III.9. The triple interaction term $Inside \times T \times PriceIndex$ is positive for high agricultural prices and negative and significant for high prices of commodities produced within the reserve. The treatment interaction term $Inside \times T$ accounts for the effect of the SFM zone after its implementation in the times of low timber prices. In columns (1) and (2) the table exhibits an increase in deforestation rates after the designation of the zone independently of the prices. However, in presence of high agricultural prices the coeffcients are only significant at the 10% level and not significant in columns (3) and (4). The external effect shown in column (2) suggests that high prices for cattle products increase deforestation rates in the forests that surround the extractive reserves. .

Columns (5) and (6) show the expected negative values of high timber prices on the zone after designation. Also within the first 10 km outside the zone a significant reduction is found. This points in the direction of higher resistance against the pressure from the forest industry of the public zones after the official establishment, while similarly timber production inside the zone remains stable.

Columns (7) and (8) focus on non-timber forest products and reveal a negative coefficient of the triple interaction term for the inside effect. This is the expected result, since forest density is positively correlated with the outcome of these products (Thomas et al., 2017). Table III.A.28 dismantles the NTFP index and estimates the effect for each of the three products. It can be shown that while the treatment effect is always negative for high prices, it is only significant in the case of brazil nuts. A possible explanation for this is that the global popularity of these nuts increases more and more and, simultaneously, that their harvest requires a intact ecosystem of the forest (Wadt et al., 2008). Regarding the magnitude in the bottom lines of table III.10, one sees that for both timber and NTFP the total treatment effect is slightly higher in the presence of high prices but still very similar to the outcome with low prices.

These main estimates are quite robust to different sizes of the control group, shown in the appendix table III.A.25 and III.A.26. To check of spatial autocorrelation in tables III.A.31 and III.A.32 cluster the error terms at the municipality-year level and finds almost identical results. One exception is the corn price effect that loses significance when controlling for spatial clustering in column (3). Additionally, I include the second price lag to control for time autocorrelation as suggested by Bazzi and Blattman (2014). Tables III.A.29 and III.A.30 show that results are also robust to this test.

## III.6 Discussion and Conclusion

This paper started with the rather broad question of whether forests which are managed sustainably decrease deforestation compared to the contrafactual. To answer this question, I empirically assessed various parameters that could influence the effectiveness of public and private sustainable-use zones in the Brazilian Amazon.

The results imply that deforestation rates increased significantly in FSC certified zones after certification between 0.5 and 1.2%, while the increase in deforestation after the implementation of the public zones declines over time. In a related study, Blackman et al. (2018) assess FSC certified FMUs in Mexico and finds positive effects of certification on deforestation, however, results are not statistically significant. The results examining deforestation dynamics over time illustrate that while deforestation rates within FSC certified zones are reduced in the years before the first audit occurs, deforestation rates jump immediately to a higher level after a successful certification. Since the certified area has to be examined each year, a reason for the consequent increase in deforestation could be that auditing agencies are less strict in their shorter annual reports than in the first principle assessment or less willing to suspend a certified zone, which they have approved once. I also cannot rule out that the higher deforestation rates after the certification are still within the harvest limits given by the FSC. However, I could show that the forests studied in this paper would have experienced less deforestation without certification.

For the public extractive reserves, the small positive impact of designation on deforestation vanishes, when I control for spatial or time specific trends. Literature on deforestation patterns in extractive reserves show that while deforestation is found to be less often and smaller than in the neighbouring land, an increase in deforestation within the zone is found close to riverbanks and roads (Ruiz-Perez et al., 2005). Reasons for these higher deforestation rates are associated with a fall in rubber prices and with the entry of intensive agriculture into the area of the reserve (Funi and Paese, 2012). Moreover, it is argued that the co-management between state and local population, which is to be the key to the effective protection of environmental assets, does not always work well (Da Silva, 2004).

Additionally, the results show how important it is to take geographical heterogeneity of sustainable-use zones into account. For both types of zones, I find that the increase in deforestation is higher and only significant in zones implemented in forests, which are remote from markets and transport possibilities. Particularly, I find that private zones with higher distance to cities lose about 90% of there reductive effect on deforestation after certification and public zones remote from roads even lose 97% of their effect after designation. These results are in line with other studies which find that the mitigating effect on deforestation is estimated to be about 2-5 times higher for zones located close to cities and roads (Pfaff et al., 2015) and up to ten times higher if they are located in a region with high agriculture activity (Anderson et al., 2016).

Moreover, in case of public zones, I show that spillover effects on the adjoining forests are significant and equivalent to the internal effects: Closer to human settlements, public zones have a reductive effect on deforestation in their direct neighbourhood but for public zones located further away spillovers lead to higher deforestation rates in the direct neighbourhood.

This supports, on the one hand, the hypothesis that sustainable-use projects bring more forest loss and degradation into intact forest lands, since they provide access for non-sustainable harvesting and agriculture projects (see Brandt et al. (2016); Kleinschroth et al. (2017)). On the other hand, it also emphasizes the potential of mitigating deforestation within and even beyond a zone's border if located in environments where pressure on the forest is high.

Deriving policy implications from these results is not that straight forward as one would maybe expect. Simply putting zones where they are most needed is a valid request since it has been shown here that SFM zones could have a high impact on overall deforestation if located at the right spots. However, one has to keep in mind that the primary objective for the implementation of these SFM zones is not to avoid as most deforestation as possible. The communities, firms or private agents, who seek for a FSC certification, are aiming to increase the profits of their timber production by acting in a sustainable manner which guarantees a long-term harvest and the appreciation of important export markets. For them, the ideal placement of their forest would be a location where, on the one hand, markets and sawmills are still easily accessible, to keep transport costs low, and where, on the other hand, monitoring costs are not too high. Monitoring costs,per se, increase where large scale agriculture is expanding rapidly and illegal deforestation is frequently observed.

The federal government implements extractive reserves in order to clear land tenures and to provide a habitat for traditional populations that received international attention in the past. For the state, it is similarly important to keep monitoring costs low and provide places, which are not permanently threaten by growing human settlements and agricultural projects. Nevertheless, bringing timber production into closed forest - even if it is sustainable - and leave the most threatened parts of the forest for agricultural extension, could not be the desired solution. A carefully edited plan is necessary that decides about which forest plots are adequate for sustainable-use by private actors and how monitoring in and protection of public reserves could be improved to give them a realistic chance to also work in high-pressure areas.

Finally, findings from exogenous price shocks on the zones have useful lessons in terms of their effectiveness to reduce deforestation. Forest in extractive reserves are shown to benefit from high prices of brazil nuts, which implies that their extraction should be further supported and potentially promoted as particularly forest-saving. As mentioned by Hutton and Leader-Williams (2003), the major part of the revenues of extractive products does not reach the local inhabitants of such reserves but is distributed between retailers along the supply chain. Thus, significant improvements for the income of local producers could be made by if companies shorten their supply chain or begin to directly source from the collecting communities.

The results of this study underpin conclusions from former studies, which emphasize the limited effectiveness of forest certification as a market-based instrument in the combat against forest clearing. This has several reasons, starting from the small diffusion of timber certification in tropical countries and a self selection bias into the program to failures in the monitor and control system. Future studies have to reflect the conceptual short-comings of the policy and potentially wrong incentives which, as this study shows, could be implemented unintentionally.

This study also joins the broad opinion of the academic literature, which identifies the location of a public sustainable-use as the essential determinant for its effectiveness in reducing deforestation. It goes beyond former studies by illustrating the importance of considering deforestation dynamics over time, which appear to be quite important for the evaluation of the zones as one is able to distinguish long-term and short-term effects of the implementation and identify when a lack of compliance is most probable. Moreover, I could identify different cases of positive spillover effects, which were especially strong for public zones in environments with growing pressure on the forest. Finally, the relationship between high commodity prices and the effectiveness of sustainable forest management has been emphasized as a fact which is often neglected in the discussion on sustainable-use zones as an instrument of environmental protection.

A limitation of this study could be seen in some missing important information. Data on the ownership, the pre-production volume of timber or other purpose of the certificated areas before certification could be important to better understand the selection into the program and the decrease-increase dynamics of deforestation. Another weakness of the study is to not detect leakage which is indirectly linked to the implementation of a SFM zone. For instance, lumber companies could also use certification as a way of "green washing" their image by officially presenting the certified forests and hiding the unsustainable production somewhere else (Rico et al., 2018) or buying timber from other operators in order to maintain the supply of timber in the region (Aukland et al., 2003). Therefore, to compute the net effect of the policies these leakages have to be further investigated and quantified.

These shortcomings prevent me from drawing stronger conclusions on the effectiveness of public and private SFM zones in the Brazilian Amazon. However, the shortcomings do not jeopardize the main conclusion of this paper that - independently of its governance form - sustainable forest management cannot be seen as an encompassing solution for high deforestation rates in economically weak environments but could be an ingredient in a well-elaborated policy mix, which might need international support and continuous evaluation.

# III.A Appendix

## Data

### Creation of the FSC Dataset

To receive spatial referenced data was possible by using public reports on the certified areas available on the FSC website (FSC, 2017). These reports, written by the third party audit agencies, reveal information about size, company, types of tree harvested, fertilizers and socio economic background of the municipality as well as working conditions. As shown in figure III.A.3 in most cases they also give at least one coordinate point per SFM unit. Further information, like maps of the units or even shape files, are available on company websites. However the exact localization is only possible with the help of the Rural Environmental Registry (CAR, 2017). This is a national coverage electronic registry that has been mandatory for all rural properties since 28 May 2012, when the Law of the Protection of the Native Forests (Law 12.651/2012) has entered into force in Brazil. National implementation of a rural registry is based on past experiences of other states, such as Mato Grosso and Par, that required a registration since 2008 as a condition for obtaining rural credit in the priority municipalities. Information on the owner of rural property is not publicly available. The CAR data provide geo referenced data as well as information on the size on all registered properties in Brazil. By careful comparison between the form and location on company maps (see figure III.A.4), coordination points, and size of the certificated units, it was possible to identify 49 FSC certificated areas in the Brazilian Amazon.

| | | | |
|---|---|---|---|
| **E. Classificação da área florestal** | | | |
| Área Total Certificada | | | 50.044,703 ha |
| 1. Área total florestal | | | 49884,13 ha |
| a. Área total de florestas de produção | | 41874,28 ha | |
| b. Área total de florestas sem produção (sem colheita) | | 8009,85 ha | |
| - Área de florestas protegidas (reserva absoluta) | 3860,45 ha | | |
| - Área sem colheita de madeira e gerenciado apenas para a produção de produtos florestais não-madeireiros e serviços | 3183,33 ha | | |
| - Remanescentes florestais não produtivos | 966,07 ha | | |
| 2. Total de áreas não florestais (ex. Corpos d água, áreas úmidas, campos, afloramentos rochosos, estradas, etc.*)* | | | 160,57 ha |
| **F. Propriedade/Classificação do Manejo** | | | |
| Propriedade da terra | | | State/Public own |
| Gestão da posse *(listar Posse Primária para certificados de Grupo)* | | | private managem |
| A área certificada é: Manejo privado | 50.044,703 ha | | |
| Manejo público/do Estado | - ha | | |

**C. Data da Certificação**

A empresa foi certificada em 30/12/2005

**D. Latitude e longitude da operação**

Localização geográfica do portão de entrada da Unidade de Manejo Florestal:
W 62,6316
S 08,9973

*Figure III.A.3: Certification Report*

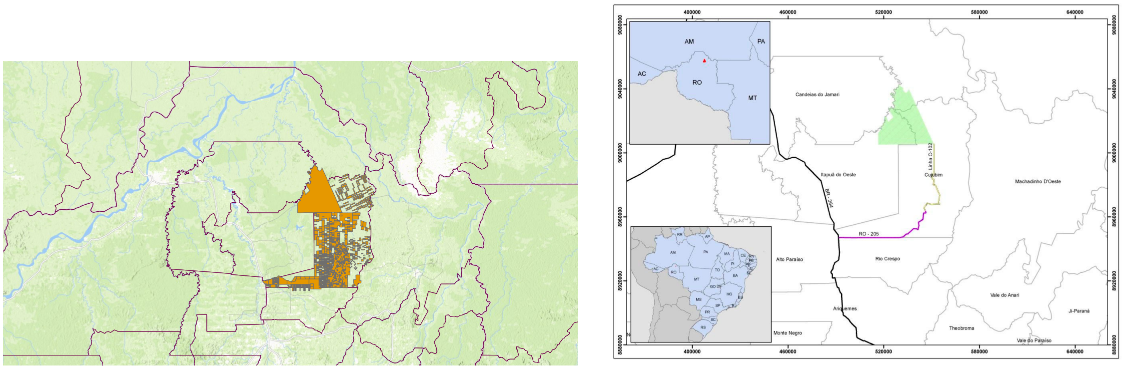
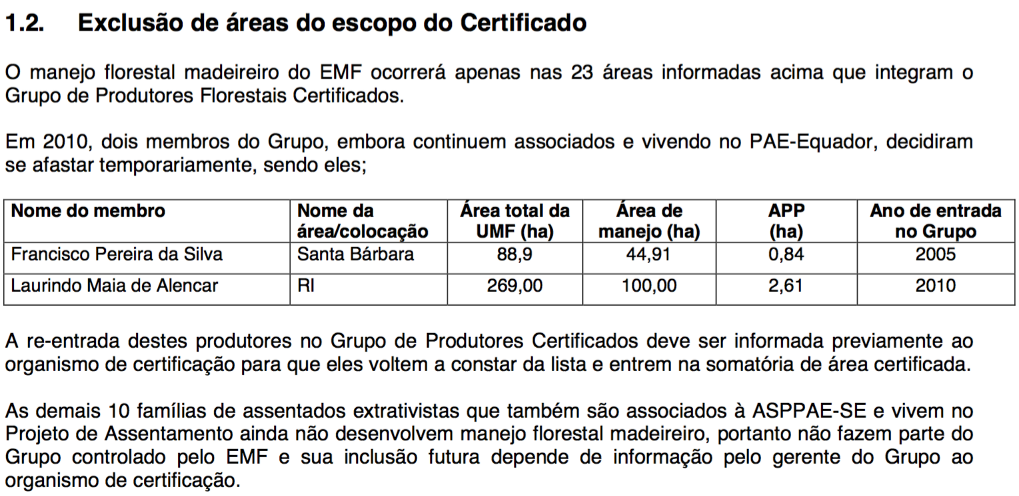



*Figure III.A.4: CAR Data and FSC Report Map*

Moreover, to account for possible changes in the area which is under the scope of certification, I went through each report given for the identified areas in order to document changes in the scope of certification. For instance figure III.A.5 gives an example of the change in size of the PAE Equador.

*Figure III.A.5: Change in the Scope of Certification*



**1.2. Exclusão de áreas do escopo do Certificado**

O manejo florestal madeireiro do EMF ocorrerá apenas nas 23 áreas informadas acima que integram o Grupo de Produtores Florestais Certificados.

Em 2010, dois membros do Grupo, embora continuem associados e vivendo no PAE-Equador, decidiram se afastar temporariamente, sendo eles;

| Nome do membro | Nome da área/colocação | Área total da UMF (ha) | Área de manejo (ha) | APP (ha) | Ano de entrada no Grupo |
|---|---|---|---|---|---|
| Francisco Pereira da Silva | Santa Bárbara | 88,9 | 44,91 | 0,84 | 2005 |
| Laurindo Maia de Alencar | RI | 269,00 | 100,00 | 2,61 | 2010 |

A re-entrada destes produtores no Grupo de Produtores Certificados deve ser informada previamente ao organismo de certificação para que eles voltem a constar da lista e entrem na somatória de área certificada.

As demais 10 famílias de assentados extrativistas que também são associados à ASPPAE-SE e vivem no Projeto de Assentamento ainda não desenvolvem manejo florestal madeireiro, portanto não fazem parte do Grupo controlado pelo EMF e sua inclusão futura depende de informação pelo gerente do Grupo ao organismo de certificação.

## Descriptives

*Table III.A.1: Descriptive Statistics*

| Variable | Unit | Obs. | Mean | Min. | Max. | Source |
|---|---|---|---|---|---|---|
| Deforestation rate | % | 23,642,122 | 0.66 | 0 | 100 | own cal. |
| Deforestation | ha | 23,642,122 | 0.33 | 0 | 100 | INPE (2017) |
| Forest cover | ha | 23,642,122 | 71.96 | 0 | 100 | INPE (2017) |
| Inside FSC | $km^2$ | 1,688,723 | 0.02 | 0 | 1 | FSC (2017) |
| Inside RESEX | $km^2$ | 1,688,723 | 0.23 | 0 | 1 | MMA (2017) |
| Non-Forest Area | $km^2$ | 1,688,723 | 0.03 | 0 | 1 | INPE (2017) |
| Soil quality | 1-5 | 1,688,723 | 1.7 | 1 | 7 | FAO (2017) |
| Distance city | km | 1,688,723 | 64.57 | 0 | 364 | MMA (2017) |
| Distance roads | km | 1,688,723 | 42.49 | 0 | 251 | INPE (2017) |
| Distance sawmill | km | 1,688,723 | 201.17 | 0 | 694 | MMA (2017) |
| Distance river | km | 1,688,723 | 19.73 | 0 | 172 | MMA (2017) |
| MUNICIPALITY LEVEL | | | | | | |
| Deforestation | $km^2$ | 10,794 | 19.73 | 0 | 1,895 | INPE (2017) |
| Forest cover | $km^2$ | 10,794 | 3,725 | 0 | 13,7627 | INPE (2017) |
| GDP | Mio R$ | 10,794 | 327 | 2.74 | 67,572 | IBGE (2017) |
| Exports | Mio R$ | 2,702 | 80.28 | 0 | 12,015 | SECEX (2017) |
| Extraction Logs | Tsd $m^3$ | 10,794 | 17.56 | 0 | 1,521 | IBGE (2017) |
| Extraction Fuelwood | Tsd $m^3$ | 10,794 | 14.89 | 0 | 1,000 | IBGE (2017) |
| Extraction Acai | tons | 10,794 | 192.8 | 0 | 34,421 | IBGE (2017) |
| Extraction Brazil Nuts | tons | 10,794 | 44.06 | 0 | 7,085 | IBGE (2017) |
| Extraction Rubber | tons | 10,794 | 4.22 | 0 | 550 | IBGE (2017) |
| Employees | pers. | 10,794 | 4,542 | 2 | 587,866 | IBGE (2017) |
| Population(2000) | pers. | 771 | 26,624 | 958 | 1,405,835 | IBGE (2017) |
| Cattle | stock | 771 | 83,293 | 100 | 1,264,991 | IBGE (2017) |
| Soil quality | 1-5 | 771 | 2.55 | 1 | 5 | FAO (2017) |
| Accessibility | 1-5 | 771 | 2.16 | 1 | 5 | FAO (2017) |

*Table III.A.2: FSC Zones*

| Company | First year certified | Last year certified | Reason for ending | Tenure | Area ($km^2$) |
|---|---|---|---|---|---|
| Agrocortex Madeiras do Acre Agroflorestal Ltda. | 2015 | 2020 | valid | F | 1910 |
| AMARCA | 2004 | 2018 | expired | C | 417 |
| Amata S/A. - Unidade Florestal Jamari | 2012 | 2018 | valid | F | 521 |
| APPAE Seringal Equador | 2005 | 2015 | expired | C | 74 |
| COMARU RDS Rio Iratapuru | 2004 | 2013 | suspended | C | 8777 |
| COOMFLONA | 2013 | 2018 | valid | C | 259 |
| FLONA Tapajós | 2013 | 2018 | valid | C | 5330 |
| Florestal Estadual do Antimary | 2005 | 2014 | expired | C | 352 |
| Florestal Santa Maria SA | 2002 | 2016 | expired | F | 807 |
| Indústria de Madeiras Manoa Ltda. | 2005 | 2020 | valid | F | 744 |
| Jari Florestal | 2004 | 2017 | suspended | F | 3443 |
| Juruá Fazenda Arataú | 2002 | 2012 | expired | F | 439 |
| Juruá Fazenda Picapau | 2009 | 2017 | expired | F | 24.5 |
| Juruá Fazenda Sucupira | 2009 | 2017 | expired | F | 28.3 |
| Juruá Florestal Ltda. | 2002 | 2017 | expired | F | 59 |
| Laminados Triunfo Ltda. | 2005 | 2013 | expired | F | 76.7 |
| LN Guerra Uberlandia | 2015 | 2020 | valid | F | 1544 |
| LN Guerra Industria e Comércio de Madeiras Ltda. | 2012 | 2017 | expired | F | 470 |
| Madeireira Segredo | 2007 | 2016 | expired | F | 1057 |
| Madeireira Vale Verde Ltda. (caracai) | 2008 | 2013 | expired | F | 176 |
| Mil Madeiras Preciosas Ltda.: Faz. Saracá | 2007 | 2022 | valid | F | 359 |
| Mil Madeiras Preciosas Ltda.: Faz. Dois Mil | 2007 | 2022 | valid | F | 777 |
| Mil Madeiras Preciosas Ltda.: Faz. Monte Verde I-V | 2010 | 2022 | valid | F | 105 |
| Mil Madeiras Preciosas Ltda.: Faz. Carribe II and II | 2010 | 2022 | valid | F | 855 |
| Ouro Verde Fazenda Canari | 2006 | 2011 | expired | F | 87 |
| Ouro Verde Fazenda Sao Jorge | 2006 | 2011 | expired | F | 11.9 |
| Ouro Verde Fazenda Bellas Aguas | 2006 | 2011 | expired | F | 23.7 |
| Ouro Verde Fazenda Ipanema | 2006 | 2011 | expired | F | 23 |
| Ouro Verde Fazenda Nova Uberaba | 2006 | 2011 | expired | F | 21.15 |
| Porto Dias | 2002 | 2018 | expired | C | 221 |
| Rohden Industria Lignea Ltda. | 2003 | 2013 | expired | F | 255 |
| Rondobel Indústria e Comércio de Madeiras Ltda. | 2012 | 2013 | expired | F | 205 |
| RRX Mineração e Serviços Ltda. - EPP | 2015 | 2020 | valid | F | 873 |

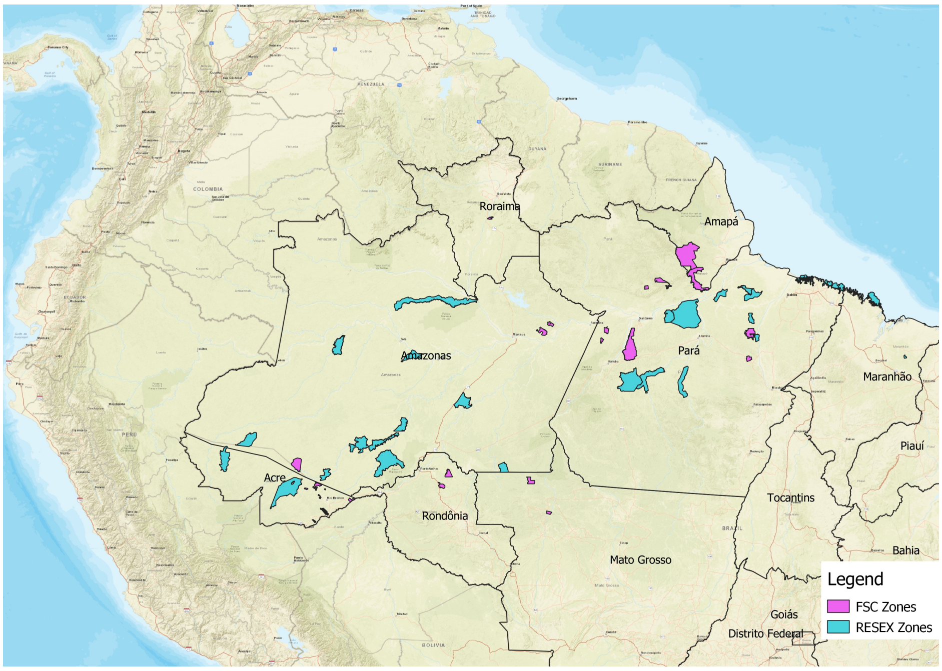
Note: Column (1) gives the name of the company or organization that applied for the FSC certificate. *First year certified* reports the year when the organization obtained the certification and *Last year of certification* reports the year when the certificate expired or was suspended. Column (4) gives information about the status of the certificate and column (5) categorizes the certificated organization in "F" for firm or "C" for community. The last column reports the size of the certificated area. For the FSC zones COOMFLONA, COMARU, FLONA Tapajós and Porto Dias, there the area corresponds to the area of the total PAE or FLONA respectively. The coordinates of the UMFs are not exactly available but are located within the parks.

*Table III.A.3: RESEX Zones*

| RESEX Name | First Year | Municipalities | State | Admin. | Area($km^2$) |
|---|---|---|---|---|---|
| Arapixi | 2006 | Boca do Acre | AM | federal | 1336.4 |
| Arióca Pruanã | 2005 | Oeiras do Pará | PA | federal | 834.5 |
| Canutama | 2009 | Canutama | AM | estadual | 1979.9 |
| Catuá-Ipixuna | 2003 | Coari (66.15 %), Tefé (33.85 %) | AM | estadual | 2174.9 |
| Cazumbá-Iracema | 2002 | Sena Madureira (98%) Manoel Urbano (2%) | AC | federal | 7508 |
| Chocoaré - Mato Grosso | 2002 | Santarém Novo | PA | federal | 27.9 |
| Cururupu | 2004 | Bacuri (4%) Cururupu (94%) Serrano do Maranhao (6%) | MA | federal | 1850.5 |
| Guariba | 2005 | Apuí (71.69 %), Novo Aripuanã (28.31 %) | AM | estadual | 1504.7 |
| Lago do Capanã Grande | 2004 | Manicoré | AM | federal | 3041.5 |
| Médio Purus | 2008 | Lábrea (91.41 %), Pauini (8.26 %), Tapauá (0.33 %) | AM | federal | 6042.1 |
| Rio Gregório | 2007 | Ipixuna (58.76 %), Eirunepé (41.22 %) | AM | estadual | 4270 |
| Rio Jutaí | 2002 | Jutaí | AM | federal | 2755.3 |
| Rio Unini | 2006 | Barcelos | AM | federal | 8333.5 |
| Gurupá-Melgaço | 2006 | Gurupá (51.78 %), Melgaço (48,22 %) | PA | federal | 1453 |
| Ipaú-Anilzinho | 2005 | Baião | PA | federal | 558.2 |
| Ituxi | 2008 | Lábrea | AM | federal | 7769.4 |
| Lago do Cedro | 2006 | Aruanã | MT | federal | 173.4 |
| Mãe Grande de Curuçá | 2002 | Curuçá | PA | federal | 370.6 |
| Mapuá | 2005 | Breves | PA | federal | 944.6 |
| Marinha Cuinarana | 2014 | Magalhães Barata | PA | federal | 110.4 |
| Marinha de Araí-Peroba | 2005 | Augusto Corra | PA | federal | 442.6 |
| Marinha de Caeté-Taperaçu | 2005 | Bragança | PA | federal | 418.1 |
| Marinha de Gurupi-Piriá | 2005 | Viseu | PA | federal | 740.8 |
| Marinha de Tracuateua | 2005 | Tracuateua (65,71 %), Bragança (0,71 %) | PA | federal | 185.9 |
| Marinha do Maracanã | 2002 | Maracanã | PA | federal | 300.2 |
| Marinha Mestre Lucindo | 2014 | Marapanim | PA | federal | 192.5 |
| Marinha Mocapajuba | 2014 | So Caetano de Odivelas | PA | federal | 210.3 |
| Renascer | 2009 | Prainha | PA | federal | 2117.4 |
| Rio Iriri | 2006 | Altamira | PA | federal | 3989.4 |
| Rio Xingu | 2008 | Altamira | PA | federal | 3038.4 |
| Riozinho da Liberdade | 2005 | Cruzeiro do Sul (2,79%) Tarauacá (95,59%) | AC | federal | 3256 |
| Riozinho do Anfrísio | 2004 | Altamira | PA | federal | 7363.4 |
| São João da Ponta | 2002 | São João da Ponta | PA | federal | 32 |
| Terra Grande-Pracuúba | 2006 | Curralinho (64.58 %), São Sebastião da Boa Vista (35.42 %) | PA | federal | 1947 |
| Verde para Sempre | 2004 | Porto de Moz | PA | federal | 12887.2 |

Note: Column (1) reports the name of the RESEX zone. Column (2) gives the first year officially recognized as a sustainable use zone under legal protection. Column (3) shows to which % the zone is located in which municipalities and the corresponding state (column(4)). The Administrative level is given in column (2), which is here either national or federal. The size of the zone is visible in the last column. For marine reserves ("Marinha"), only the onshore area is included.

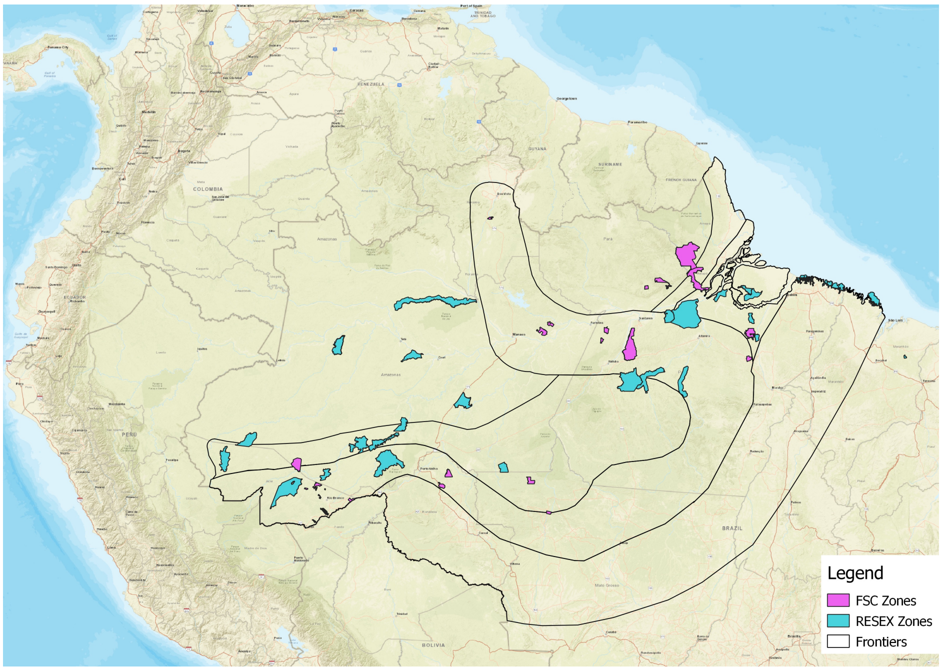
*Figure III.A.6: Map: States*




Layer Source:ESRI Standard

Map displays FSC and RESEX zones distributed over the Brazilian Amazon. The black lines mark the state frontiers.

*Figure III.A.7: Map: Agricultural Frontier*

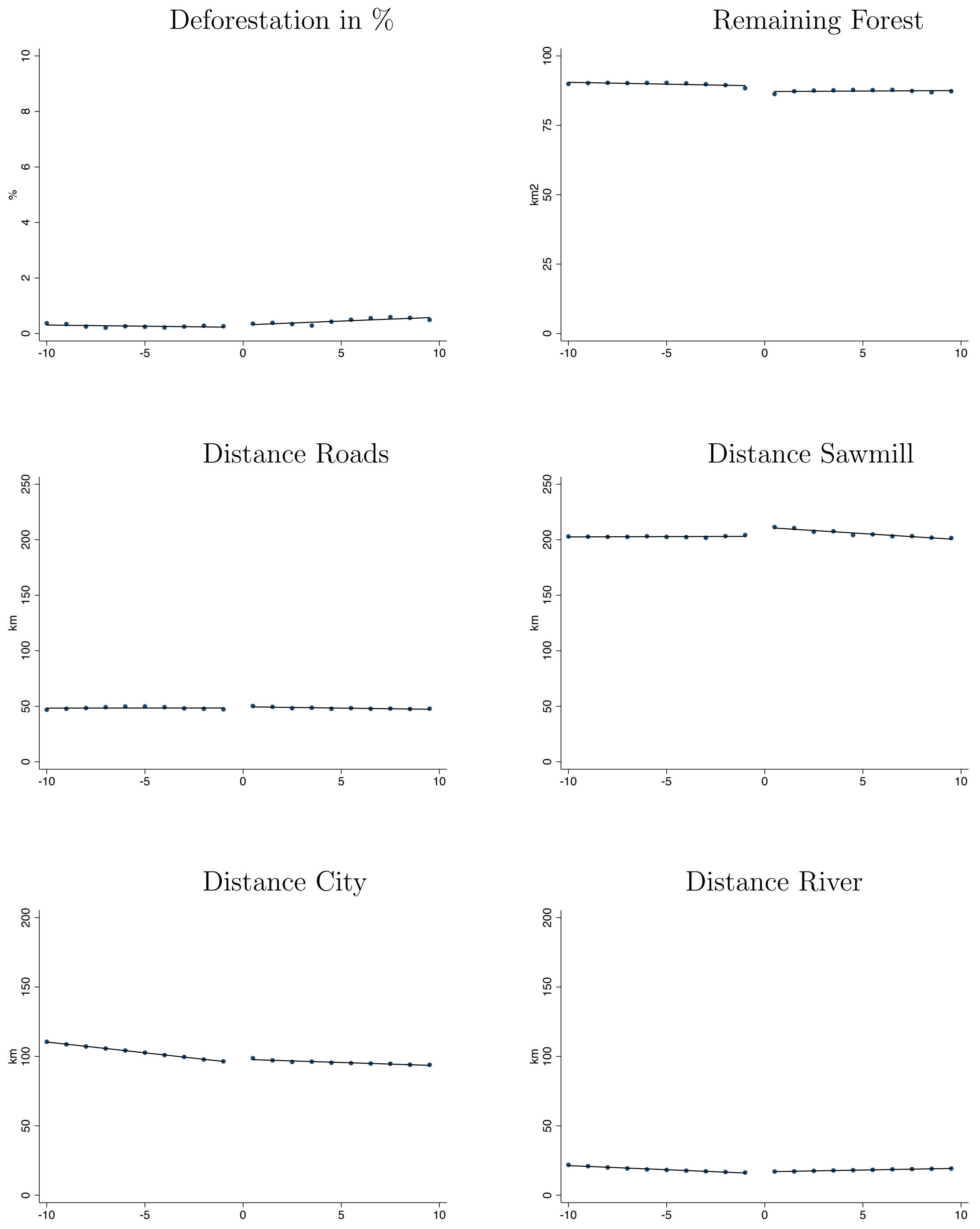



Layer Source:ESRI Standard

Map displays FSC and RESEX zones distributed over the Brazilian Amazon. The black lines mark the agricultural frontier or arc of deforestation where most of deforestation takes place.

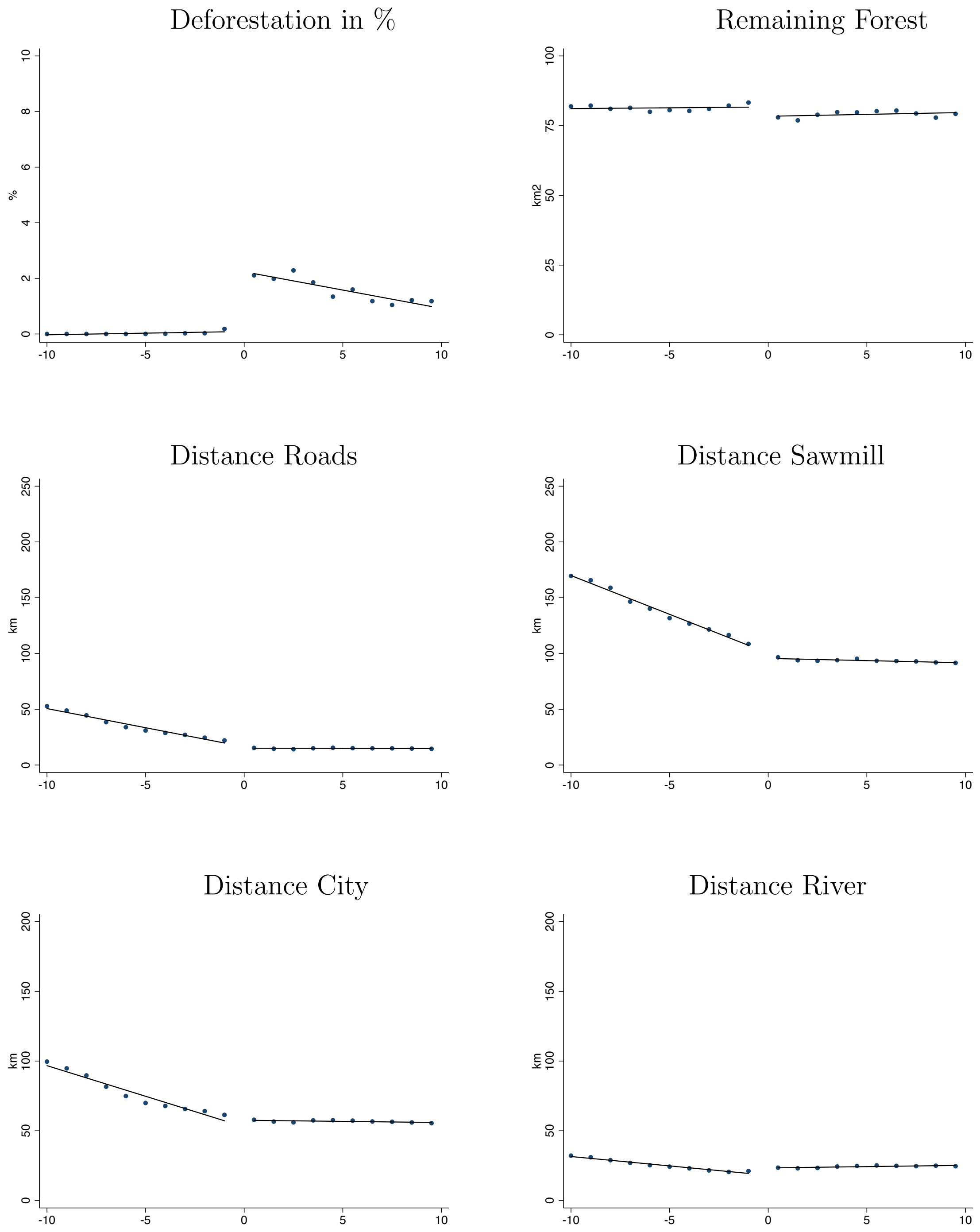
# Figures and Maps

*Figure III.A.8: Covariates at the RESEX Border*



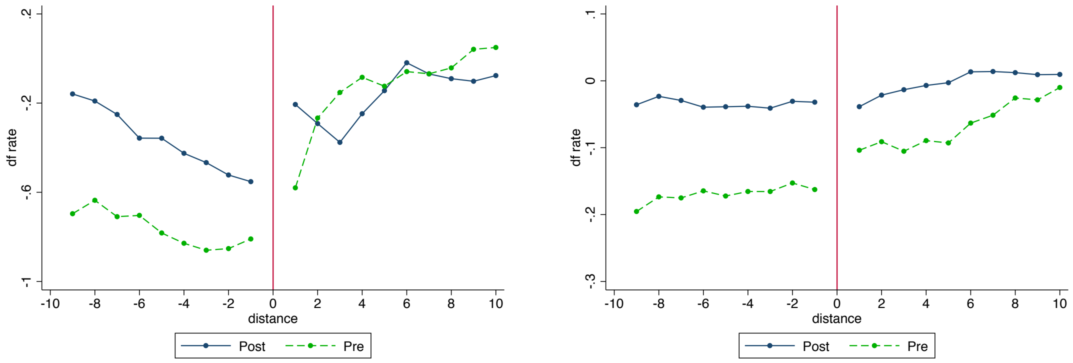

Note: Graphs plot the average value of each variable against distance to a zone's border at 500 m bins around the border. Negative values indicate grid cells inside a zone and positive values indicate grid cells outside the zone. Distances variables are time invariant. Values of the year 2002 before any zone was implemented are used to plot remaining forest and deforestation in %.

*Figure III.A.9: Covariates at the FSC Border*



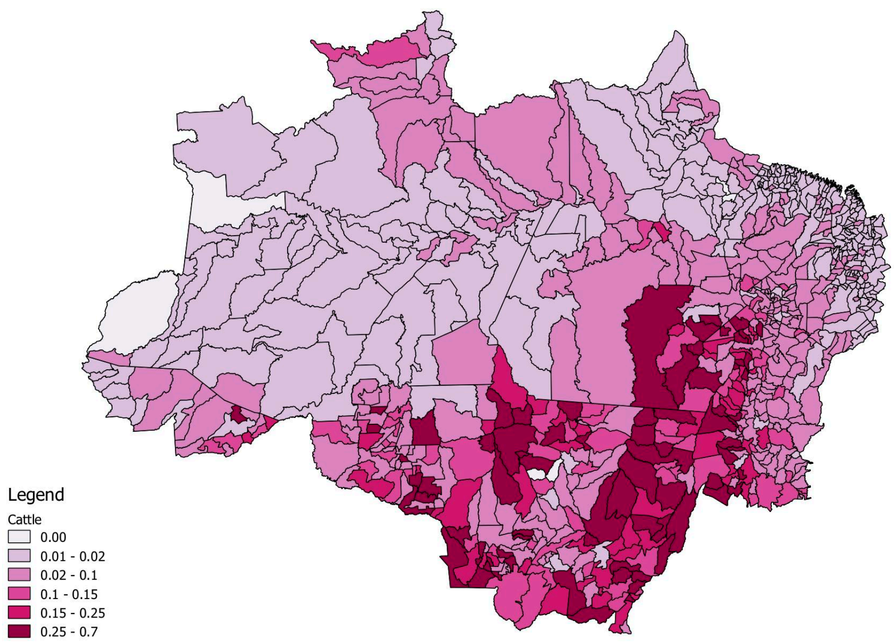

Note: Graphs plot the average value of each variable against distance to a zone's border at 500 m bins around the border. Negative values indicate grid cells inside a zone and positive values indicate grid cells outside the zone. Distances variables are time invariant. Values of the year 2002 before any zone was implemented are used to plot remaining forest and deforestation in %.

*Figure III.A.10: Spatial RDD: Private and Public Zones 10 km*



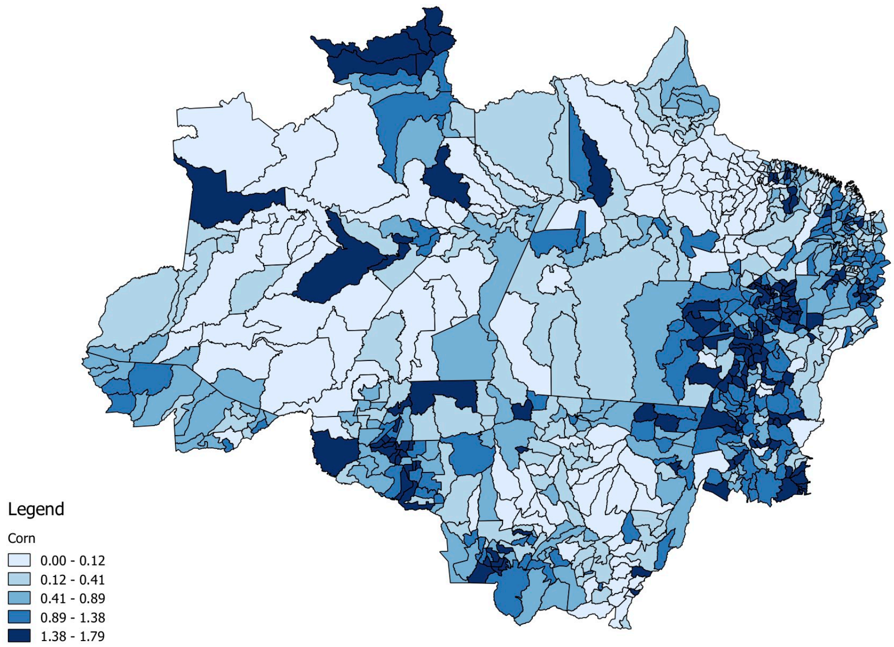

Note: The figure plots the $\beta$ coefficients of the treatment on deforestation against the distance to the zone border for private zones (left panel) and public zones (right panel). The regression, which is subject to this graph, is identical with equation III.5 but replaces the $D \times T$ variables with full sets of distance-to-the-border effects as well as includes a dummy variable for each bin shown in the figure. The bins have a size of 1 km. Negative distances indicate that the grid cell is located inside a zone and positive distances are for grid cells outside. The dashed green line plots the predicted relation between the two variables *before* the zone was established and the solid blue line the values *after* the implementation.

*Figure III.A.11: Map: Cattle Intensity*



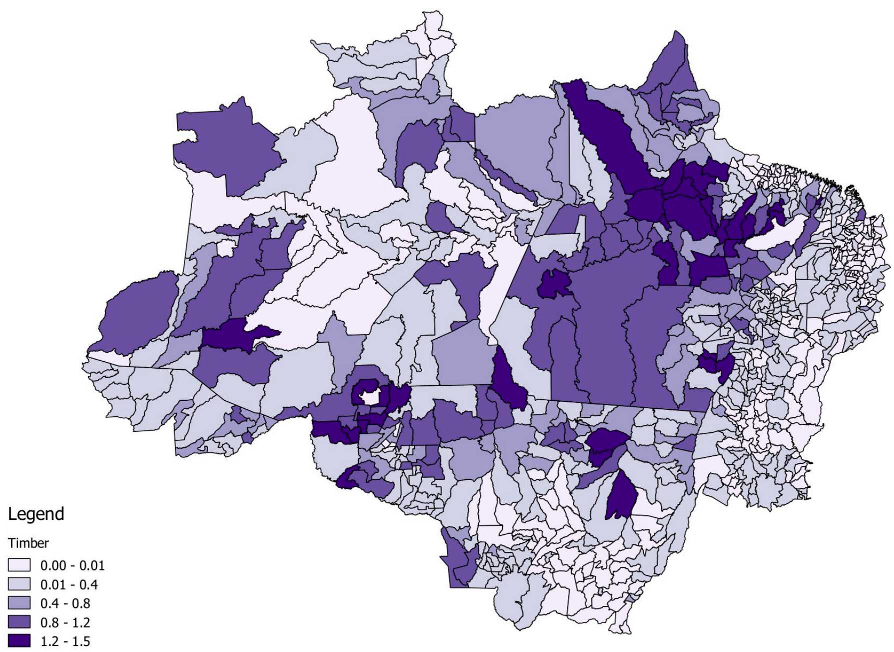

Note: Map illustrates the cattle weights calculated by equation III.2 across the Amazonian municipalities.

*Figure III.A.12: Map: Corn Intensity*



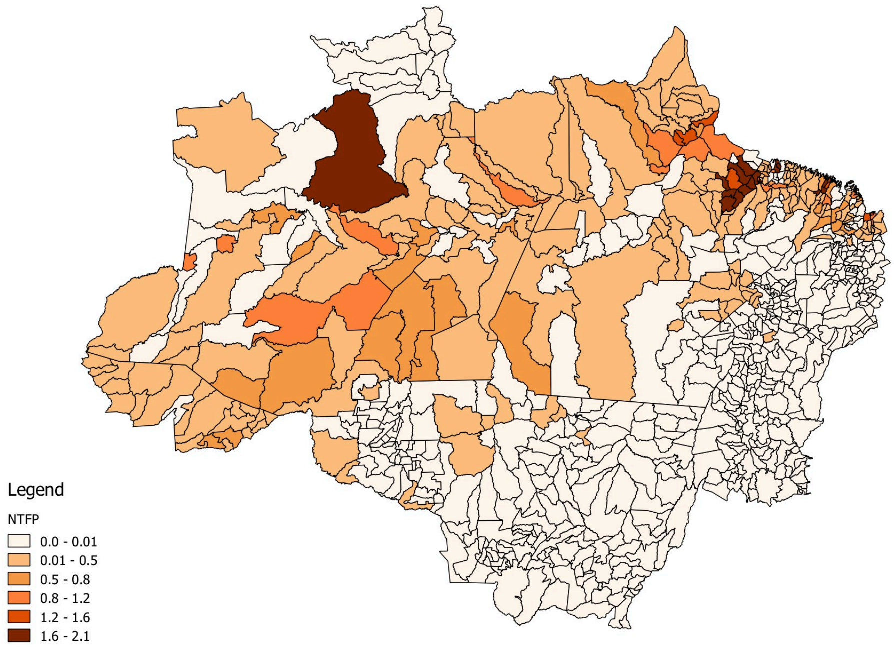

Note: Map illustrates the corn weights calculated by equation III.2 across the Amazonian municipalities.

*Figure III.A.13: Map: Timber Intensity*



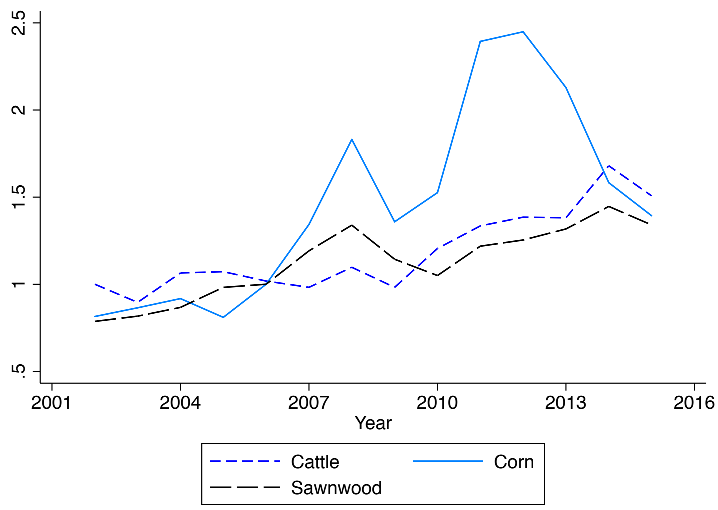

Note: Map illustrates the timber weights calculated by equation III.2 across the Amazonian municipalities.

*Figure III.A.14: Map: NTFP Intensity*



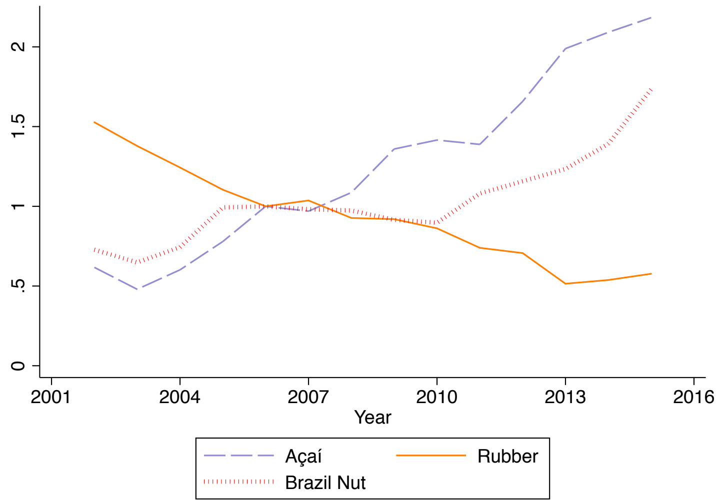

Note: Map illustrates the NTFP weights calculated by equation III.2 across the Amazonian municipalities.

*Figure III.A.15: Commodity Price Development*




Note: Graph plots the price indexes of cattle, corn and sawnwood over time, from 2002-2015.

*Figure III.A.16: NTFP Price Development*




Note: Graph plots the price indexes of the three non timber forest products over time, from 2002-2015.

## Robustness

### Baseline

*Table III.A.4: FSC Baseline: Zone FE with Geographic Controls*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -1.320*** | -1.391*** | -0.877*** | -0.922*** | -5.977*** | -6.387*** |
| | (0.289) | (0.286) | (0.188) | (0.183) | (1.158) | (1.165) |
| T | -0.624** | -0.658** | -0.391** | -0.405** | -1.581 | -1.800* |
| | (0.304) | (0.304) | (0.160) | (0.159) | (0.990) | (0.980) |
| Inside×T | 1.169*** | 1.201*** | 0.736*** | 0.749*** | 5.280*** | 5.486*** |
| | (0.358) | (0.370) | (0.192) | (0.198) | (1.265) | (1.317) |
| Outside | | -0.218** | | -0.135** | | -1.256*** |
| | | (0.101) | | (0.065) | | (0.401) |
| Outside×T | | 0.118 | | 0.049 | | 0.755 |
| | | (0.168) | | (0.105) | | (0.711) |
| Remaining Forest | -0.026*** | -0.026*** | 0.004** | 0.004** | -0.025*** | -0.025*** |
| | (0.003) | (0.003) | (0.001) | (0.001) | (0.007) | (0.007) |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Geographic Controls Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m | 1.4m |
| R-sq | 0.05 | 0.05 | 0.04 | 0.04 | 0.08 | 0.08 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). All columns include zone and year fixed effects. Standard errors in parentheses are clustered on municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.5: RESEX Baseline: Zone FE with Geographic Controls*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -0.317*** | -0.383*** | -0.135** | -0.161** | -1.237*** | -1.490*** |
| | (0.097) | (0.106) | (0.065) | (0.068) | (0.366) | (0.396) |
| T | 0.139** | 0.079 | 0.051 | 0.025 | 0.343** | 0.129 |
| | (0.054) | (0.060) | (0.032) | (0.034) | (0.173) | (0.201) |
| Inside×T | 0.232*** | 0.293*** | 0.083** | 0.110** | 0.901*** | 1.120*** |
| | (0.061) | (0.078) | (0.036) | (0.044) | (0.236) | (0.286) |
| Outside | | -0.181*** | | -0.073*** | | -0.692*** |
| | | (0.048) | | (0.021) | | (0.175) |
| Outside×T | | 0.174*** | | 0.074*** | | 0.617*** |
| | | (0.055) | | (0.027) | | (0.180) |
| Remaining Forest | -0.014*** | -0.014*** | -0.000 | -0.000 | -0.031*** | -0.031*** |
| | (0.002) | (0.002) | (0.001) | (0.001) | (0.005) | (0.005) |
| Control Group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Geographic Controls Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 11.9m | 11.9 | 11.9m | 11.9m | 11.9 | 11.9m |
| R-sq | 0.03 | 0.03 | 0.02 | 0.02 | 0.04 | 0.04 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). All columns include zone and year fixed effects. Standard errors in parentheses are clustered on municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.6: FSC Baseline: 10 km*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -1.608*** | | -0.774*** | | -5.866*** | |
| | (0.378) | | (0.193) | | (1.229) | |
| T | -0.661** | -0.746** | -0.394*** | -0.433** | -2.075** | -2.035* |
| | (0.254) | (0.285) | (0.131) | (0.162) | (0.975) | (1.069) |
| Inside × T | 1.000*** | 1.203*** | 0.567*** | 0.660*** | 4.167*** | 4.072*** |
| | (0.367) | (0.347) | (0.198) | (0.213) | (1.225) | (1.092) |
| Total Effect | -1.27 | 0.46 | -0.60 | 0.23 | -3.77 | 2.04 |
| Treatment Group | 10km Zone | 10km Zone | 10km Zone | 10km Zone | 10km Zone | 10km Zone |
| Control Group | 10km Outside | 10km Outside | 10km Outside | 10km Outside | 10km Outside | 10km Outside |
| Observations | 557604 | 557604 | 557604 | 557604 | 557604 | 557604 |
| R-sq | 0.04 | 0.17 | 0.03 | 0.14 | 0.08 | 0.27 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.7: RESEX Baseline: 10 km*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -0.219** | | -0.102* | | -0.848*** | |
| | (0.090) | | (0.061) | | (0.323) | |
| T | 0.120** | 0.123** | 0.038 | 0.043 | 0.267* | 0.266* |
| | (0.047) | (0.047) | (0.023) | (0.029) | (0.149) | (0.138) |
| Inside × T | 0.121*** | 0.114** | 0.041 | 0.031 | 0.509*** | 0.511*** |
| | (0.046) | (0.047) | (0.026) | (0.025) | (0.147) | (0.140) |
| Total Effect | 0.02 | 0.24 | -0.02 | 0.07 | -0.07 | 0.78 |
| Treatment Group | 10km Zone | 10km Zone | 10km Zone | 10km Zone | 10km Zone | 10km Zone |
| Control Group | 10km Outside | 10km Outside | 10km Outside | 10km Outside | 10km Outside | 10km Outside |
| Observations | 5438647 | 5438647 | 5438647 | 5438647 | 5438647 | 5438647 |
| R-sq | 0.02 | 0.13 | 0.01 | 0.10 | 0.03 | 0.19 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.8: FSC Baseline: 60 km*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -1.450*** | | -0.711*** | | -5.546*** | |
| | (0.254) | | (0.132) | | (0.899) | |
| T | -0.303 | -0.318 | -0.178 | -0.181 | -0.720 | -0.724 |
| | (0.243) | (0.245) | (0.127) | (0.128) | (0.772) | (0.782) |
| Inside × T | 0.987*** | 1.115*** | 0.553*** | 0.585*** | 4.123*** | 4.159*** |
| | (0.305) | (0.215) | (0.156) | (0.120) | (1.122) | (0.973) |
| Total Effect | -0.77 | 0.80 | -0.34 | 0.40 | -2.14 | 3.43 |
| Control Group | 60km Outside | 60km Outside | 60km Outside | 60km Outside | 60km Outside | 60km Outside |
| Observations | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m |
| R-sq | 0.03 | 0.17 | 0.03 | 0.14 | 0.05 | 0.26 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.9: RESEX Baseline: 60 km*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -0.456*** | | -0.191** | | -1.823*** | |
| | (0.117) | | (0.077) | | (0.462) | |
| T | 0.182*** | 0.179*** | 0.075** | 0.076** | 0.446*** | 0.436*** |
| | (0.061) | (0.061) | (0.035) | (0.036) | (0.166) | (0.163) |
| Inside × T | 0.317*** | 0.331*** | 0.124*** | 0.122*** | 1.286*** | 1.328*** |
| | (0.071) | (0.064) | (0.040) | (0.035) | (0.278) | (0.254) |
| Total Effect | 0.04 | 0.51 | 0.01 | 0.20 | -0.09 | 1.76 |
| Control Group | 60km | 60km | 60km | 60km | 60km | 60km |
| Observations | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m |
| R-sq | 0.02 | 0.13 | 0.01 | 0.11 | 0.03 | 0.21 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.10: FSC Baseline: Spatial Autocorrelation*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -1.795*** | | -0.890*** | | -6.839*** | |
| | (0.190) | | (0.107) | | (0.512) | |
| T | -0.659** | -0.674** | -0.385** | -0.385** | -1.601* | -1.502* |
| | (0.274) | (0.272) | (0.152) | (0.154) | (0.834) | (0.788) |
| Inside × T | 1.292*** | 1.361*** | 0.717*** | 0.715*** | 5.332*** | 4.872*** |
| | (0.240) | (0.248) | (0.137) | (0.143) | (0.680) | (0.874) |
| Total Effect | -1.16 | 0.69 | -0.56 | 0.33 | -3.11 | 3.37 |
| Control Group | 30km | 30km | 30km | 30km | 30km | 30km |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-sq | 0.04 | 0.17 | 0.04 | 0.15 | 0.07 | 0.27 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the state-year level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.11: RESEX Baseline: Spatial Autocorrelation*

| | Df % | | Df ha | | Df 1/0 | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside | -0.347*** | | -0.143*** | | -1.345*** | |
| | (0.064) | | (0.042) | | (0.221) | |
| T | 0.136** | 0.133** | 0.051 | 0.051 | 0.335* | 0.320** |
| | (0.062) | (0.057) | (0.037) | (0.036) | (0.194) | (0.162) |
| Inside × T | 0.229*** | 0.238*** | 0.083* | 0.081** | 0.893*** | 0.939*** |
| | (0.075) | (0.056) | (0.049) | (0.038) | (0.248) | (0.150) |
| Total Effect | 0.02 | 0.37 | -0.01 | 0.13 | -0.12 | 1.26 |
| Control Group | 30km | 30km | 30km | 30km | 30km | 30km |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-sq | 0.02 | 0.13 | 0.01 | 0.11 | 0.03 | 0.21 |

Note: Dependent variables are: Deforestation rate (columns 1,2), deforestation area in hectare (column 3 and 4), deforestation probability (columns 5 and 6). Columns 1, 3 and 5 include zone fixed effects and columns 2, 4, and 6 include grid fixed effects. All columns include year fixed effects. Standard errors in parentheses are clustered on the state-year level. ***, **, *=significant at 1, 5 and 10 % level.

## Spatial

*Table III.A.12: Spatial Difference-in-Difference: Df in ha as Dependent Variable*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 0.663*** | 0.726*** | 0.992*** | 0.022 | 0.023 | 0.095 |
| | (0.206) | (0.243) | (0.306) | (0.037) | (0.034) | (0.074) |
| Inside × D × T | 1.219* | 1.154 | -0.062 | 0.391 | 0.321 | -0.016 |
| | (0.659) | (1.076) | (1.353) | (0.287) | (0.388) | (0.502) |
| D × T | 0.645 | 0.957 | 2.173* | -0.411*** | -0.480*** | -0.143 |
| | (0.446) | (0.953) | (1.293) | (0.124) | (0.166) | (0.254) |
| T | -0.388* | -0.537** | -0.803** | 0.180*** | 0.123*** | 0.051 |
| | (0.215) | (0.241) | (0.311) | (0.052) | (0.042) | (0.060) |
| Outside × T | | | 0.431* | | | 0.119 |
| | | | (0.217) | | | (0.090) |
| Outside × D × T | | | -3.160 | | | -1.003 |
| | | | (1.957) | | | (0.771) |
| Total Effect | 0.27 | 0.19 | 0.19 | 0.20 | 0.15 | 0.15 |
| TE Distance | 0.82 | 0.81 | 0.81 | 0.20 | 0.11 | 0.11 |
| Control group | 60km | 30 km | 30(-10)km | 60km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 2.83m | 1.42m | 1.42m | 17.3m | 11.9m | 11.9m |
| R-sq | 0.14 | 0.15 | 0.15 | 0.11 | 0.11 | 0.11 |

Note: Dependent variable is deforested area in hectare. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.13: Spatial Difference-in-Difference: Second Polynomial Order*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × D × T | 2.428 | 3.281 | 1.231 | 1.524** | 3.013*** | 2.576*** |
| | (3.331) | (3.897) | (3.947) | (0.723) | (0.780) | (0.822) |
| (Inside × D × T)$^2$ | -3.335 | -4.870 | -4.876 | -1.429 | -7.542* | -7.541* |
| | (11.024) | (12.502) | (12.499) | (1.361) | (4.155) | (4.155) |
| Inside × T | 1.263*** | 1.275*** | 1.729*** | 0.066 | -0.001 | 0.092 |
| | (0.378) | (0.421) | (0.525) | (0.076) | (0.047) | (0.113) |
| D × T | 1.135 | 1.001 | 3.053 | -0.932*** | -1.156*** | -0.719* |
| | (0.780) | (1.498) | (1.978) | (0.237) | (0.328) | (0.435) |
| T | -0.682* | -0.833** | -1.286** | 0.416*** | 0.307*** | 0.214** |
| | (0.392) | (0.395) | (0.513) | (0.091) | (0.071) | (0.104) |
| Outside × D × T | | | 11.473 | | | 2.484 |
| | | | (11.379) | | | (2.258) |
| (Outside× D × T)$^2$ | | | -125.112 | | | -34.540* |
| | | | (89.370) | | | (18.666) |
| Outside × T | | | 0.288 | | | 0.078 |
| | | | (0.502) | | | (0.139) |
| Control group | 60km | 30 km | 30(-10)km | 60km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 2.8m | 1.42m | 1.42m | 1.73m | 11.9 | 11.9m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.13 | 0.13 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.14: Spatial Difference-in-Difference: Different Control Groups*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 1.348*** | 1.121*** | 1.127*** | 0.085 | 0.012 | -0.061 |
| | (0.373) | (0.398) | (0.419) | (0.067) | (0.056) | (0.059) |
| Inside × D × T | 1.461 | 4.008* | 2.270 | 1.071*** | 1.872*** | 3.366** |
| | (1.129) | (2.364) | (4.456) | (0.408) | (0.573) | (1.300) |
| D × T | 1.454* | -0.812 | 0.441 | -0.936*** | -1.460** | -2.091* |
| | (0.867) | (1.911) | (3.832) | (0.236) | (0.569) | (1.058) |
| T | -0.828** | -0.652* | -0.771** | 0.412*** | 0.261*** | 0.241*** |
| | (0.402) | (0.355) | (0.371) | (0.090) | (0.074) | (0.083) |
| Total Effect | 0.52 | 0.47 | 0.36 | 0.50 | 0.27 | 0.18 |
| TE Distance | 1.38 | 1.41 | 1.15 | 0.53 | 0.36 | 0.45 |
| **Control group** | **50 km** | **20 km** | **10km** | **50 km** | **20 km** | **10 km** |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 2.4m | 1.01m | 0.56m | 17.1m | 9.14m | 0.54m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.13 | 0.13 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

## Time

*Table III.A.15: Time Difference-in-Difference: Df in ha as Dependent Variable*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 0.824*** | 1.516*** | 0.860*** | -0.161*** | -0.034 | -0.163*** |
| | (0.210) | (0.431) | (0.235) | (0.050) | (0.034) | (0.058) |
| Inside × YT | -0.074** | -0.365*** | -0.087*** | 0.089*** | 0.056** | 0.101*** |
| | (0.030) | (0.123) | (0.032) | (0.024) | (0.024) | (0.028) |
| Inside × YT × T | 0.124** | 0.376*** | 0.134*** | -0.088*** | -0.077** | -0.099*** |
| | (0.051) | (0.128) | (0.050) | (0.031) | (0.036) | (0.034) |
| T | -0.404** | -0.756*** | -0.441** | 0.144** | 0.025 | 0.147** |
| | (0.175) | (0.248) | (0.194) | (0.064) | (0.052) | (0.072) |
| YT × T | -0.041 | 0.016 | -0.051 | 0.043 | -0.014 | 0.054 |
| | (0.045) | (0.120) | (0.045) | (0.030) | (0.037) | (0.033) |
| Outside × YT | | | -0.049* | | | 0.035** |
| | | | (0.028) | | | (0.015) |
| Outside × YT × T | | | 0.038 | | | -0.033** |
| | | | (0.051) | | | (0.016) |
| Outside × T | | | 0.139 | | | -0.010 |
| | | | (0.172) | | | (0.042) |
| Total Effect | 0.43 | 0.79 | 0.41 | 0.03 | -0.04 | 0.04 |
| TE Over Time | 0.42 | 0.76 | 0.42 | -0.02 | -0.01 | -0.02 |
| Sample | 10 years | 5 years | 10 years | 10 years | 5 years | 10 years |
| Control group | 30km | 30 km | 30(-10)km | 30km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 1.42m | 0.82m | 1.42m | 11.9m | 7.2m | 11.9m |
| R-sq | 0.15 | 0.22 | 0.15 | 0.29 | 0.38 | 0.29 |

Note: Dependent variable is deforested area in hectare. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.16: Time Difference-in-Difference: Second Polynomial Order*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × T | 2.050*** | 2.330 | 2.114*** | -0.321*** | 0.107 | -0.345*** |
| | (0.688) | (1.492) | (0.734) | (0.108) | (0.106) | (0.116) |
| Inside × YT | -0.625*** | -0.665 | -0.641*** | 0.222*** | 0.015 | 0.256*** |
| | (0.209) | (0.683) | (0.215) | (0.063) | (0.059) | (0.068) |
| Inside × YT × T | 1.225*** | 1.715* | 1.244*** | -0.261*** | -0.008 | -0.295*** |
| | (0.319) | (0.938) | (0.322) | (0.088) | (0.079) | (0.091) |
| (Inside × YT)$^2$ | -0.062*** | -0.014 | -0.062*** | 0.007 | -0.031* | 0.009 |
| | (0.023) | (0.136) | (0.023) | (0.011) | (0.016) | (0.012) |
| (Inside × YT × T)$^2$ | 0.015 | -0.313* | 0.014 | -0.004 | 0.046* | -0.006 |
| | (0.029) | (0.185) | (0.029) | (0.013) | (0.025) | (0.013) |
| T | -0.660** | -1.367*** | -0.734** | 0.352*** | 0.063 | 0.355*** |
| | (0.329) | (0.456) | (0.364) | (0.101) | (0.092) | (0.113) |
| YT × T | -0.080 | 0.088 | -0.092 | 0.122** | -0.025 | 0.140** |
| | (0.073) | (0.203) | (0.077) | (0.049) | (0.061) | (0.055) |
| (Outside × YT × T)$^2$ | | | -0.040 | | | -0.051*** |
| | | | (0.024) | | | (0.013) |
| (Outside × YT)$^2$ | | | 0.013 | | | 0.048*** |
| | | | (0.017) | | | (0.013) |
| Outside × YT | | | 0.082 | | | 0.414*** |
| | | | (0.181) | | | (0.090) |
| Outside × YT × T | | | 0.120 | | | -0.387*** |
| | | | (0.250) | | | (0.100) |
| Outside × T | | | -0.195 | | | -0.511*** |
| | | | (0.430) | | | (0.130) |
| Sample | 10 years | 5 years | 10 years | 10 years | 5 years | 10 years |
| Control group | 30km | 30 km | 30(-10)km | 30km | 30 km | 30(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 1.42m | 0.82m | 1.42m | 11.9m | 7.2m | 11.9m |
| R-sq | 0.17 | 0.25 | 0.17 | 0.13 | 0.22 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.17: Time Difference-in-Difference: 60km*

| | Private Zones (FSC) | | | Public Zones (Resex) | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Inside × YT | -0.065* | -0.503*** | -0.068* | 0.229*** | 0.141*** | 0.248*** |
| | (0.034) | (0.162) | (0.037) | (0.044) | (0.037) | (0.048) |
| Inside × YT × T | 0.253*** | 0.669*** | 0.263*** | -0.221*** | -0.154*** | -0.240*** |
| | (0.069) | (0.182) | (0.070) | (0.050) | (0.051) | (0.054) |
| Inside × T | 0.860*** | 1.855*** | 0.821*** | -0.323*** | -0.062 | -0.322*** |
| | (0.263) | (0.576) | (0.271) | (0.081) | (0.064) | (0.091) |
| T | -0.272 | -0.913*** | -0.234 | 0.399*** | 0.012 | 0.399*** |
| | (0.244) | (0.304) | (0.248) | (0.108) | (0.087) | (0.115) |
| YT × T | -0.125** | -0.076 | -0.136** | 0.144*** | -0.039 | 0.161*** |
| | (0.058) | (0.160) | (0.061) | (0.054) | (0.055) | (0.058) |
| Outside × YT | | | -0.023 | | | 0.105*** |
| | | | (0.044) | | | (0.039) |
| Outside × YT × T | | | 0.086 | | | -0.104*** |
| | | | (0.095) | | | (0.040) |
| Outside × T | | | -0.300 | | | -0.029 |
| | | | (0.252) | | | (0.094) |
| Total Effect | 0.65 | 1.03 | 0.65 | 0.23 | -0.10 | 0.25 |
| TE Over Time | 0.59 | 0.94 | 0.59 | 0.08 | -0.05 | 0.08 |
| Sample | 10 years | 5 years | 10 years | 10 years | 5 years | 10 years |
| Control group | 60km | 60 km | 60(-10)km | 60km | 60 km | 60(-10)km |
| Treatment group | FSC | FSC | FSC | RESEX | RESEX | RESEX |
| Observations | 2.8m | 1.6m | 2.8m | 17.3m | 10.5m | 17.3 |
| R-sq | 0.17 | 0.25 | 0.17 | 0.13 | 0.21 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.18: Time Difference-in-Difference: 10km*

| | FSC | | RESEX | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Inside × T | 1.027*** | 1.697*** | -0.259*** | -0.145* |
| | (0.318) | (0.618) | (0.071) | (0.075) |
| Inside × YT | -0.033 | -0.408** | 0.126*** | 0.085** |
| | (0.038) | (0.185) | (0.032) | (0.035) |
| Inside × YT × T | 0.141 | 0.662*** | -0.116*** | -0.064* |
| | (0.113) | (0.245) | (0.034) | (0.037) |
| YT × T | -0.061 | -0.215 | 0.081 | -0.041 |
| | (0.096) | (0.248) | (0.050) | (0.067) |
| T | -0.672** | -1.222** | 0.325*** | 0.133 |
| | (0.291) | (0.493) | (0.089) | (0.082) |
| Total Effect | 0.40 | 0.52 | 0.16 | -0.03 |
| TE Over Time | 0.35 | 0.47 | 0.07 | -0.01 |
| Sample | 10 years | 5 years | 10 years | 5 years |
| Control group | 10km | 10 km | 10km | 10 km |
| Observations | 0.55m | 0.32m | 5.4m | 3.3m |
| R-sq | 0.17 | 0.25 | 0.13 | 0.21 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

## Local Heterogeneity

*Table III.A.19: Local Heterogeneity: Private Zones 60km*

| | (1) City | (2) City | (3) Roads | (4) Roads | (5) Sawmill | (6) Sawmill | (7) River | (8) River |
|---|---|---|---|---|---|---|---|---|
| Inside | -0.859*** | -0.852*** | -0.644** | -0.678** | -0.260 | -0.282 | -1.008*** | -1.022*** |
| | (0.310) | (0.298) | (0.270) | (0.288) | (0.277) | (0.287) | (0.293) | (0.308) |
| Inside × Dist. Site | -1.240*** | -1.228*** | -1.577*** | -1.418*** | -1.953*** | -1.871*** | -0.557 | -0.488 |
| | (0.316) | (0.298) | (0.348) | (0.337) | (0.393) | (0.381) | (0.466) | (0.451) |
| Inside × T × Dist. Site | -0.405 | -0.481 | -0.241 | -0.400 | -0.029 | -0.235 | -0.488 | -0.475 |
| | (0.496) | (0.530) | (0.514) | (0.534) | (0.471) | (0.476) | (0.481) | (0.506) |
| Inside × T | 1.021** | 1.006** | 0.730** | 0.727** | 0.565* | 0.596* | 0.906** | 0.835** |
| | (0.420) | (0.451) | (0.309) | (0.333) | (0.292) | (0.306) | (0.366) | (0.389) |
| T | 0.053 | 0.063 | 0.107 | 0.100 | 0.389* | 0.356* | 0.046 | 0.097 |
| | (0.194) | (0.196) | (0.178) | (0.179) | (0.206) | (0.209) | (0.210) | (0.217) |
| T × Dist. Site | -0.136 | -0.090 | -0.226 | -0.130 | -0.678*** | -0.544** | -0.139 | -0.166 |
| | (0.204) | (0.219) | (0.242) | (0.244) | (0.221) | (0.228) | (0.232) | (0.240) |
| Outside | | 0.070 | | -0.280* | | -0.197 | | -0.061 |
| | | (0.357) | | (0.167) | | (0.165) | | (0.182) |
| Outside × T × Dist. Site | | 0.095 | | 0.900** | | 0.559 | | 0.378 |
| | | (0.488) | | (0.364) | | (0.375) | | (0.381) |
| Outside × T × Dist. Site | | -0.447 | | -1.235** | | -1.286*** | | -0.077 |
| | | (0.624) | | (0.549) | | (0.469) | | (0.474) |
| Outside × T | | -0.084 | | 0.217 | | 0.302 | | -0.284 |
| | | (0.391) | | (0.294) | | (0.217) | | (0.276) |
| Post Dist< 0.5 | -1.57 | -1.58 | -1.85 | -1.80 | -1.97 | -1.98 | -1.24 | -1.22 |
| Post Dist> 0.5 | 0.16 | 0.15 | 0.09 | 0.05 | 0.30 | 0.31 | -0.10 | -0.19 |
| Pre Dist< 0.5 | -2.10 | -2.08 | -2.22 | -2.10 | -2.21 | -2.15 | -1.57 | -1.51 |
| Control Group | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km |
| Observations | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m |
| R-sq | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |

Note: Dependent variable is deforestation rate. All columns include zone and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.20: Local Heterogeneity: Public Zones 60km*

| | (1) City | (2) City | (3) Roads | (4) Roads | (5) Sawmill | (6) Sawmill | (7) River | (8) River |
|---|---|---|---|---|---|---|---|---|
| Inside | -0.232* | -0.300** | -0.429*** | -0.501*** | -0.401*** | -0.453*** | -0.310* | -0.352** |
| | (0.139) | (0.144) | (0.063) | (0.076) | (0.076) | (0.085) | (0.160) | (0.162) |
| Inside × Dist. Site | -0.274* | -0.252 | 0.153 | 0.189 | 0.131 | 0.125 | -0.151 | -0.184 |
| | (0.158) | (0.162) | (0.189) | (0.190) | (0.159) | (0.160) | (0.176) | (0.178) |
| Inside × T × Dist. Site | 0.032 | 0.041 | 0.024 | 0.050 | 0.249*** | 0.277*** | -0.011 | -0.017 |
| | (0.116) | (0.127) | (0.121) | (0.130) | (0.095) | (0.098) | (0.107) | (0.117) |
| Inside × T | 0.272*** | 0.316*** | 0.299*** | 0.335*** | 0.178*** | 0.206*** | 0.335*** | 0.389*** |
| | (0.057) | (0.069) | (0.061) | (0.068) | (0.054) | (0.062) | (0.102) | (0.116) |
| T | 0.360*** | 0.321*** | 0.332*** | 0.295*** | 0.458*** | 0.434*** | 0.146* | 0.092 |
| | (0.110) | (0.114) | (0.102) | (0.103) | (0.108) | (0.113) | (0.082) | (0.087) |
| T × Dist. Site | -0.248* | -0.257* | -0.246** | -0.271** | -0.492*** | -0.521*** | 0.092 | 0.098 |
| | (0.126) | (0.136) | (0.119) | (0.121) | (0.127) | (0.128) | (0.092) | (0.098) |
| Outside | | -0.320*** | | -0.477*** | | -0.159** | | -0.080 |
| | | (0.086) | | (0.081) | | (0.067) | | (0.098) |
| Outside × T × Dist. Site | | 0.170 | | 0.516*** | | -0.154 | | -0.320*** |
| | | (0.120) | | (0.115) | | (0.152) | | (0.115) |
| Outside × T × Dist. Site | | -0.031 | | -0.240** | | 0.257*** | | 0.175* |
| | | (0.128) | | (0.108) | | (0.098) | | (0.104) |
| Outside × T | | 0.243*** | | 0.339*** | | 0.087 | | 0.147 |
| | | (0.074) | | (0.063) | | (0.063) | | (0.092) |
| Post Dist< 0.5 | -0.09 | -0.13 | 0.13 | 0.10 | 0.12 | 0.07 | 0.10 | 0.03 |
| Post Dist> 0.5 | 0.04 | 0.02 | -0.13 | -0.17 | -0.22 | -0.25 | 0.02 | 0.04 |
| Pre Dist< 0.5 | -0.51 | -0.55 | -0.28 | -0.31 | -0.27 | -0.33 | -0.46 | -0.54 |
| Control Group | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km |
| Observations | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m |
| R-sq | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

Note: Dependent variable is deforestation rate. All columns include zone and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.21: Local Heterogeneity: FSC with Grid FE*

| | City (1) | City (2) | Roads (3) | Roads (4) | Sawmill (5) | Sawmill (6) | River (7) | River (8) |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 1.447*** | 1.403*** | 0.792** | 0.725** | 0.801** | 0.827** | 1.769*** | 1.675*** |
| | (0.430) | (0.468) | (0.350) | (0.352) | (0.318) | (0.361) | (0.368) | (0.379) |
| Inside × T × Dist. Site | -0.234 | -0.166 | 0.917* | 1.003** | 0.864* | 0.821* | -0.796* | -0.621 |
| | (0.473) | (0.493) | (0.477) | (0.468) | (0.437) | (0.465) | (0.464) | (0.475) |
| Outside × T | | -0.139 | | -0.212 | | 0.089 | | -0.303 |
| | | (0.319) | | (0.251) | | (0.264) | | (0.349) |
| Outside × T × Dist. Site | | 0.222 | | 0.283 | | -0.147 | | 0.592 |
| | | (0.497) | | (0.471) | | (0.435) | | (0.488) |
| T × Dist. Site | -0.246 | -0.313 | -1.508*** | -1.595*** | -1.511*** | -1.468*** | 0.175 | 0.000 |
| | (0.482) | (0.501) | (0.498) | (0.491) | (0.477) | (0.496) | (0.462) | (0.459) |
| T | -0.528 | -0.484 | 0.155 | 0.222 | 0.179 | 0.153 | -0.764** | -0.671* |
| | (0.467) | (0.508) | (0.473) | (0.482) | (0.458) | (0.485) | (0.380) | (0.397) |
| TE Dist> 0.5 | 0.92 | 0.92 | 0.95 | 0.95 | 0.98 | 0.98 | 1.01 | 1.00 |
| TE Dist< 0.5 | 0.44 | 0.44 | 0.36 | 0.36 | 0.33 | 0.33 | 0.38 | 0.38 |
| Control group | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km | 30km | 30(-10)km |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-squared | 0.170 | 0.170 | 0.171 | 0.171 | 0.171 | 0.171 | 0.170 | 0.170 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.22: Local Heterogeneity: RESEX with Grid FE*

| | City (1) | City (2) | Roads (3) | Roads (4) | Sawmill (5) | Sawmill (6) | River (7) | River (8) |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.033 | 0.053 | -0.011 | -0.016 | 0.109*** | 0.129** | 0.244*** | 0.312*** |
| | (0.035) | (0.050) | (0.009) | (0.010) | (0.040) | (0.062) | (0.058) | (0.082) |
| Inside × T × Dist. Site | 0.372*** | 0.448*** | 0.512*** | 0.650*** | 0.259** | 0.329** | -0.019 | -0.026 |
| | (0.096) | (0.125) | (0.099) | (0.127) | (0.126) | (0.158) | (0.104) | (0.132) |
| T × Dist. Site | -0.517*** | -0.594*** | -0.714*** | -0.852*** | -0.449*** | -0.519*** | -0.001 | 0.006 |
| | (0.126) | (0.150) | (0.124) | (0.141) | (0.155) | (0.181) | (0.130) | (0.154) |
| T | 0.433*** | 0.414*** | 0.485*** | 0.493*** | 0.350*** | 0.332*** | 0.134 | 0.067 |
| | (0.098) | (0.105) | (0.097) | (0.099) | (0.094) | (0.108) | (0.087) | (0.104) |
| Outside × T | | 0.056 | | -0.015 | | 0.051 | | 0.184** |
| | | (0.044) | | (0.011) | | (0.072) | | (0.086) |
| Outside × T × Dist. Site | | 0.227* | | 0.399*** | | 0.230* | | -0.001 |
| | | (0.118) | | (0.116) | | (0.121) | | (0.107) |
| TE Dist> 0.5 | 0.47 | 0.47 | 0.47 | 0.48 | 0.46 | 0.46 | 0.38 | 0.38 |
| TE Dist< 0.5 | 0.32 | 0.32 | 0.27 | 0.28 | 0.27 | 0.27 | 0.36 | 0.36 |
| Control group | Outside 30km | Outside 30(-10)km | Outside 30km | Outside 30(-10)km | Outside 30km | Outside 30(-10)km | Outside 30km | Outside 30(-10)km |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-squared | 0.132 | 0.132 | 0.132 | 0.132 | 0.132 | 0.132 | 0.131 | 0.131 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

## Prices

*Table III.A.23: Exogenous Price Shocks: Private Zones Deforestation in ha*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.466** | 0.462** | 0.586** | 0.458** | 0.449** | 0.587** | 0.669*** | 0.617*** |
| | (0.198) | (0.211) | (0.232) | (0.217) | (0.219) | (0.231) | (0.194) | (0.199) |
| Price Index | 8.643 | 10.034 | 0.838* | 1.239** | -0.173 | -0.154 | 0.457 | 0.707 |
| | (5.659) | (7.143) | (0.489) | (0.521) | (0.886) | (1.018) | (1.209) | (1.221) |
| Inside × T × Price Index | 3.669 | 3.882 | 0.691** | 1.078*** | 0.500 | 0.233 | -0.249 | 0.102 |
| | (2.824) | (3.152) | (0.253) | (0.287) | (0.494) | (0.493) | (1.086) | (1.054) |
| T | -0.081 | -0.078 | -0.079 | 0.049 | -0.296 | -0.429* | -0.476** | -0.424* |
| | (0.229) | (0.238) | (0.273) | (0.274) | (0.206) | (0.215) | (0.227) | (0.235) |
| Inside × Price Index | 2.812 | 1.379 | -1.275*** | -1.673*** | 0.247 | 0.244 | -0.574 | -0.829 |
| | (13.780) | (14.307) | (0.396) | (0.472) | (0.805) | (0.930) | (1.651) | (1.668) |
| T × Price Index | -5.508*** | -5.714** | -0.766** | -1.147*** | -0.153 | 0.107 | 0.918 | 0.569 |
| | (1.993) | (2.218) | (0.284) | (0.312) | (0.383) | (0.403) | (1.105) | (1.055) |
| Outside × T | | -0.007 | | -0.381* | | 0.433*** | | -0.181 |
| | | (0.123) | | (0.192) | | (0.122) | | (0.191) |
| Outside × Price Index | | -5.455 | | -1.342*** | | -0.046 | | -0.936 |
| | | (7.373) | | (0.342) | | (0.682) | | (0.583) |
| Outside × T × Price Index | | 0.569 | | 1.169*** | | -0.894** | | 1.207* |
| | | (2.024) | | (0.320) | | (0.356) | | (0.664) |
| PI Effect Post | 0.43 | 0.36 | 0.01 | -0.14 | 0.46 | 0.46 | 0.21 | 0.17 |
| PI Effect Pre | 0.50 | 0.50 | -0.16 | -0.16 | 0.04 | 0.05 | -0.02 | -0.02 |
| Ex. PI Post | | -0.55 | | -0.82 | | -0.42 | | -0.50 |
| Ex. PI Pre | | 0.20 | | -0.04 | | -0.10 | | -0.03 |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-sq | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |

Note: Dependent variable is deforested area in hectare. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.24: Exogenous Price Shocks: Public Zones Deforestation in ha*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.051** | 0.065** | 0.045* | 0.063* | 0.159*** | 0.203*** | 0.113** | 0.144** |
| | (0.023) | (0.031) | (0.026) | (0.036) | (0.054) | (0.070) | (0.049) | (0.057) |
| Price Index | 0.804 | 1.341 | 0.209 | 0.223 | -0.429* | -0.536* | -0.202 | -0.168 |
| | (1.752) | (1.932) | (0.156) | (0.187) | (0.231) | (0.285) | (0.199) | (0.259) |
| Inside × T × Price Index | 0.727 | 1.050 | 0.184 | 0.221 | -0.366*** | -0.426*** | -0.185* | -0.184 |
| | (0.933) | (1.034) | (0.201) | (0.233) | (0.116) | (0.133) | (0.109) | (0.141) |
| T | 0.133*** | 0.120*** | 0.092** | 0.074* | 0.052 | 0.009 | -0.012 | -0.042 |
| | (0.043) | (0.043) | (0.041) | (0.041) | (0.043) | (0.049) | (0.073) | (0.078) |
| Inside × Price Index | -0.096 | -0.635 | -0.126 | -0.141 | 0.838*** | 0.947*** | 0.273* | 0.239 |
| | (1.703) | (1.891) | (0.314) | (0.341) | (0.240) | (0.297) | (0.139) | (0.181) |
| T × Price Index | -2.653*** | -2.975*** | -0.227* | -0.265 | 0.063 | 0.123 | 0.271* | 0.269 |
| | (0.924) | (1.018) | (0.135) | (0.169) | (0.102) | (0.121) | (0.162) | (0.201) |
| Outside × T | | 0.037 | | 0.047 | | 0.133** | | 0.090** |
| | | (0.035) | | (0.039) | | (0.058) | | (0.037) |
| Outside × Price Index | | -1.791* | | -0.084 | | 0.334 | | -0.079 |
| | | (0.950) | | (0.176) | | (0.244) | | (0.207) |
| Outside × T × Price Index | | 1.143** | | 0.155 | | -0.190** | | -0.011 |
| | | (0.566) | | (0.152) | | (0.087) | | (0.152) |
| In. PI Effect Post | 0.12 | 0.10 | 0.10 | 0.09 | 0.47 | 0.53 | 0.18 | 0.17 |
| In. PI Effect Pre | 0.02 | 0.02 | 0.02 | 0.02 | 0.20 | 0.20 | 0.02 | 0.02 |
| Ex. PI Effect Post | | 0.04 | | 0.07 | | 0.27 | | 0.09 |
| Ex. PI Effect Pre | | -0.01 | | 0.03 | | -0.10 | | -0.05 |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-sq | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |

Note: Dependent variable is deforested area in hectare. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.25: Exogenous Price Shocks: Private Zones 60km*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.719** | 0.714** | 0.886** | 0.785** | 0.775** | 0.833** | 0.903*** | 0.860*** |
| | (0.303) | (0.311) | (0.355) | (0.352) | (0.356) | (0.355) | (0.221) | (0.208) |
| Price Index | 5.766 | 5.118 | 1.765*** | 1.951*** | -2.111 | -2.196 | 1.049 | 0.916 |
| | (6.279) | (6.880) | (0.436) | (0.520) | (1.742) | (1.834) | (1.612) | (1.518) |
| Inside × T × Price Index | 5.296 | 4.879 | 1.073** | 1.304** | 0.277 | 0.100 | -0.160 | -0.089 |
| | (4.261) | (4.451) | (0.459) | (0.525) | (0.782) | (0.773) | (1.797) | (1.717) |
| T | 0.075 | 0.078 | 0.314 | 0.414 | -0.524 | -0.575 | -0.345 | -0.301 |
| | (0.358) | (0.356) | (0.446) | (0.438) | (0.498) | (0.498) | (0.361) | (0.352) |
| Inside × Price Index | 12.097 | 12.679 | -1.596*** | -1.778*** | 1.956 | 2.069 | 1.825 | 1.963 |
| | (18.434) | (18.692) | (0.534) | (0.631) | (1.697) | (1.803) | (3.443) | (3.480) |
| T × Price Index | -7.822** | -7.396** | -1.518*** | -1.741*** | 0.399 | 0.564 | 0.447 | 0.376 |
| | (2.880) | (2.947) | (0.489) | (0.551) | (0.693) | (0.688) | (1.667) | (1.569) |
| Outside × T | | -0.058 | | -0.691** | | 0.470* | | -0.364* |
| | | (0.159) | | (0.331) | | (0.242) | | (0.197) |
| Outside × Price Index | | 2.362 | | -1.182* | | 1.117 | | 1.430 |
| | | (10.236) | | (0.598) | | (1.480) | | (1.531) |
| L.Outside × T × Price Index | | -2.047 | | 1.460* | | -1.590*** | | 0.526 |
| | | (2.700) | | (0.716) | | (0.498) | | (1.196) |
| PI Effect Post | 1.21 | 1.24 | 0.48 | 0.42 | 1.70 | 1.76 | 0.79 | 0.80 |
| PI Effect Pre | 0.78 | 0.78 | 0.06 | 0.06 | -0.08 | -0.07 | 0.31 | 0.31 |
| Ex. PI Post | | -0.29 | | -0.79 | | -0.06 | | -0.41 |
| Ex. PI Pre | | 0.33 | | 0.27 | | -0.59 | | 0.26 |
| Control Group | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km |
| Observations | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m | 2.8m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.26: Exogenous Price Shocks: Public Zones 60km*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.194*** | 0.222*** | 0.205*** | 0.244*** | 0.477*** | 0.543*** | 0.455*** | 0.518*** |
| | (0.063) | (0.075) | (0.076) | (0.090) | (0.146) | (0.167) | (0.118) | (0.135) |
| Price Index | 2.735 | 3.392 | 0.125 | 0.139 | -0.392 | -0.594 | -0.919* | -0.944* |
| | (3.397) | (3.573) | (0.425) | (0.469) | (0.517) | (0.557) | (0.503) | (0.552) |
| Inside × T × Price Index | 4.039* | 4.514** | 0.555 | 0.598 | -0.793*** | -0.875*** | -0.872*** | -0.922*** |
| | (2.124) | (2.243) | (0.444) | (0.492) | (0.236) | (0.260) | (0.263) | (0.304) |
| T | 0.385*** | 0.361*** | 0.272*** | 0.234** | 0.172 | 0.107 | 0.005 | -0.054 |
| | (0.105) | (0.106) | (0.092) | (0.094) | (0.106) | (0.115) | (0.132) | (0.140) |
| Inside × Price Index | -4.863* | -5.528* | -0.292 | -0.308 | 1.894*** | 2.103*** | 1.368*** | 1.395** |
| | (2.827) | (3.026) | (0.505) | (0.552) | (0.442) | (0.514) | (0.495) | (0.541) |
| T × Price Index | -5.687** | -6.158*** | -0.457 | -0.498 | 0.125 | 0.206 | 0.821*** | 0.870** |
| | (2.190) | (2.302) | (0.402) | (0.450) | (0.170) | (0.191) | (0.297) | (0.334) |
| Outside × T | | 0.122 | | 0.162* | | 0.350*** | | 0.316*** |
| | | (0.074) | | (0.082) | | (0.128) | | (0.111) |
| Outside × Price Index | | -4.035* | | -0.285 | | 1.088** | | 0.200 |
| | | (2.113) | | (0.441) | | (0.514) | | (0.435) |
| Outside × T × Price Index | | 3.336** | | 0.433 | | -0.477** | | -0.307 |
| | | (1.519) | | (0.386) | | (0.186) | | (0.273) |
| In. PI Effect Post | 0.35 | 0.33 | 0.43 | 0.42 | 1.23 | 1.33 | 0.75 | 0.75 |
| In. PI Effect Pre | -0.07 | -0.07 | -0.04 | -0.04 | 0.71 | 0.71 | 0.10 | 0.10 |
| Ex. PI Effect Post | | 0.24 | | 0.31 | | 0.84 | | 0.43 |
| Ex. PI Effect Pre | | -0.02 | | -0.04 | | 0.23 | | -0.16 |
| Control Group | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km | 60 km | 60(-10)km |
| Observations | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m | 17.3m |
| R-sq | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.27: Exogenous Price Shocks: Private Zones NTFP*

| | (1)<br>Acai | (2)<br>Acai | (3)<br>Brazil Nuts | (4)<br>Brazil Nuts | (5)<br>Rubber | (6)<br>Rubber |
|---|---|---|---|---|---|---|
| Inside × T | 1.342*** | 1.335*** | 1.201*** | 1.187*** | 1.401*** | 1.392*** |
| | (0.359) | (0.373) | (0.328) | (0.347) | (0.381) | (0.402) |
| Price Index | 3.713 | 4.288 | -0.890 | -0.741 | -1.144 | 0.289 |
| | (6.049) | (6.129) | (5.312) | (5.067) | (10.896) | (9.986) |
| Inside × T × Price Index | -1.020 | -0.431 | 0.234 | 0.456 | -5.607 | -5.682 |
| | (4.269) | (4.195) | (3.212) | (3.310) | (13.306) | (13.185) |
| T | -0.683* | -0.676* | -0.728 | -0.714 | -0.690 | -0.680 |
| | (0.378) | (0.394) | (0.433) | (0.455) | (0.409) | (0.429) |
| Inside × Price Index | 0.775 | 0.196 | 0.485 | 0.329 | -4.154 | -5.630 |
| | (5.641) | (5.695) | (7.434) | (7.260) | (17.243) | (17.233) |
| T × Price Index | 0.596 | 0.009 | 1.012 | 0.792 | 2.123 | 2.156 |
| | (4.155) | (4.141) | (3.103) | (3.209) | (7.814) | (7.601) |
| Outside × T | | -0.024 | | -0.051 | | -0.030 |
| | | (0.235) | | (0.252) | | (0.250) |
| Outside × Price Index | | -2.124* | | -0.642 | | -6.190 |
| | | (1.156) | | (3.767) | | (11.475) |
| Outside × T × Price Index | | 2.146 | | 0.744 | | -0.739 |
| | | (1.316) | | (1.196) | | (6.347) |
| PI Effect Post | 0.67 | 0.65 | 0.62 | 0.61 | 0.58 | 0.55 |
| PI Effect Pre | 0.12 | 0.12 | -0.04 | -0.04 | -0.09 | -0.09 |
| Ex. PI Post | | -0.70 | | -0.69 | | -0.79 |
| Ex. PI Pre | | 0.06 | | -0.12 | | -0.10 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.28: Exogenous Price Shocks: Public Zones NTFP*

| | (1) Acai | (2) Acai | (3) Brazil Nuts | (4) Brazil Nuts | (5) Rubber | (6) Rubber |
|---|---|---|---|---|---|---|
| Inside × T | 0.243*** | 0.311*** | 0.337*** | 0.408*** | 0.246*** | 0.301*** |
| | (0.069) | (0.091) | (0.090) | (0.110) | (0.071) | (0.087) |
| Price Index | -1.224* | -0.803* | 1.417*** | 1.215** | -3.706* | -2.807 |
| | (0.626) | (0.457) | (0.452) | (0.492) | (1.940) | (2.957) |
| Inside × T × Price Index | -0.518 | -0.317 | -0.894*** | -1.004*** | -0.643 | -0.763 |
| | (0.348) | (0.414) | (0.252) | (0.289) | (0.791) | (0.929) |
| T | 0.094 | 0.028 | 0.085 | 0.017 | 0.153* | 0.099 |
| | (0.069) | (0.078) | (0.097) | (0.108) | (0.085) | (0.092) |
| Inside × Price Index | 0.948* | 0.526 | 1.041** | 1.245** | -0.164 | -1.064 |
| | (0.567) | (0.575) | (0.439) | (0.567) | (1.719) | (2.955) |
| T × Price Index | 0.850*** | 0.650** | 0.405 | 0.514* | -0.822 | -0.704 |
| | (0.295) | (0.267) | (0.257) | (0.303) | (1.033) | (1.165) |
| Outside × T | | 0.195** | | 0.207** | | 0.161** |
| | | (0.083) | | (0.087) | | (0.072) |
| Outside × Price Index | | -1.165* | | 0.612 | | -2.341 |
| | | (0.660) | | (0.438) | | (3.272) |
| Outside × T × Price Index | | 0.537 | | -0.351 | | -0.500 |
| | | (0.355) | | (0.236) | | (0.592) |
| In. PI Effect Post | 0.42 | 0.40 | 0.50 | 0.52 | 0.36 | 0.35 |
| In. PI Effect Pre | -0.02 | -0.02 | 0.33 | 0.33 | -0.08 | -0.08 |
| Ex. PI Effect Post | | 0.22 | | 0.33 | | 0.18 |
| Ex. PI Effect Pre | | -0.13 | | 0.24 | | -0.11 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-sq | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.29: Exogenous Price Shocks: Private Zones Lagged Prices*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 1.046*** | 1.101*** | 0.950** | 0.760** | 0.815* | 1.038** | 0.952** | 0.993** |
| | (0.342) | (0.382) | (0.351) | (0.360) | (0.450) | (0.480) | (0.358) | (0.401) |
| Price Index | 7.502 | 6.710 | 0.575 | 0.901* | -0.402 | -0.636 | 6.576* | 6.941* |
| | (7.344) | (8.993) | (0.464) | (0.474) | (0.996) | (1.147) | (3.769) | (3.764) |
| L.Price Index | -11.069 | -8.465 | 1.743** | 2.090** | -1.263 | -1.384 | -6.632* | -7.277** |
| | (15.370) | (18.818) | (0.727) | (0.855) | (1.483) | (1.640) | (3.555) | (3.406) |
| Inside × T × Price Index | -4.367 | -3.550 | 1.981** | 2.620*** | -0.357 | -0.669 | 1.158 | 1.114 |
| | (9.081) | (10.384) | (0.746) | (0.922) | (0.983) | (0.976) | (2.888) | (2.936) |
| L.Inside × T × Price Index | 7.368** | 5.990** | 0.529 | 0.639 | 1.238* | 1.055* | 1.511 | 1.321 |
| | (3.172) | (2.750) | (0.445) | (0.448) | (0.622) | (0.617) | (1.894) | (1.832) |
| T | -0.367 | -0.419 | 0.042 | 0.234 | -0.384 | -0.600 | -0.545 | -0.586 |
| | (0.394) | (0.417) | (0.523) | (0.530) | (0.408) | (0.434) | (0.444) | (0.479) |
| Inside × Price Index | 8.463 | 9.227 | 0.007 | -0.304 | 0.729 | 0.973 | -8.505* | -8.875* |
| | (12.297) | (13.525) | (0.496) | (0.518) | (1.113) | (1.230) | (4.483) | (4.477) |
| L.Inside × Price Index | 0.717 | -1.907 | -3.626*** | -3.989*** | 0.231 | 0.356 | 2.843 | 3.492 |
| | (26.965) | (29.642) | (1.032) | (1.216) | (1.254) | (1.455) | (3.495) | (3.364) |
| T × Price Index | -2.660 | -3.485 | -1.579*** | -2.207*** | -0.764 | -0.458 | -2.090 | -2.046 |
| | (4.771) | (6.185) | (0.539) | (0.607) | (0.678) | (0.704) | (2.476) | (2.526) |
| L.T × Price Index | -2.146 | -0.763 | -0.314 | -0.421 | 0.887 | 1.066 | 3.176** | 3.367** |
| | (2.877) | (3.003) | (0.413) | (0.409) | (0.705) | (0.766) | (1.408) | (1.326) |
| Outside × T | | 0.196 | | -0.574* | | 0.673*** | | 0.140 |
| | | (0.216) | | (0.294) | | (0.230) | | (0.270) |
| Outside × Price Index | | 1.647 | | -0.813* | | 0.788 | | -1.226 |
| | | (7.314) | | (0.449) | | (0.957) | | (1.864) |
| L.Outside × Price Index | | -8.254 | | -1.496** | | 0.529 | | 2.213 |
| | | (16.305) | | (0.570) | | (0.973) | | (1.677) |
| Outside × T × Price Index | | 2.531 | | 2.030*** | | -0.980** | | -0.154 |
| | | (3.896) | | (0.653) | | (0.406) | | (1.179) |
| L.Outside × T × Price Index | | -4.421 | | 0.368 | | -0.665 | | -0.640 |
| | | (3.066) | | (0.266) | | (0.613) | | (0.718) |
| PI Effect Post | 0.74 | 0.78 | 1.14 | 1.03 | 0.23 | 0.36 | -0.82 | -0.87 |
| PI Effect Pre | 0.70 | 0.70 | 0.21 | 0.22 | 0.17 | 0.17 | -0.25 | -0.25 |
| Ex. PI Post | | -0.19 | | -0.70 | | -0.26 | | -0.89 |
| Ex. PI Pre | | 0.36 | | 0.03 | | 0.08 | | 0.74 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km m | 30 km | 30(-10)km |
| Observations | 1.29m | 1.29m | 1.29m | 1.29m | 1.29m | 1.29m | 1.29m | 1.29m |
| R-sq | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.30: Exogenous Price Shocks: Public Zones Lagged Prices*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.109*** | 0.139** | 0.103** | 0.143** | 0.243*** | 0.306*** | 0.199*** | 0.249*** |
| | (0.039) | (0.055) | (0.046) | (0.064) | (0.083) | (0.108) | (0.068) | (0.080) |
| Price Index | -0.889 | -1.147 | 0.086 | 0.054 | -0.331 | -0.461 | 0.332 | 0.304 |
| | (1.798) | (2.109) | (0.238) | (0.279) | (0.314) | (0.339) | (0.330) | (0.327) |
| L.Price Index | -0.178 | 0.957 | -0.360 | -0.283 | -0.043 | -0.185 | -1.020** | -0.806* |
| | (2.188) | (2.668) | (0.282) | (0.312) | (0.530) | (0.558) | (0.413) | (0.481) |
| Inside × T × Price Index | 3.543*** | 3.593*** | 0.300 | 0.299 | -0.277* | -0.307 | -0.360** | -0.365* |
| | (0.903) | (1.057) | (0.335) | (0.358) | (0.153) | (0.191) | (0.171) | (0.206) |
| L.Inside × T × Price Index | -4.280*** | -3.927*** | -0.496 | -0.449 | -0.461* | -0.547** | -0.084 | -0.032 |
| | (0.726) | (0.733) | (0.569) | (0.561) | (0.269) | (0.270) | (0.122) | (0.119) |
| T | 0.250*** | 0.221*** | 0.200*** | 0.160** | 0.160** | 0.098 | 0.098 | 0.049 |
| | (0.067) | (0.070) | (0.060) | (0.065) | (0.077) | (0.088) | (0.081) | (0.086) |
| Inside × Price Index | -3.940*** | -3.680** | -0.084 | -0.050 | 1.227*** | 1.360*** | 0.692** | 0.715** |
| | (1.389) | (1.693) | (0.412) | (0.446) | (0.303) | (0.349) | (0.333) | (0.335) |
| L.Inside × Price Index | 9.229*** | 8.086*** | 0.657 | 0.577 | 0.611 | 0.758 | 0.058 | -0.149 |
| | (2.111) | (2.745) | (0.767) | (0.759) | (0.483) | (0.515) | (0.297) | (0.420) |
| T × Price Index | -2.710*** | -2.761*** | -0.254 | -0.254 | 0.047 | 0.076 | 0.135 | 0.139 |
| | (0.829) | (1.008) | (0.219) | (0.259) | (0.115) | (0.141) | (0.191) | (0.237) |
| L.T × Price Index | -0.473 | -0.823 | 0.236 | 0.191 | 0.096 | 0.180 | 0.385** | 0.333** |
| | (0.701) | (0.757) | (0.210) | (0.243) | (0.146) | (0.178) | (0.149) | (0.152) |
| Outside × T | | 0.081 | | 0.107 | | 0.190* | | 0.147** |
| | | (0.060) | | (0.065) | | (0.096) | | (0.058) |
| Outside × Price Index | | 0.878 | | 0.056 | | 0.418 | | 0.092 |
| | | (1.960) | | (0.305) | | (0.270) | | (0.259) |
| L.Outside × Price Index | | -3.807 | | -0.260 | | 0.427 | | -0.580 |
| | | (3.040) | | (0.257) | | (0.354) | | (0.594) |
| Outside × T × Price Index | | 0.301 | | 0.046 | | -0.115 | | -0.032 |
| | | (0.802) | | (0.242) | | (0.189) | | (0.165) |
| L.Outside × T × Price Index | | 1.152 | | 0.157 | | -0.247 | | 0.135 |
| | | (0.849) | | (0.221) | | (0.169) | | (0.162) |
| In. PI Effect Post | 0.26 | 0.27 | 0.29 | 0.30 | 0.89 | 0.96 | 0.40 | 0.41 |
| In. PI Effect Pre | -0.16 | -0.16 | 0.00 | 0.00 | 0.44 | 0.44 | 0.23 | 0.22 |
| Ex. PI Effect Post | | 0.25 | | 0.23 | | 0.47 | | 0.24 |
| Ex. PI Effect Pre | | -0.01 | | 0.03 | | -0.02 | | 0.09 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km m | 30 km | 30(-10)km |
| Observations | 10.9m | 10.9m | 10.9m | 10.9m | 10.9m | 10.9m | 10.9m | 10.9m |
| R-sq | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the municipality level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.31: Exogenous Price Shocks: Private Zones Spatial Autocorrelation*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.932*** | 0.974*** | 1.091*** | 0.866*** | 1.006** | 1.304*** | 1.211*** | 1.192*** |
| | (0.260) | (0.281) | (0.303) | (0.300) | (0.434) | (0.468) | (0.309) | (0.322) |
| Price Index | 8.361 | 9.289 | 1.479 | 2.017* | -0.889 | -0.996 | 2.216 | 2.538 |
| | (8.239) | (9.027) | (1.034) | (1.072) | (1.526) | (1.625) | (2.451) | (2.543) |
| Inside × T × Price Index | 6.094* | 5.825 | 1.196 | 1.894** | 0.482 | -0.054 | 0.126 | 0.363 |
| | (3.390) | (3.613) | (0.754) | (0.808) | (0.865) | (0.922) | (1.571) | (1.634) |
| T | -0.195 | -0.239 | -0.043 | 0.181 | -0.676 | -0.966** | -0.724** | -0.706** |
| | (0.296) | (0.313) | (0.329) | (0.332) | (0.420) | (0.449) | (0.325) | (0.334) |
| Inside × Price Index | 5.501 | 4.497 | -1.823 | -2.360* | 1.232 | 1.365 | -0.654 | -0.980 |
| | (18.332) | (18.661) | (1.287) | (1.370) | (1.348) | (1.467) | (3.396) | (3.508) |
| T × Price Index | -8.533*** | -8.251*** | -1.519** | -2.205*** | 0.070 | 0.593 | 0.493 | 0.258 |
| | (2.798) | (3.031) | (0.609) | (0.644) | (0.647) | (0.712) | (1.347) | (1.360) |
| Outside × T | | 0.162 | | -0.665** | | 0.925*** | | -0.067 |
| | | (0.198) | | (0.261) | | (0.287) | | (0.261) |
| Outside × Price Index | | -4.449 | | -1.779*** | | 0.417 | | -1.202 |
| | | (9.152) | | (0.525) | | (0.931) | | (1.531) |
| Outside × T × Price Index | | -1.060 | | 2.102*** | | -1.772*** | | 0.827 |
| | | (3.476) | | (0.486) | | (0.603) | | (1.160) |
| PI Effect Post | 0.87 | 0.82 | 0.26 | 0.06 | 1.24 | 1.31 | 0.48 | 0.44 |
| PI Effect Pre | 0.60 | 0.60 | -0.13 | -0.13 | 0.18 | 0.19 | 0.20 | 0.20 |
| Ex. PI Post | | -0.68 | | -1.18 | | -0.43 | | -0.79 |
| Ex. PI Pre | | 0.21 | | 0.09 | | -0.30 | | 0.17 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km m | 30 km | 30(-10)km |
| Observations | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m | 1.42m |
| R-sq | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the state-year level. ***, **, *=significant at 1, 5 and 10 % level.

*Table III.A.32: Exogenous Price Shocks: Public Zones Spatial Autocorrelation*

| | (1) Cattle | (2) Cattle | (3) Corn | (4) Corn | (5) Timber | (6) Timber | (7) NTFP | (8) NTFP |
|---|---|---|---|---|---|---|---|---|
| Inside × T | 0.154*** | 0.188*** | 0.147** | 0.187*** | 0.393*** | 0.495*** | 0.330*** | 0.399*** |
| | (0.056) | (0.061) | (0.062) | (0.068) | (0.075) | (0.085) | (0.080) | (0.091) |
| Price Index | 0.650 | 1.354 | -0.064 | -0.069 | -0.320 | -0.538 | -0.775*** | -0.644** |
| | (2.466) | (2.642) | (0.314) | (0.354) | (0.374) | (0.399) | (0.290) | (0.293) |
| Inside × T × Price Index | 2.766 | 3.381 | 0.286 | 0.350 | -0.699*** | -0.837*** | -0.606** | -0.593** |
| | (2.057) | (2.171) | (0.328) | (0.362) | (0.178) | (0.202) | (0.253) | (0.268) |
| T | 0.266*** | 0.234*** | 0.192*** | 0.153** | 0.123* | 0.023 | -0.021 | -0.088 |
| | (0.055) | (0.056) | (0.061) | (0.063) | (0.069) | (0.075) | (0.079) | (0.087) |
| Inside × Price Index | -3.038 | -3.744 | 0.049 | 0.055 | 1.493*** | 1.717*** | 0.942*** | 0.811** |
| | (4.819) | (4.878) | (0.557) | (0.585) | (0.410) | (0.452) | (0.348) | (0.356) |
| T × Price Index | -4.343*** | -4.956*** | -0.285 | -0.350 | 0.139 | 0.276* | 0.693*** | 0.680*** |
| | (1.123) | (1.258) | (0.214) | (0.258) | (0.129) | (0.144) | (0.193) | (0.207) |
| Outside × T | | 0.092** | | 0.104** | | 0.307*** | | 0.203*** |
| | | (0.038) | | (0.044) | | (0.064) | | (0.058) |
| Outside × Price Index | | -2.342 | | -0.049 | | 0.688** | | -0.332 |
| | | (2.266) | | (0.312) | | (0.310) | | (0.251) |
| Outside × T × Price Index | | 2.216* | | 0.272 | | -0.436*** | | 0.002 |
| | | (1.159) | | (0.253) | | (0.143) | | (0.169) |
| In. PI Effect Post | 0.27 | 0.25 | 0.35 | 0.35 | 0.97 | 1.08 | 0.54 | 0.51 |
| In. PI Effect Pre | -0.08 | -0.08 | -0.00 | -0.00 | 0.58 | 0.58 | 0.04 | 0.04 |
| Ex. PI Effect Post | | 0.16 | | 0.23 | | 0.59 | | 0.19 |
| Ex. PI Effect Pre | | -0.03 | | -0.03 | | 0.07 | | -0.22 |
| Control Group | 30 km | 30(-10)km | 30 km | 30(-10)km | 30 km | 30(-10)km m | 30 km | 30(-10)km |
| Observations | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m | 11.9m |
| R-sq | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |

Note: Dependent variable is deforestation rate. All columns include grid and year fixed effects. Standard errors in parentheses are clustered on the state-year level. ***, **, *=significant at 1, 5 and 10 % level.

# Chapter IV

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

Torfinn Harding[1], Julika Herzberg and Karlygash Kuralbayeva[2]

**Abstract**

We study the effectiveness of three regulatory policies (*blacklisting* of municipalities, *Soy Moratorium*, and *conservation zones*) in reducing the pressure from international agricultural prices on deforestation in the Brazilian Amazon. We use a triple difference approach that combines commodity price shocks with deforestation policies. We find that the blacklisting program was most effective in reducing deforestation. The magnitude of the effect implies that agriculture-driven deforestation in the treated municipalities would have been 17% higher in the absence of the program. Our results also reveal a novel form of leakage that halved the effectiveness of the Soy Moratorium policy.

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## IV.1 Introduction

Globalized supply chains and growing trade networks yield higher specialization in production within countries according to the latter's comparative advantages. In the case of agriculture, this has led to a shift of the production from high-income countries to developing countries, where land is still comparably cheap and climatic conditions are favorable for crop cultivation (Weinzettel et al., 2013). The expansion of grassland and pasture as well as the increase in the production of forage crops such as soy or corn could be seen as results of this growing demand. The literature, which assesses land use and demand shifts with respect to environmental outcomes, agrees on the strong relation between the expansion of the agricultural sector in tropical countries and rapidly growing deforestation rates. It is estimated that around 49% of this deforestation could be attributed to the cultivation of crops for export markets such as the EU, China, or North America (Lawson, 2014). To address deforestation problems, some governments with large tropical forests have committed to an array of command and control policies. Specifically, Brazil has led the way in the fight against tropical deforestation with an impressive set of policies between 2003 and 2015. These policies, as argued in the literature, have been effective in reducing deforestation in the Brazilian Amazon (Assunção et al., 2013a; Assunção et al., 2015). However, growing demand and higher commodity prices may increase pressure on the forest and are expected to have an opposite effect on deforestation compared to the policies. Thus, this paper aims to understand whether anti-deforestation policies are effective in reducing pressure from higher commodity prices on deforestation. We evaluate the effectiveness of three policies implemented in Brazil: the first is a blacklisting municipalities policy[3], which targets municipalities with high deforestation rates through increased monitoring and control, and through limiting access to rural credits which finance the expansion of the agricultural sector. The second policy is the Soy Moratorium, an industry-driven initiative, which claims to keep the commodity supply chain clean of soybeans from recently deforested land. The third policy, conservation zones, is a land restrictive policy, which declares certain areas of municipalities as being under strict land regulation such as national parks or indigenous lands. Our dataset is a balanced panel of 660 municipalities in the Brazilian Amazon from 2002 to 2013.

We begin our analysis by estimating the direct effects of commodity prices on deforestation. Our key measure of price variation is a municipality-level commodity price index constructed according to the baseline cultivated area of different crops within municipal-

[3]The blacklisted municipalities were also called "priority" municipalities. Throughout the paper, we use the terms "priority" list policy and "black-listed" policy interchangeably.

ities.[4] Consistent with the findings of the existing literature on the relation between agricultural prices and deforestation in the Amazon during the 2000s (Hargrave and Kis-Katos, 2013), we find that commodity prices are associated with higher deforestation. Specifically, we find that a 100% increase in the global agricultural prices leads to an increase of the area of deforestation by 17% on average across all municipalities. The 80% price increase for agricultural commodities in our period then translates into deforestation of about 20,682 km$^2$, which is about 13% of the total deforestation in Brazilian Amazon in our sample. The effect of commodity prices is heterogeneous across areas, with a larger effect in areas with already low forest cover, consistent with high deforestation pressure in areas already under development.

Next, we estimate how policies affected the deforestation's response to international commodity prices, which represents the main contribution of the paper. A standard difference-in-difference (DD) model would compare deforestation rates in policy-affected municipalities (treatment group) with unaffected municipalities (control group) before and after the policy implementation. An essential pre-condition for a valid DD estimation are parallel trends in the treatment and control group before the policy is implemented. This pre-condition is violated in our case, since policies are not randomly implemented. Thus, we use the index of international-commodity prices as a third component which serves as an exogenous regressor. The key assumption is that international commodity prices affect municipalities independently from roll out of policies and the price effect exhibits the same trend in treated and control municipalities. We show that the necessary common trend assumption holds, when including the price index in the interaction.

Taking the policies into account, we find that the policy of black-listing municipalities reduced the impact of commodity prices on deforestation by about 17%, corresponding to 1126 km$^2$ of saved forest over the years 2008-2013. This is because the policy of targeting the most deforesting municipalities, by operating through reduction in credit lines and more intense monitoring, increases the general costs of deforestation, leading to a general reduction in the pressure on the forest in those municipalities.

We also find a reduction in deforestation in response to higher commodity prices due to the Soy Moratorium amounted 628 $km^2$ over 2006-2013 period. The policy of targeting one particular crop, as the Soy Moratorium does, is expected to punish deforestation related to soy only. Alternative crops, such as corn, could then be moved to newly deforested areas, whereas soy could expand on previous corn fields. It is not surprising that we find that the Soy Moratorium shifted deforestation pressures to other crops, and the net effect of 628 $km^2$ of additional deforestations stems from two effects, which work in opposite directions: deforestation *decreases* in response to higher soy prices, but

[4]Similar indexes were constructed to study the relation between commodity prices and conflict (Bazzi and Blattman, 2014; Dube and Vargas, 2013)

*increases* in response to higher prices of other crops, such as corn.

Finally, the policy of conservation zones takes away land from the land supply, and therefore increases the land rents and the pressure on the unprotected land. Consistent with this reasoning, we find that conservation zones led to a loss of 4412 $km^2$ of forest outside of conservation zones. This effect is mainly found around strictly protected areas and sustainable-use zones, while the implementation of indigenous lands does not lead to more deforestation outside of the restricted areas.

We further strengthen the credibility of our triple difference estimates, by plotting the estimates of the price-effect for treated and control municipalities over time. We show that the necessary trend assumption in the price effect plausibly holds, whilst price effects develop differently in policy-treated municipalities compared to non-treated municipalities. While the triple difference estimate measures how policies change responsiveness of deforestation to international commodity prices, another concern is the possibility of cross-border municipality spillovers. We address this concern by opening up the spatial dimension of our data and graphically inspecting the price effect at geographical policy boundaries. By plotting the price effect at different distances from policy boundaries, we find that spillovers to neighboring municipalities seem to be limited in the case of the priority municipalities, i.e. the non-treated municipalities follow their pre-treatment trend when the policy is implemented in the adjoining municipality. For conservation zones we illustrate spillovers from the inside to the outside of conservations zones which points on the shift of deforestation activities instead of their reduction. In the case of the Soy Moratorium we can graphically show the switch from one crop to another after the policy implementation. Despite the analysis above, we still cannot rule out that there are spillovers to other parts of Brazil or neighbouring countries due to Brazil's environmental policies.

Reducing deforestation is considered as a cost-effective measure to tackle climate change problems. To contribute to this discussion, we assess the "cost-effectiveness of the policies, by estimating how these policies changed the influence of commodity prices on municipal GDPs and carbon stock. The underlying idea is that policies may reduce municipal GDP, but also reduce carbon loss. The triple difference estimates of polices on municipal GDP show that the Soy Moratorium is the only policy initiative that marginally affects the economic output negatively, decreasing the GDP by about 1.1% in the affected municipalities. In terms of effects on carbon stock, we consider the amount of carbon stored in the remaining forest in a municipality and calculate the carbon loss corresponding to the size and type of forest area lost. We find that the total amount of carbon lost due to agricultural price increases in our period is 0.96 Pg C. The priority municipality policy resulted in 0.02 Pg C of avoided carbon loss, while conservation zone policies led to an additional loss of 0.08 Pg C.

Our paper makes three contributions to the existing literature. First, the paper contributes to the growing literature that aims to estimate causal effects of policies aimed at reducing deforestation activity in the Brazilian Amazon by documenting new effects of these policies. Our strategy, which builds on a triple difference set-up, enables clean identification of the effect of policies through the prices.[5] Our strategy allows us to control for a large set of observable and unobservable characteristics, including rich heterogeneity in the price effect. In addition, we take advantage of spatial variation of high resolution and investigate spatial discontinuities in the price effects across policy boundaries.[6] Our analysis leads to general policy interest as the lessons learnt on the relative importance of monitoring and targeting specific areas with higher deforestation rates versus supply chain commitments can be insightful for governments of other countries, such as Indonesia, where deforestation rates are highly influenced by commodity prices.
The paper's second contribution lies in its estimates of leakage related to anti-deforestation policies. In contrast to the existing literature that has focused on the problems of leakage mostly associated with operation of conservation programs (Pfaff and Robalino, 2017), our high resolution spatial data allow us to provide evidence on within-municipality leakage related to three policies with different targets (area, crop, and deforestation rates directly). Contrary to studies which evaluate the effectiveness of non-conservation policies, such as the Soy Moratorium, e.g. Gibbs et al. (2015b), we show that the crop-specific Soy Moratorium increases the deforestation pressure related to other crops and leads to substitution across crops in newly deforested lands. In terms of policy implications, these findings provide support for economists calling for actions that involve simultaneous large-scale efforts over broad regions and all crops to reduce leakage.[7]

The third contribution of the paper is to the literature that studies how booming commodity prices trigger various forms of responses in commodity-exporting economies. The literature has focused on impacts of macroeconomic fluctuations (Fernández et al., 2017; Drechsel and Tenreyro, 2018), on structural adjustment via Dutch disease mecha-

[5]Existing studies have tried several approaches to deal with endogenous placement of policies. Assunção et al. (2015), for instance, use a measure of 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. (2013a) argue that satellite-based enforcement contributed to reductions in deforestation rates and compare places with more or with less cloud cover. Assunção et al. (2013b) use 2008 change in access to rural credit lines conditional on farmers' environmental compliance in order to show that this policy change reduced deforestation rates in municipalities where cattle ranching is a dominant economic activity.

[6]The latter is close in spirit to the approach of Burgess et al. (2017), who focus on spatial discontinuities at the Brazilian Amazon's border with its neighboring countries.

[7]For instance, Boucher and Elias (2013) point out to necessity of such efforts, particularly involving large countries, such as Brazil and Indonesia. Even though they mostly refer to potential cross-country leakage, their policy recommendations are also supported by our results.

nisms (Harding and Venables, 2016), and on conflict (Dube and Vargas, 2013; Bazzi and Blattman, 2014). Our paper uses an empirical approach that combines price shocks and the geographical and time variation in deforestation policies to analyze the effectiveness of policies in agriculture-driven deforestation In this way, it brings a new angle provided by the agricultural price shocks to the existing literature.

The remainder of this paper is organized as follows. Section IV.2 presents the data and the institutional context. It outlines how policies can influence the relation between commodity prices and deforestation activities. Section IV.3 discusses the empirical strategy. Section IV.4 discusses empirical results, and Section IV.5 concludes.

## IV.2 Background and Data

### IV.2.1 Background

To address high deforestation rates, the Brazilian government implemented a set of policies, including three key ones: (i) priority municipalities list policy, (ii) conservation zones, and (iii) the Soy Moratorium.

**Blacklisting of municipalities** The policy was introduced in 2008, when the Brazilian Ministry of the Environment set up a list of 35 municipalities which were subject to higher monitoring and enforcement, given their high deforestation rates. This group of municipalities accounted for 45% of the deforestation in the Brazilian Amazon in the year before the policy was implemented. Seven municipalities were added in 2009, another seven were included in 2011, and eight municipalities entered the list in 2017. Priority status has been determined based on three municipality-level criteria: (i) total deforested area; (ii) total deforested area over the past three years; and (iii) increase in the deforestation rate in at least three of the past five years. The upper map on the right-hand side of figure IV.1 shows that these municipalities are mainly located in the southern part of the Amazon region and along the arc of deforestation. Notably, figure IV.A.4 shows that the priority status depends on the absolute deforestation rate (in $km^2$) rather than on the relative deforestation rates (ratio of deforestation to forest cover remaining). A more stringent system of deforestation monitoring and environmental law enforcement has been applied towards the priority municipalities by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA), the national environmental police and law enforcement authority. Municipalities on this blacklist also became subject to a series of other administrative measures, not officially established through legislation. Examples include compromised political reputation of mayors of priority municipalities (Abman, 2014) and economic sanctions applied by agents of the commodity industry, with politicians pressuring farmers to comply with environmental legislation, big slaughterhouses refusing to buy meat from irregular producers, and bank managers facilitating access to credit for producers who comply with environmental legislation. Figure IV.A.8 illustrates the different channels on how the policy has aimed to target deforestation. Exiting the list of priority municipalities is conditioned upon significantly reducing deforestation and pledging not to deforest by registering at least 80% of its territory at the Brazilian land register.[8]

**Soy Moratorium** Soy is Brazil's most profitable crop and a large share of the soybeans plantation occurs in the Amazon region, where production started in the early 2000s. At that time, global demand for protein-intense animal food increased rapidly and a new generation of genetically modified soybean seeds was released in Brazil, which adapts better to the difficult soil conditions in the Amazon (Bustos et al., 2016). Soybeans are the most important export crop with an estimated export share of 75% (Lawson, 2014). Main importers in 2013 were China (48%) and the EU (31%) (UN Comtrade, 2018). Karstensen et al. (2013) show that 29% of export-induced deforestation can be attributed to the soybean production. This rapid expansion of soybean plantations on formal forest lands combined with the strong link to downstream markets in the EU and North America has raised international awareness. Pressure on the soybean producers to stop deforesting for higher profits resulted in the 2006 signed Soy Moratorium (SoyM), which was announced by the Brazilian Association of Vegetable Oil Industries (ABIOVE) and the National Association of Cereal Exporters (ANEC). Retailers, who join the Moratorium, ban the purchase of soybeans which have been planted on farmland that was cleared after June 2006. Brazil's Soy Moratorium was the first voluntary "no deforestation" commitment undertaken by private companies. Although it was supposed to terminate in 2016, Brazil's soy industry extended it indefinitely in May 2016.

**Conservation zones** From 2003 to 2008, Brazil expanded the area of Amazon forest recognized as protected areas or conservation zones by 640,000 square kilometers, an area the size of France. By December 2010, conservation zones covered a total area of about 2.2 million km$^2$ including 44% of the territory of the Brazilian Amazon. These zones are managed by the federal, state, or municipal governments. The areas are of three types: strictly protected areas, sustainable use zones, and indigenous lands. In strictly protected areas (SP), harvesting of trees or settlements of traditional or non-traditional populations are completely prohibited. By contrast, in sustainable use zones (SU) the extraction of forest resources as well as logging are permitted to some extent under a sustainable

[8]The Cadastro Ambiental Rural (CAR) is the Rural Environmental Registry system, which has been expected to improve transparency and compliance, via the registration of private properties (mainly farmland) in Brazil.

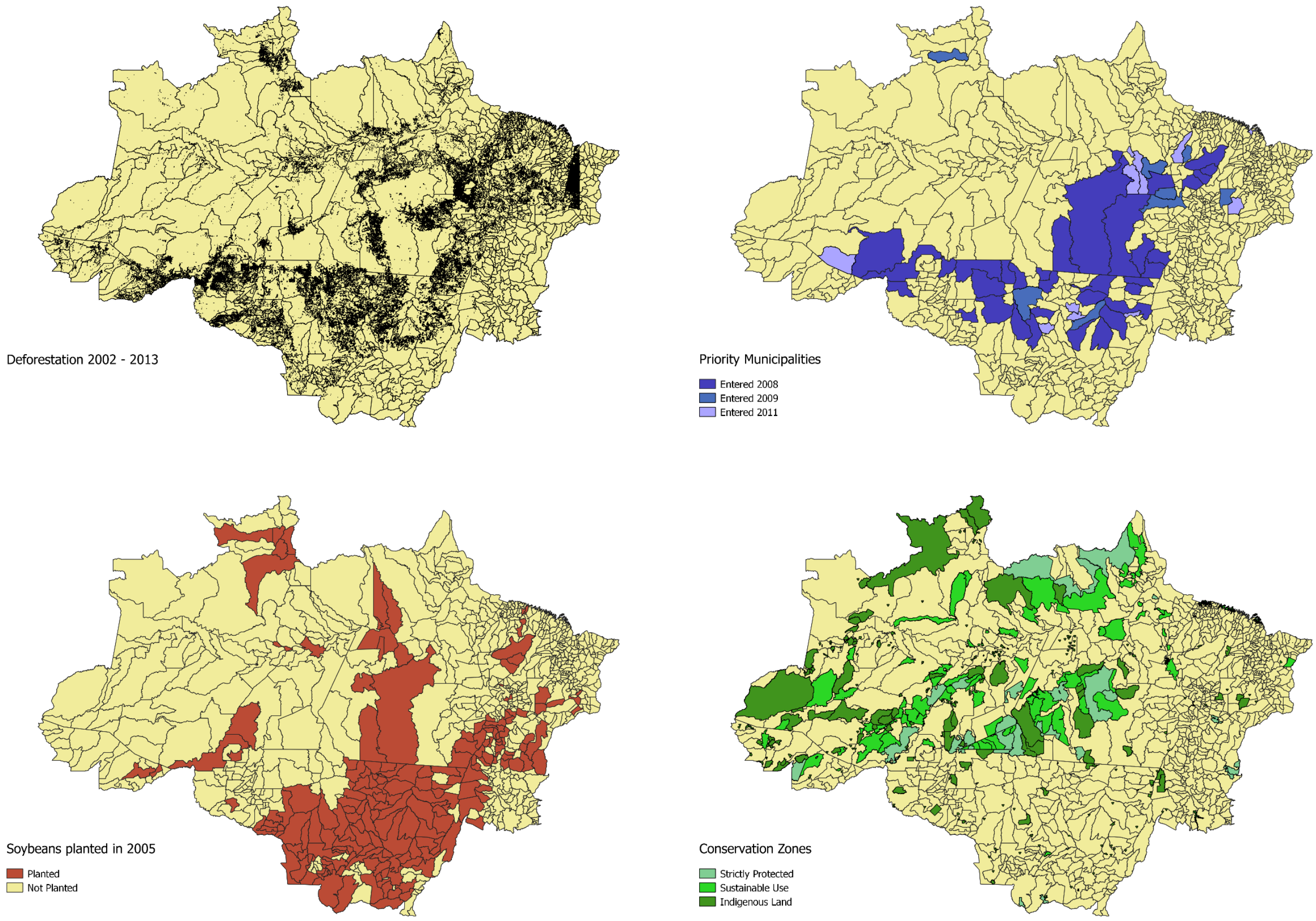
management standard (Verissimo et al., 2011). Another type of protected areas is that of indigenous lands which are federal territories where, in accordance with the Federal Constitution of 1988, indigenous populations have the right to possess permanently and to use exclusively the natural resources that exist in their lands.

Finally, the effectiveness in reducing deforestation of such zones depends principally on the total size it covers, the monitoring efforts which are taken to prevent illegal deforestation there, and their micro-location within the Amazon Basin. Prior to 2003, the conservation zones managed by the federal government were created in remote territories. Only as of this period did the federal government adopt the creation of conservation zones as a strategy to hamper the advance of deforestation on active frontiers under imminent threat of deforestation. Approximately 55% of the strictly protected areas and 58% of the sustainable-use zones established between 2003 and 2010 were in regions with "high" or "medium" human pressure such as urban areas, rural settlements or mining areas. In contrast, before 2003, the conservation units managed by the state government were mostly placed in remote areas, with only 14% of the state SP and 33% of the SU being placed in areas under "high" or "moderate" pressure. What is the logic of creating conservation zones in remote areas? There could be several reasons why this can be justified: (i) protection of fragile ecosystems; (ii) regulation of land prior the human occupation; (iii) prevention of land-grabbing (Verissimo et al., 2011). Additionally, at locations where pressure on forest is comparatively high (e.g. due to rapid development of agricultural business) monitoring of the zones could be more challenging, and law enforcement is often more difficult, as many interests conflict with each other (Pedlowksi et al., 2005).

### IV.2.2 Data

Our basic data set is a balanced panel of 771 municipalities in the Legal Brazilian Amazon from 2002 until 2013. For our empirical estimation we use the 660 municipalities that had at least some forest cover left in the year 2002. For a complete overview of source and description of the relevant variables used in this paper, see table IV.A.1. Below, we provide more information about the most central variables.

*Figure IV.1: Policy and Deforestation Maps*




**Deforestation** For annual data on deforestation and forest cover we use data based on NASA satellite imagines which have then been processed by the Brazilian space research agency, *Instituto Nacional de Pesquisas Espaciais (INPE)*, to depict deforestation. This processing also includes the clearance of any form of forest plantation, since we are only interested in primary forest loss. The data are organized in 1 $km^2$ grid cells and cover the entire Amazon. For our main specification, we aggregate the spatial data to the municipal level and measure the sum of deforestation in $km^2$ per year. The average deforestation per municipality dropped from 31 square kilometers in 2002 to 6.5 square kilometers in 2013. The upper right map of figure IV.1 shows the deforested area from 2002-2013 and highlights the areas under larger pressure.

**Priority municipalities.** The data on a priority list municipalities comes from the Brazilian Department of the Environment, *Ministério do Meio Ambiente, MMA*. The ministry publishes the list of those municipalities which receive the "priority" status as well as the date when they enter the list. In our sample, 49 municipalities were blacklisted in our period of observation. During 2011-2013, eleven municipalities were allowed to leave the list due to a remarkable decline in deforestation rates. For an empirical analysis, we generated an *Active* (denoted as $A$) dummy that becomes one for those municipalities and years when municipalities were in the list and an *Ever* (denoted as $E$) dummy, which indicates whether a municipality is blacklisted at any point in time during the period of analysis.

**Soy Moratorium.** As the SoyM started in 2006, we assume that those municipalities, which produced soybeans in 2005, are most affected by the policy. The lower left hand part of figure IV.1 maps the 190 municipalities that planted soy in 2005. This group of municipalities form our treatment group of this policy. The *Ever* variable, in the case of the SoyM, is defined as the logged area of soy plantations in 2005 and is time invariant. We create a dummy which is one for all years after 2005, in order to have an indicator for the years since when the policy is in place. In 2013, the last year of observation, 201 municipalities planted soy. We also include a robustness test which takes the municipalities that have soybean fields in 2013 as the treatment group and which shows that results are robust. Data on the planted area and production volume of soy are published in the municipal agricultural report *Produção Agrícola Municipal* (IBGE, 2017). Additionally, for the graphical examination of the soy policy, we use spatial data on soybean fields by Gibbs et al. (2015b), in which the authors use a satellite-based dataset to track the area and location of annual soy expansion from 2001 to 2014.

**Conservation zones.** The data on implementation date and location of the zones were obtained from the Brazilian ministry of environment MMA (2017) and processed in ArcGIS to obtain data on a spatial grid level and on a municipality level. The sample contains 258 conservation zones which were implemented between 2003 and 2014. These conservation zones consist of 118 indigenous lands, 92 sustainable use zones, and 48 strictly protected zones. Figure IV.1 illustrates how they are distributed over the Amazon. Note that we only include zones established in 2003 or later, in order to have a pre-treatment observation for each municipality. For the empirical estimation, the variable *Active* is the logged area of the conservation zone in a municipality and dummy variable *Ever* indicates whether a municipality received a conservation zone in the considered period.

**International prices** In our price index we include ten internationally traded crops are for which we obtain the market prices from the World Bank. These ten crops are: banana, coffee, groundnut, maize, orange, rice, sorghum, soybean, sugar cane, and wheat. Data on the land dedicated to each crop in a municipality are provided by an annual survey on agricultural production across all Brazilian municipalities IBGE. Together they account for over 80% of the agricultural area in the Amazon region. Figure IV.A.7 shows the frequency a crop is planted across the Amazonian municipalities.[9] The crop that occupies the most crop-planted area in the Amazon is soy. The area planted with soy increased from 41,965 $km^2$ to 66,976 $km^2$ in 2006 and reached 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 being increasingly planted on recently deforested land in the legal Amazon (Martinelli and Filoso, 2008).

In order to give the exogenous international prices a cross-sectional dimension, we use the share of a crop's area in 2002 and construct the price index for agriculture as follows:

$$P_{a,it} = \sum_j w_{ij,2002} P_{jt}, \quad w_{ij,2002} = \frac{area_{ij,2002}}{\sum_j area_{ij,2002}} \tag{IV.1}$$

where $P_{jt}$ is the price of crop $j$ in time $t$, normalized to 1 in year 2002, 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 the price index itself being affected by the farmers' behavior during the period we study. All weights sum up to one.

## IV.3 Empirical 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 the literature on the Dutch disease (Harding and Venables, 2016). To identify the direct effect of agriculture commodity prices on deforestation, we estimate the following equation:

$$\ln DF_{it} = \alpha + \beta_1 P_{a,it-1} + X_{it-1}\lambda + I_i + I_t + \epsilon_{it} \tag{IV.2}$$

where $DF_{it}$ denotes the sum of deforestation in municipality $i$ in year $t$ (August t-1 to August t). $\alpha$ is the constant. $P_{a,it-1}$ is the municipality-specific price index, with area allocated to the different crops in 2002 as the weights (see section IV.2). $I_i$ and $I_t$ in equation (IV.2) refer to municipality and year fixed effects. $X_{it-1}$ is a vector of controls, which always includes remaining forest cover (*ln RF*). We also show specifications where

[9] The most frequently (not most extensive) planted crop in the Amazon, which is not part of our price index, is cassava. However, since it is not an export crop but mainly planted for own consumption or the domestic market, we do not think that it is a main driver of large-scale agricultural consumption. Moreover, cassava plantation accounted for less than 4% of the agricultural area in 2013.

we control for mineral prices and land allocated to agriculture. Note that we lag all right-hand side variables due to the odd timing of deforestation. The coefficient of interest, $\beta_1$, is identified to the extent the $\epsilon_{it}$ is uncorrelated with $P_{a,it-1}$, which is plausible given the pre-determined weights and international prices. However, we discuss in detail threats to identification in the section (IV.4.4).

Second, we estimate how policies aimed at reducing deforestation affect the deforestation's response to international commodity prices. The first difference compares this outcome across policy-treated municipalities before and after the treatment took place. Since this difference is likely to be confounded by the several other changes taking place in the country during the same time period, we use municipalities, which have never been exposed to the anti-deforestation policies (or non-treated municipalities) as a control group. The idea is that these control municipalities would have been exposed to all the other changes that were taking place in the country during the period of interest, but anti-deforestation policies were *not* implemented there. In table 1 we test for the parallel trends assumption in the Difference-in-Differences (DD) model(upper part) and in the triple differences model (DDD). The dependent variable is deforestation in logs which implies for the parallel trends that growth rates have to be parallel. We find significant differences between treatment and control group for all three policies in the DD model. As policies were targeted at municipalities that were performing worse than the others in terms of deforestation, this result is not surprising.

*Table IV.1: Testing the Parallel Trends Assumption*

| | (1)<br>Prio | (2)<br>Soy | (3)<br>CZs |
|---|---|---|---|
| *Testing parallel trends for difference-in-differences (DD)* | | | |
| L.Trend x Ever | -0.077* | 0.129*** | -0.137*** |
| | (0.039) | (0.044) | (0.042) |
| L.Trend | -0.547*** | -0.074** | 0.022 |
| | (0.037) | (0.032) | (0.036) |
| Observations | 2,640 | 1,980 | 1,980 |
| R-sq | 0.199 | 0.036 | 0.038 |
| *Testing parallel trends for triple differences (DDD)* | | | |
| L.Trend x Ever x PI ag | 0.142 | 0.241 | 0.314 |
| | (0.189) | (0.260) | (0.307) |
| L.Trend x Ever | -0.256 | -0.102 | -0.482 |
| | (0.206) | (0.284) | (0.349) |
| L.Ever x PI ag | 0.339 | -1.420* | -0.438 |
| | (0.853) | (0.851) | (0.617) |
| L.Trend x PI ag | -0.118 | -0.381** | -0.556** |
| | (0.085) | (0.152) | (0.282) |
| L.Trend | -0.414*** | 0.331* | 0.615* |
| | (0.110) | (0.182) | (0.330) |
| L.PI ag | 0.866*** | 0.902** | 1.103** |
| | (0.248) | (0.349) | (0.511) |
| Observations | 2,640 | 1,980 | 1,980 |
| R-sq | 0.204 | 0.046 | 0.050 |

Note: The dependent variable is the natural logarithm of deforestation in a municipality in the years before the policy was implemented. *Trend* is a trend variable increasing with years. *Ever* indicates if a municipality is affected by the policy during the period of observation. In column 1 the assessed policy is the blacklisting policy (2002-2007), in column 2 it is the Soy Moratorium (2002-2005) and in column(3) 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 IV.2. *PI ag* is a price index for agricultural commodities. Includes municipality and year fixed effects. Standard errors are in parenthesis and clustered on the municipality level.

We, therefore, construct a triple difference (DDD) estimate of the policy effect by including the exogenous commodity prices indexes, which affect municipalities independently from roll out of policies and at a comparable level since we account for the production structure of the municipalities. These conditions ensure that in the DDD estimation, the only factor which differs the trends in the price effects between policy-treated and control municipalities in the post-treatment period are the policies. In the lower panel of table IV.1 we test for parallel trends in the triple difference model before the policy was implemented and find that we cannot reject the null hypothesis of parallel trends, with the coefficient on the triple interaction term being insignificant.

We expand the econometric model of equation IV.2 with interaction terms between the orice and the policy variables. The triple difference estimate of the effect of policies on deforestation is estimated by:

$$\begin{aligned}\ln DF_{it} = \beta_1 P_{a,it-1} + \beta_2 P_{a,it-1} \times E_i + \beta_3 P_{a,it-1} \times E_i \times A_{it-1} + \beta_4 E_i \times A_{it-1} + \\ \lambda_1 P_{a,it-1} \times I_t + \lambda_2 X_{it-1} + \lambda_3 P_{a,it-1} \times X_{it-1} + I_i + I_t + \epsilon_{it}\end{aligned} \tag{IV.3}$$

The main parameter of interest is $\beta_3$ (the triple difference estimate), indicating how the price-effect depends on the presence of the policy. To keep the model tractable, we estimate equation IV.3 separately for each policy. In general, variable $E_i$ is an indicator for an municipality to be in the treatment group at some point during the period of observation. In the case of the blacklisting of municipalities , we have a binary treatment variable. For the other policies, we have intensity of treatment in the form of area devoted to soybeans in the year before the Soy Moratorium or the area in protected areas in a given year. The variable $A_{it-1}$ is the dummy variable which indicates when a policy is implemented. As the blacklisting and conservation zone policies were rolled out in several intervals, $A_{it-1}$ does not clearly define one common period for all municipalities treated by these policies but is municipality specific. Only for the Soy Moratorium the variable is homogenous across all municipalities since the Moratorium was introduced in 2006 and lasted over the rest of our observed period. To take this heterogeneity in timing into account we control for price trends over time by including an interaction term between years and the price index $P_{a,it-1} \times I_t$. The variables $I_i$ and $I_t$ account for municipality and year fixed effects; and $X_{it-1}$ is a vector of controls, which always includes remaining forest cover. Standard errors are clustered at the municipality level. As we discuss in section IV.4.4 below, we test if our results remain robust when we control for overlap in policies implementation.

A final issue in equation IV.3 is how to control for the effect of the policy itself, $\beta_4$. In the case of priority municipalities, the policy was assigned on the basis of past deforestation trends. To control for this, we allow for separate sets of time dummies in the treatment and control groups by including an interaction between $E$ and the time dummies in the case of the priority municipality policy. This accounts for separate deforestation trends in the two groups in a flexible manner. We are still able to identify the interaction effect, $\beta_3$. For the two other policies, we have continuous treatments, i.e. the area allocated to soy in 2005 and the area covered by conservation zones. For these two policies, we account for the policy itself by including $E_i \times A_{it-1}$, as in equation IV.3. In robustness checks we show, however, that the results do not change if we instead include interactions between the time dummies and the area allocated to soy in the case of priority municipalities and the mean area in conservation zones in the case of CZs. This approach is synonymous with the inclusion of separate time dummies in the case of the priority municipalities: the area of soy in 2005 (the mean area in conservation zones) picks up something unobservable that indicates how prone the municipality is to being treated by the Soy Moratorium (conservation zones). Interacting this variable with the time dummies allows for these unobservable factors to have different effects for each year. This is a very flexible way of controlling for the underlying that characteristics the policy may have been assigned on.

# IV.4 Empirical results

## IV.4.1 Agriculture Prices and Policies' Impacts

The fixed effect model estimates of agricultural commodity prices, based on equation (2), and the triple-difference estimates of the impact of policies through prices, based on equation (3), are presented in columns 1-3, and columns 4-6 of table IV.2, respectively. The estimates of the fixed effects model with no controls (column 1) and with the remaining forest cover controls (columns 2 and 3) suggest that lagged commodity prices are associated with higher deforestation. The price effect is stronger in municipalities with lower levels of remaining forests. Columns 1-2 suggest that a 10% increase in the price index leads to about 2% higher deforestation. Our calculations show that an area of 20682 $km^2$, which is 12.7% of the entire deforestation in this period, is driven by the increase in agricultural prices.[10]

Note that the main specification in table IV.2 is the most conservative specification that we have in the paper. Alternative specification in tables IV.A.17-IV.A.20, which are explained in more detail in section IV.4.4, suggest an increase in deforestation between 7-19% for a 10% increase in the commodity prices.

[10] This number is based on a total deforestation of 162648 $km^2$ between 2002 and 2013, a 80% increase in agricultural prices in this period in our sample, and the coefficient of column 1 in table IV.2. The $km^2$ of forest that would have been saved without the commodity price boom: $162648 - \frac{162648}{e^{(0.17 \cdot 0.8)}} = 20681.89$. This corresponds to a deforested area of almost the size of New Jersey due to higher commodity prices over the 12 observed years.

*Table IV.2: Baseline Results Prices and Policies*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.170* | 0.189** | 0.983*** | 0.952*** | 1.026*** | 1.303*** |
| | (0.089) | (0.088) | (0.091) | (0.094) | (0.091) | (0.100) |
| L.PI ag x Ever x Active | | | | -0.274*** | 0.020 | 0.080*** |
| | | | | (0.093) | (0.023) | (0.019) |
| L.PI ag x Ever | | | | 1.769*** | -0.028 | -0.047 |
| | | | | (0.396) | (0.024) | (0.117) |
| L.Ever x Active | | | | | -0.070*** | -0.080*** |
| | | | | | (0.026) | (0.028) |
| L.ln RF | | 0.242*** | 0.752*** | 0.695*** | 0.780*** | 0.781*** |
| | | (0.085) | (0.110) | (0.107) | (0.117) | (0.098) |
| L.PI ag x ln RF | | | -0.163*** | -0.147*** | -0.161*** | -0.206*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.33 | 0.38 | 0.39 | 0.40 | 0.39 |
| Total(mean) | | | | 1.58 | 0.07 | 0.14 |
| Total(p25) | | | | 1.85 | 0.37 | 0.42 |
| Total wo(mean) | | | | 1.85 | 0.05 | 0.04 |
| Total wo(p25) | | | | 2.13 | 0.35 | 0.42 |

Note: In column 1 the effect of the agricultural price index on deforestation is estimated. Column 2 estimates the price effect and controls for remaining forest cover. Column 3 also includes an interaction between RF and the price index. Column 4 to 6 include the policies. *Ever* and *Active* is defined according to the policy type as described in section IV.3. Column 4 includes the triple interaction term to estimate the policy effect in priority municipalities Not shown in the table but included in the estimation are interactions between the *Ever* dummy and year-dummies, to take into account different trends in prio and non-prio municipalities. Columns 5-6 include the time-varying policy variable (*Ever x Active*), instead of interaction between policy variable and time dummies. Column 5 estimates the effect of the soy policy and column 6 estimates the effect of the conservation zone policy. All columns include interactions between the price index and each year as well as municipal and year fixed effects. Standard errors are clustered on the municipality level. "Total" gives the percent change in the annual deforested area at the municipality-level for a 1 percentage point change in the price index, for columns 4-6 with policies in place. "Total wo" gives the same for the treated municipalities without the policies in place."mean" and "p25" in parentheses refer to the sample mean and sample 25th percentile of the remaining forest used for the calculations. The mean of RF is 5.9, while the 25 percentile is 3.9.

Columns 4-6 of table IV.2 present the DDD estimates of the impact of three policies - priority municipalities list policy (Prio), Soy Moratorium (Soy), and conservation zones (CZs) on deforestation, respectively. The question which interests us is whether the policies have reduced the pressure of higher commodity prices on deforestation. The main parameter of interest is the triple-difference estimate (row 2), which measures how commodity prices affect deforestation, given that policies have changed how deforestation responds to commodity prices. Our results suggest that the effect of the prices on deforestation is about 17% lower when municipalities were blacklisted (1.58 vs 1.85).

Back-of-the-envelope calculations show that in municipalities on the blacklist, deforestation is about 1126 $km^2$ lower than it would have been without the policy, which is around 6% of the total deforestation over 2008-2013 in the affected municipalities.[11] The Soy Moratorium (column 5) does not have any differential effect on how commodity prices affect deforestation. We explore what drives this result by splitting up the price index into a soy price index, and a price index without soy prices, and discuss the results in the section 4.1.1 below.

The results presented in column 6 of table IV.2 illustrate that in municipalities with conservation zones, the price effect is amplified. In column 6 of table IV.2 we focus on non-protected area in the municipalities which obtained a conservation zone between 2003 and 2013 in order to capture the effect of land restriction (due to a new conservation zone) on deforestation. We find that in treated municipalities deforestation is 4412 $km^2$ higher than without the zones.[12] This suggests that the implementation of a conservation zone, which is actually supposed to clear property rights, the rivalry for the remaining land increases and deforestation is used as a form of taking land into possession.[13] For completeness, table IV.A.8 repeats table IV.2 including also the area within the zones and shows that results are almost equal. Table IV.A.9 includes only area that lies within conservation zones, to show how prices and policies affected the specific areas which have been put under the state's protection. While the price pressure on the forest within the zones is slightly larger, the coefficient of the interaction term changes to a negative sign but is not significant. The same yields for the soy policy. Note that if the zone is located in an active priority municipality, price-induced deforestation within a zone decreases over 20% within a zone's border.

[11]Total deforestation in the priority municipalities between 2008-2013 is 19568 $km^2$. The mean of the price index was in these municipalities 1.2 in 2002-2007 and 2 for the period 2008-2013, a 66% increase. The total price effect with the policy was 1.58, as reported in the lower part of table 2, and suggests that the price increase of 66% led to an increase in deforestation as follows: Relative change in DF from t to t+1: $lnY_t = \beta x_t \Rightarrow \frac{Y_{t+1}}{Y_t} = \frac{e^{\beta x_{t+1}}}{e^{\beta x_t}} \Rightarrow Y_t = \frac{Y_{t+1} e^{\beta x_t}}{e^{\beta x_{t+1}}}$. This translates to a counterfactual deforestation of $\frac{e^{1.58 \cdot 1} \cdot 19568 km^2}{e^{1.58 \cdot 1.66}} = 6897 km^2$. The deforestation without the increasing prices would have been $19568 km^2 - 6897 km^2 = 12671 km^2$. Without the policy, the coefficient would have been 1.85, the counterfactual deforestation 5771 $km^2$ and the deforestation due to the price increase 13797 $km^2$. The policy therefore saved $13797 km^2 - 12671 km^2 = 1126 km^2$, related to the price increase.

[12]Total deforestation in the municipalities with zones between 2003-2013 is 59955 $km^2$. The price index in these municipalities was 1.05 in 2003 and 1.88 in 2013, a 79% increase. The total price effect with the policy was 0.14, as reported in the lower part of table 2, and suggests that an increase in deforestation without the price increase as follows: $\frac{e^{1 \cdot 0.14} \cdot 59955 km^2}{e^{1.79 \cdot 0.14}} = 53678 km^2$. Without the policy, the coefficient would have been 0.04. This implies that the deforestation without price increase and without the policy would be: $\frac{e^{1 \cdot 0.04} \cdot 59955 km^2}{e^{1.79 \cdot 0.04}} = 58090 km^2$ The policy therefore caused a loss of $53678 km^2 - 58090 km^2 = -4412 km^2$, related to the price increase.

[13]As mentioned in section IV.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).

### Soy Moratorium and Different Crops

The results of column 5 (table IV.2) show that the Soy Moratorium has no statistically significant effect on the responsiveness of deforestation to commodity prices. This appears to be surprising, since the Soy Moratorium targets soy producers and retailers, who are supposed to be directly affected by agricultural price changes. Below, we investigate what drives this result by estimating the triple difference model, based on equation (3), for the Soy Moratorium policy under different commodity price indexes. Column 1 is identical to column 5 of table IV.2 and provides estimates with the baseline agricultural price index. Next, we split up the price index and present the results with a soy price index (column 2), a price index which excludes soy (column 3). Tables IV.A.5 and table IV.A.7 show the complete baseline specification with the separated price indices. The negative (and statistically significant) sign of the triple-difference term in column 2 points into the direction of a reduction in deforestation in response to higher soy prices when the Soy Moratorium policy is active. We find a total effect of 1449 $km^2$ saved forest. This result might appear surprising considering the fact that the production of soybeans in the Brazilian Amazon were 1.5 times higher in 2013 than in 2006 and that the export value grew up to $ 7.5 billion US (SECEX, 2017). However, this expansion of soy production is not necessarily linked to deforestation which has several reasons.[14] One explanation gives column 3 of table IV.A.5 which shows that deforestation increases as a response to large non-soy crop prices in the presence of the Soy Moratorium (row 2).

[14] Besides of various forms of leakage of this policy, which are mentioned above, Bustos et al. (2016) remark the introduction of novel biotechnology as a driver of the massive yield expansion in Brazil, as genetically modified seeds were officially released in 2006. Thus, part of this increase was achieved on the intensive rather than extensive margin.

*Table IV.3: Soy Moratorium with Different Price Indexes*

| | (1) PI Argi | (2) PI Soy | (3) PI wo Soy |
|---|---|---|---|
| L.PI ag | 1.026*** | 3.358*** | 0.976*** |
| | (0.091) | (0.885) | (0.095) |
| L.PI ag x Ever x Active | 0.020 | -0.165*** | 0.050*** |
| | (0.023) | (0.038) | (0.019) |
| L.PI ag x Ever | -0.028 | 0.255*** | -0.076*** |
| | (0.024) | (0.088) | (0.023) |
| L.Ever x Active | -0.070*** | -0.061*** | -0.077*** |
| | (0.026) | (0.016) | (0.018) |
| L.PI ag x ln RF | -0.161*** | -0.492*** | -0.155*** |
| | (0.010) | (0.040) | (0.010) |
| L.ln RF | 0.780*** | 0.269*** | 0.758*** |
| | (0.117) | (0.091) | (0.116) |
| Observations | 7260 | 7260 | 7260 |
| R-sq | 0.40 | 0.38 | 0.39 |
| Total(mean) | 0.07 | 0.55 | 0.04 |
| Total(p25) | 0.37 | 1.46 | 0.32 |
| Total wo(mean) | 0.05 | 0.71 | -0.01 |
| Total wo(p25) | 0.35 | 1.62 | 0.27 |

Note: Repeats column 5 of table IV.2 including an *active* dummy that is 1 for all years after 2006, when the Moratorium was implemented, and takes the logged area on which soy was planted in 2005 as the *ever* variable. Column 1 includes the agricultural price index with initial weights. Column 2 takes the soy prices weighted by the initial area of soy in a municipality. Column 3 takes the agricultural price index as in column 1 but excludes the soy price. All columns include municipal and time fixed effects. Standard errors are clustered at the municipality level.

We find that the deforested area increased by 767 $km^2$ due to rising prises of other crops.[15] Thus, we show that the net effect of the Soy Moratorium results in a 628 $km^2$ of avoided deforestation. This finding suggests that farmers could plant crops, which are not part of the SoyM, on recently deforested land without bearing the risk of being banned by retailers or export markets, whereas they could replace the soy plantations on fields on which other crops were grown before. Further, the positive and significant coefficient of the interaction between prices (PI *ag*) and *Ever* suggests that deforestation was higher in the soy planting municipalities, when soy prices increased. This is consistent with anecdotal evidence provided by Gibbs et al. (2015b), who mention that farmers were

[15] Total deforestation in municipalities treated by the SoyM was 20280 $km^2$ between 2006-2013. The increase in soy price in these municipalities was 69% between 2006 and 2013. The total price effect with the policy was 0.55 and without 0.71, as reported in the lower part of table IV.3, and suggests that the deforestation avoided by the Soy Moratorium policy is: $\frac{e^{0.55\cdot 1}\cdot 20280km^2}{e^{0.55\cdot 1.69}} - \frac{e^{0.71\cdot 1}\cdot 20280km^2}{e^{0.71\cdot 1.69}} = -1449km^2$. The increase in non-soy agricultural price index of 76% in 2006-2013 and taking the total price effect with the policy of 0.04 and without -0.01, as reported in the lower part of table IV.3, we find a loss of $\frac{e^{0.04\cdot 1}\cdot 20280km^2}{e^{0.04\cdot 1.76}} - \frac{e^{-0.01\cdot 1}\cdot 20280km^2}{e^{-0.01\cdot 1.76}} = 767km^2$. The net effect is therefore:$1449 - 767 = 628km^2$

likely to accelerate deforestation in the years before they signed the moratorium, in order to ensure a possible expansion of soy fields to newly cleared lands during the time of the Moratorium.

These results suggest that the Soy Moratorium policy leads to a substitution of the production of soy to production of other crops on newly deforested lands. The strength of this substitution effect clearly depends on how easily production of soybeans could be substitutable by the production of other crops. For instance, corn has been found to grow under the same climatic and geological conditions as soy, implying that substitution is feasible in the area. While in 2006 corn was a minor crop produced in the Legal Amazon, its production figures quadrupled (IBGE, 2017) and it became the second most important crop in the Brazilian Amazon in terms of export share after soy.[16] Table IV.A.6 separates out the corn price and shows that high corn prices increase deforestation when the Soy Moratorium is active, which supports our thesis of a shift to other crops on recently deforested land, while plating soy on those fields which have been cleared before 2006.

Our results point out to a novel form of leakage associated with the policy which was not documented before in the existing literature. Instead, the previous studies identified two forms of leakage associated with this industry-driven initiative. One is seen in the extremely high deforestation rates during the preceding years which 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). The other type of leakage is viewed to be across space. Since the Moratorium comprises only the Biome of the Legal Amazon, deforestation rates in the Cerrado[17] increased after the establishment of the soy Moratorium (Gibbs et al., 2010).

### Heterogeneity in the CZ policy impact

In section IV.2, we discussed that conservation zones can be distinguished between three types depending on management structure. Empirical studies, which have examined if effectiveness of conservation zones to prevent or reduce deforestation can depend on its governance structure, find mixed results. On the one hand, sustainable-use zones have often been seen as most effective, since they allow the use of forest resources, but also help to reduce deforestation rates as they are often located close to areas with high deforestation pressure (Pfaff et al., 2014). On the other hand, it has been argued, that if such zones are located at remote sites, they can open up paths for commercial forestry and agriculture, by building roads to reach the sustainably managed zones and to transport

[16] The export share of corn in 2006 was $51.4 M US and $4.3 B US in 2013. Soy and corn are responsible for over 95% of the vegetable exports of the region (SECEX, 2017)

[17] 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.

the products extracted there (Brandt et al., 2016).

In this section, we contribute to this strand of research, by examining how these different types of zones might influence the responsiveness of deforestation to international commodity prices. Table IV.4 summarizes the triple-difference results based on estimating equation (3), where we distinguish across different types of conservation zones: indigenous lands (columns 1 and 2), sustainable use zones (columns 3 and 4), and strictly protected zones (columns 5 and 6). As further discussed in section IV.2, the effectiveness of conservation zones depends not only on their size but on their location within the within the forest area. Specifically, some conservation zones established between 2003 and 2010 were placed in areas with "high" human pressure, foremost in or close by the "arc" of deforestation (see figure IV.1). The general idea is that conservation zones could prevent further expansion of deforestation frontier into virgin lands. We examine how spatial location of zones affect our baseline results, and estimate the model for two samples: the whole (baseline) sample and a sample which includes municipalities located within the arc of deforestation. Estimates presented in columns 1,3, and 5 are based on the former, while estimates in columns 2,4, and 6 are based on the latter sample.

*Table IV.4: Types of Conservation Zones and Deforestation*

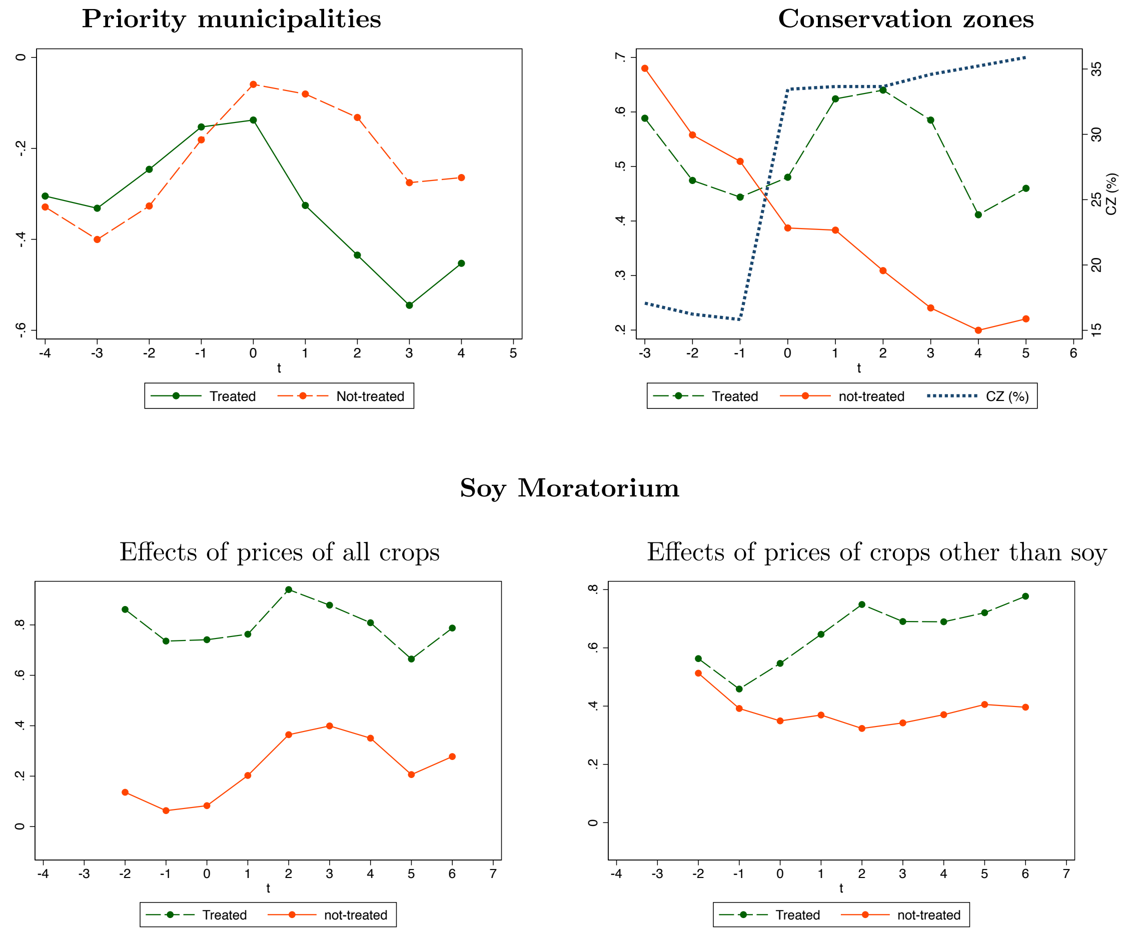
| | (1) IL | (2) IL | (3) SU | (4) SU | (5) SP | (6) SP |
|---|---|---|---|---|---|---|
| L.PI ag | 1.162*** | 1.229*** | 1.237*** | 1.326*** | 1.122*** | 1.230*** |
| | (0.098) | (0.116) | (0.103) | (0.122) | (0.100) | (0.119) |
| L.PI ag x Ever x Active | 0.025 | 0.039 | 0.075*** | 0.070** | 0.087*** | 0.080** |
| | (0.029) | (0.032) | (0.028) | (0.028) | (0.032) | (0.035) |
| L.Ever x Active | -0.011 | -0.056 | -0.072** | -0.063* | -0.080* | -0.082* |
| | (0.047) | (0.052) | (0.037) | (0.037) | (0.042) | (0.046) |
| L.PI ag x Ever | 0.173 | 0.081 | -0.011 | -0.042 | -0.398* | -0.336* |
| | (0.143) | (0.144) | (0.188) | (0.184) | (0.209) | (0.203) |
| L.PI ag x ln RF | -0.181*** | -0.187*** | -0.183*** | -0.192*** | -0.167*** | -0.180*** |
| | (0.011) | (0.012) | (0.011) | (0.012) | (0.011) | (0.012) |
| L.ln RF | 0.759*** | 2.201*** | 0.760*** | 2.003*** | 0.751*** | 2.190*** |
| | (0.106) | (0.148) | (0.105) | (0.169) | (0.111) | (0.147) |
| Observations | 7271 | 5797 | 7260 | 5786 | 7271 | 5797 |
| R-sq | 0.39 | 0.44 | 0.38 | 0.44 | 0.38 | 0.44 |
| Total(mean) | 0.27 | 0.17 | 0.19 | 0.15 | -0.25 | -0.20 |
| Total(p25) | 0.62 | 0.53 | 0.55 | 0.53 | 0.12 | 0.19 |
| Total wo(mean) | 0.25 | 0.15 | 0.14 | 0.10 | -0.28 | -0.22 |
| Total wo(p25) | 0.59 | 0.49 | 0.48 | 0.46 | 0.04 | 0.11 |

Note: Repeats column 6 of table IV.2 splitting up conservation zones into different types. Columns 1 and 2 include only indigenous lands ($IL$), columns 3 and 4 include only sustainable use zones $SU$ and columns 5 and 6 include only strictly protected zones ($SP$). For each type, forest cover and deforestation located within the zones' border is excluded. In columns 2, 4 and 6 the sample is limited to municipalities located within the arc of deforestation. Columns for $IL$ and $SP$ have a higher number of observation since they include municipalities which are entirely covered by a sustainable use zone. These are excluded from the basic sample and the $SU$ sample, respectively. All columns include municipal and time fixed effects. Standard errors are clustered at the municipality level.

The results suggest that the DDD estimates presented in Table IV.2 are driven by sustainable use zones (SU) and strictly protected zones (SP). The deforestation within the indigenous lands is not responsive to international commodity prices. Estimates for zones placed around the arc of deforestation are very similar in terms of magnitude to ones in the baseline specification. Thus, we find that the governance form plays a important role to prevent leakage. The good performance of the indigenous lands in reducing deforestation, which we find here, is in line with results of other studies that point on the effectiveness of this conservation policy (Nepstad et al., 2006; Nelson and Chomitz, 2011; Nolte et al., 2013). Tables A9-A11 in appendix present the estimates of the fixed effect model of agricultural prices and the triple-difference estimates of the policy impacts for each type of conservation zones.

## IV.4.2 Heterogeneity of the Price Effect Across Time

*Figure IV.2: Policies: Price Effects Over Time*




Note: The underlying regression equation of the figure is:
$\ln DF_{it} = \beta_1 E_i \times A_{it-1} + \beta_2 P_{a,it-1} \times I_t + \beta_3 P_{a,it-1} \times I_t \times E_i + X_{it-1}\lambda_1 + P_{a,it-1} \times X_{it-1}\lambda_2 + I_i + I_t + \epsilon_{it}$
where $i$ indicates the municipality and $t$ indicates the year. Other variables are identical to the main empirical estimation equation IV.3. The figure plots estimated $\beta_3$ for each year. Coefficient shown as 3-year moving average. Left panel (priority list); Middle panel (CZ), $t = 0$ defined as year with maximum expansion of zones in municipality. For municipalities without expansion in the 2002-2013 period, i.e. "control group", we set t=-4 in 2003, as t=-4 is the mean t in 2003 for the municipalities with expansion, i.e. the "treatment group".The lower right panel of the soy moratorium separates out the soy price as the explanatory price index. Right panel includes the complete agricultural price index as above and for both panels $t = 0$ is defined as 2006 and a municipality belongs to the treated group if it had at least one soy field in 2005.

In table IV.2, we presented the triple difference estimates of the impact of commodity prices on deforestation. In table IV.1 we showed that we can assume parallel trends in the triple difference model. In this section, we explore this assumption further by plotting the price effects in treated and control municipalities before and after each policy was implemented.

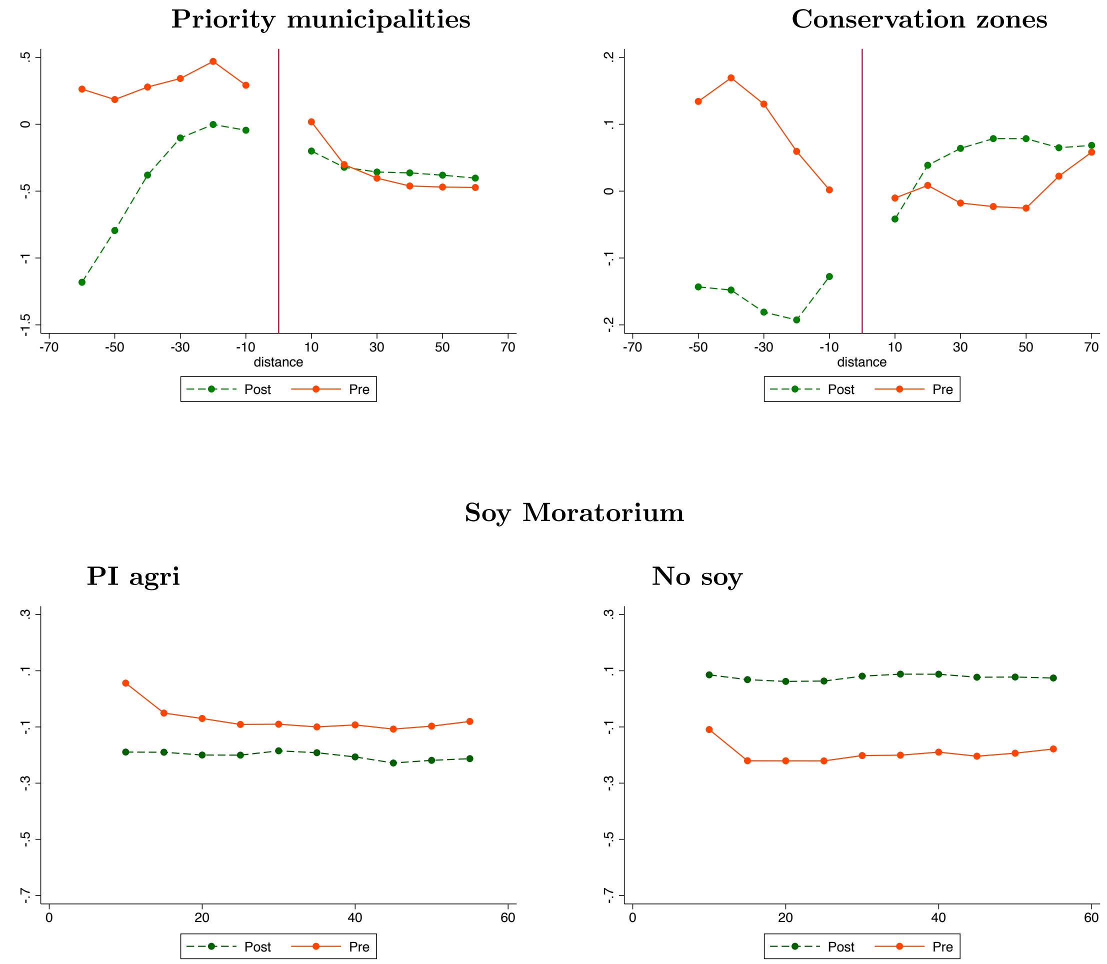
Figure IV.2 presents difference-in-differences graphs, showing the the effect of agriculture prices in treated and non-treated municipalities for each of the three policies. The upper left-hand side graph shows the price effect in municipalities on the blacklist (solid line) and in municipalities not on the blacklist (dashed line). In the years before those municipalities came onto the list, the effect followed the same trends, with somewhat higher level in these municipalities to be put on the list later. As the list became established, the price effect diverged in the two groups. The non-listed municipalities experienced higher price effects, but they arguably followed the pre-trend. However, we cannot rule out leakage across municipality borders and the results of decreased deforestation due to the blacklist found in table 1 should be interpreted with this caveat in mind. We return to this issue when we comment on spillovers into neighboring municipalities below.

The upper right-hand graph in figure IV.2 presents the price effect in municipalities with and without expansion in conservation zones. As we in this case do have a continuous treatment (the area covered by CZs), we need to define the year that the policy kicks in to organize the figure. We chose the year with the largest expansion in CZs in the municipality as $t = 0$. The blue dotted line indicates the average number of $km^2$ covered by CZs across the municipalities with expanding CZs, as indicated on the right-hand side y-axis. This average varies from 15% to 35%. For the municipalities without expansion in the CZs, we see a falling price effect throughout the period. In contrast, the price effect increases in the treated municipalities with expanding CZs. Essential to our identification strategy, the price effect follows the same trends as before the CZ expansions.

The two graphs in the lower panel of figure IV.2 show the price effects across those municipalities growing soy and those not growing soy in the year 2005, the year before the Soy Moratorium was introduced. The price index behind the estimates in the left-hand side graph includes all crops, also soy. Although the effect is much higher in the soy-growing municipalities, the trends in the price effects, before as well as after the introduction of the moratorium are quite parallel. In the right-hand side graph, we exclude the soy price from the index. In the non-soy municipalities there is no clear change in the price effect around $t = 0$, consistent with them continuing with business as usual. In contrast, the effect of the non-soy prices on deforestation increases in the soy-producing municipalities around $t = 0$. Intuitively, these municipalities switch their focus over to other crops, leading to a leakage from suddenly more intensively monitored activities related to soy to other crops without such a change in the monitoring.

## IV.4.3 Geographic Location of the Price Effect

*Figure IV.3: RD-Graphs: Price Effects Across Policy Boundaries*




Note upper panel: The underlying regression equation is:
$\ln DF_{it} = \beta_1 P_{a,it-1} + \beta_2 P_{a,it-1} \times I_j + \beta_3 P_{a,it-1} \times I_j \times A_{jt-1} + \beta_4 I_j \times A_{jt-1} + X_{jt-1}\lambda_1 + P_{a,jt-1} \times X_{jt-1}\lambda_2 + I_i + I_t + \epsilon_{jt}$
where $j$ indicates the grid cell, $i$ indicates the municipality and $t$ indicates the year. Other variables are identical to the main empirical estimation equation IV.3. The upper graphs plot estimated $\beta_3$ on pi ag at the border of priority municipalities (left) and conservation zones (right) against distance in $km^2$ from the municipality border and conservation zone border respectively. Negative distances indicate grid cells that are located inside the treated municipality or zone and positive distance numbers that they are located outside of the treated area. Coefficient shown as 15 km moving average. The pre line (orange) indicates the development before the policy was implemented and the post line (green) after the implementation.
Note lower panel: Plots estimated $\beta_3$ on the index of the agricultural price index (left panel) and excluding soy (right panel) to distance in $km^2$ from the closest soy field in 2005. Coefficient shown as 15 km moving average. The pre line (orange) indicates the development before the Soy Moratorium in 2006 and the post-line (green) after the implementation.

We now open up the spatial dimension of our data and estimate the price effect at different distances from the policy boundaries. For the two upper panels, the estimates for the treatment group are shown with negative distance numbers (left-hand side), whereas the estimates for the control group is to the right (positive distance numbers). Figure IV.3, upper left graph, shows that for the priority municipalities the agricultural price effect clearly drops after the priority policy becomes active in the affected municipalities (negative distance numbers), while the difference in the price effect between the pre-and-post-line is not visible for the neighbouring municipalities (positive distance numbers). At the border, itself the effect is quite small. The reduction in deforestation increases with distance to the border and seems to be driven from the center of the municipality. These results suggest that spillovers just across the municipality border do not seem to have taken place. However, we cannot rule out that leakage due to the blacklist policy might happen somewhere else.While it seems natural that small-scale loggers might move to new spots close by with less monitoring, large agricultural companies might also move further north, dropping off the public authorities' radar. Note that in figure IV.3, the control group are those municipalities that share at least one border with the priority municipalities but are not on the blacklist themselves, while in table IV.2 all municipalities are included.

The right graph in the upper panel of figure IV.3 provides the agricultural price effect on deforestation inside (left-hand side) and outside (right-hand side) conservation zones. After such a zone is legally approved, the price effect on deforestation drops remarkably inside of the zone. The difference before and after the protection policy is present, becomes larger with distance to a zone's border. This is plausible since the further away from the border a grid cell is located, the more remote it is from potential threats and the more difficult it becomes to access the forest. For the not protected forest outside of the zone, this trend revolves and the pressure increases compared to before the zone was established. This is consistent with the theory predicting that the limitation of one part of the land that could possibly be converted into agricultural area will increase the pressure for the other part.

Figure IV.3, lower panel, is the spatial counterpart to the lower panel of figure IV.2. We show the price effects on deforestation before and after adoption of the Moratorium in 2006. The x-axis shows, we use the distance from existing soy fields in 2005. The green line represent the price effect on deforestation after the Soy Moratorium entered into force in 2006 and the orange line the effect before 2006. The price effects in the left panel are based on all crops, whereas soy is excluded in the right hand panel. The deforestation price effect was higher before the Moratorium when soy is included, with the pattern is opposite when soy is excluded (right hand panel). This indicates that the Moratorium was successful in terms of reducing the pressure of high soy prices on the forest but may have led to leakage to other crops. Our model suggests that a moratorium that is specific to one single crop will not stop forest conversion to increase the planted area for other crops. In terms of the variation across space, the effects seems quite uniform, which is consistent with the Soy Moratorium being enforced by the buyers and affect all soy produced in the legal Amazon.[18]

### IV.4.4 Threats to Identification

In this section we discuss potential threats to identification and how we seek to address them.

**Non-random Policy Assignment.** The key threat to identification in this paper is non-random policy assignment. Our first strategy to deal with this is to estimate a triple-differences model, i.e. we estimate how the effect of the commodity prices changes with the policies. This pertains to a difference-in-difference estimation in the price effect. The key identifying assumption is, then, common trends in the price effect in treated vs. non-treated municipalities. We present difference-in-differences graphs on the price effects of the policy in section IV.4.2. More precisely, for each year, we estimate the effect of the prices separately for "treated" and "non-treated" municipalities, and we plot the coefficients. Visibly parallel trends before the policy was implemented provide support in favor of the common trend assumption. Furthermore, diverging trends after the policy was implemented provide support in favor of effects of the policies. Our second strategy is to bring in spatial variation in section IV.4.3, in order to inspect whether the effect of the prices changes discontinuously at the geographic boundaries of the policies. The results show that the estimated effects do change at the policy boundaries. This further supports the claim that the effects we pick up in the panel analysis are due to the policies instead of something else, to the extent this "something else" does not exactly follow the same boundaries as the policies.

In order to check whether the location where the policy is implemented does systematically differ from the non-treated locations, we run pre-balancing tests of covariates. Table IV.A.13 examines whether the 11 political and economic variables are balanced across treatment and control group in the years before policy implementation. In column 1, for the municipalities with conservation zones, we find significant lower level of forest cover than in the control group. As anecdotal evidence suggests that conservation zones are established in more remote places, far away from agricultural and economic activity, where opportunity costs for deforestation are lower. This corresponds with lower soy value in these municipalities. Municipalities with soybean cultivation show a higher coefficient for GDP per capita as well as agricultural characteristics. A small but significant

[18] In contrast to our specification in table IV.2, where the treatment group is defined by the area of soy fields in 2005 across the Amazon, data on soy fields with spatial reference are not available for the entire Legal Amazon. Instead, our graphical approximation is based on the data by Gibbs et al. (2015a) that contains 88 municipalities with at least 1000 ha in soy production in three states: Mato Grosso, Par, and Rondnia.

coefficient points to a slightly higher GDP per capita in priority municipalities before the policy was implemented. Except for the cases mentioned above, coefficients for all other variables are statistically insignificant.

As explained in section III.4, we include in the case of priority municipalities separate time dummies in the treatment and control groups. These absorb any characteristic that makes the deforestation systematically vary between the two groups from year to year. For the Soy Moratorium and the conservation zones, we present in columns 1 and 3 in table IV.A.14 robustness tests where we include interaction between the time dummies and the *ever* treated variable (the area planted with soy in 2005 in the case of the Soy Moratorium and mean expansion of conservation zones in the case of CZs). The results are unaffected compared to our baseline results. Column 2 simply repeats our baseline result. Column 4 is identical to our baseline regression for CZs, except that we include an interaction between the ever-treated variable, as defined for column 3, and the price. This does not affect the results.

**Alternative specification** In our baseline specification, we include the lagged remaining forest as a control variable to account for the potential for deforestation and the heterogeneity in municipal size. In order to show that these controls do not drive our results, we exclude them from table IV.A.15 and obtain similar results. Additionally, we use different definitions of the dependent variable. In table IV.A.16, the alternative specification is to instead measure the deforestation in % of the remaining forest cover. It produces the results that are equal in sign and significance and a bit larger in size, indicating that potential correlation between the lagged stock of forest and the error term is not biasing our results. The dependent variable in table IV.A.17 is deforestation in % of municipality area. Results are in line with those in the main specification.
A criticism towards our baseline specification is that the use of log requires us to deal with municipalities with zero deforestation by adding 1 before taking logs. As an alternative, we use in table IV.A.18 the inverse hyperbolic sine of deforestation as the dependent variable, which allows for zeros. The results are very similar to those based on ln (deforestation+1), and our conclusions do not change.
We also run regressions with variations of the cross sectional weighting of the commodity prices. As explained in section IV.2, we use the share of agricultural crop areas in 2002 to have a weight which does not correlate with the deforestation in the years after 2002. In table IV.A.19, we use instead the average share of the crop areas over the whole period, to better incorporate the expansion of certain crops over the 12 years of observation. Not surprisingly, the coefficient of the agricultural price index is 2.5 times higher than in the baseline specification and significant at the 1% level. Other results are similar to the baseline specification in size and significance, except the triple interaction capturing

the policy effect of the Soy Moratorium term which is significant and negative. Another variation of municipality weights are shown in table IV.A.20, which shows results for an agricultural price index weighted by potential yields of 7 out of the 10 crops we use in the baseline weighting. Potential yields is a measure provided by the FAO GAEZ database which calculates potential harvest outcomes based on geological and climatic conditions of the geographical location. The coefficient of the price index is slightly higher and the positive policy effect of the conservation zones is slightly smaller. Still, results remain qualitatively and quantitatively stable over various variations of the baseline specification.

**Correlation across policies.** The policies we consider may be correlated and may overlap in certain municipalities. 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 which is similar to the Soy Moratorium. Seeking to insulate the effect of the different policies, table IV.A.21 assesses different combinations of the policies. This is executed by including the triple interaction for two policy types as well as the interaction term that controls whether the municipality was ever treated. Neither the negative effect of the blacklist policy nor the positive effect of the conservation zones, vanish in these specifications.

**Policies could correlate with soil quality or other geographical characteristics.** Policies are correlated with geographical characteristics. To test whether our triple-difference estimates pick up the effects of geographic characteristics such as soil quality instead of the policies, we include interactions between such geographic characteristics and the prices. We use data of a high resolution of 5 arc-minutes on the basis of the year 2000 available from the FAO GAEZ database (see also figure IV.A.9). Tables IV.A.22-IV.A.24 include interactions with 4 soil quality characteristics and an access variable. The *nutrient*(1) concentration refers to soil fertility that is particularly important for low input farming, while *nutrient*(2) concentration is more relevant for the effectiveness of fertiliser application. The availability of *oxygen* in the soil, which is particularly important for root development, is also included as well as a variable for the soil volume limitations of a soil unit, affecting *root* penetration and constraining yield formation. Moreover we use the *access* variable, which provides the estimated travel time to the nearest city with 50,000 or more inhabitants. Map IV.A.10 provides an illustration of the distribution of this variable. Plausibly it also accounts for possible higher transport costs that could affect the commodity price effect on deforestation. Our estimates area robust to these controls and suggest that geographical heterogeneity is not an issue here.

**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 neighboring municipalities. For instance, soy production is concentrated within certain areas, as shown in the map in figure IV.1. Thus, price shocks as well as the Soy Moratorium could be correlated across space and could bias the standard error. To deal with both a potential bias in coefficients and the standard errors , we follow Cameron et al. (2011) and cluster the standard errors at the state-time level in table IV.A.28, which does not change the conclusions of this paper. To examine whether our results are influenced by geographical affiliation, tables IV.A.25-IV.A.27 include an interaction between the agricultural price index and a state dummy.[19] Additionally, in the last two columns, we control whether a municipality is located within the agricultural frontier, i.e. where the expansion of agriculture into the Brazilian Amazon is the most intense. Allowing the estimates to vary across states or according to the forest frontier show that our results are not driven by single states or frontier places.

**Could Brazil influence the world market price of soy?** In our sample period, Brazil turned out to be 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). However the production of soy in the Brazilian Amazon, our study area, constituted only 34% of the total production of soy in Brazil in 2013. The number one producer was the US, with a market share of 36.4% on average. The US production is also mostly consumed in the domestic US markets. 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 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 (see table IV.A.29). In average across the 12 years, those municipalities were responsible for up to 35% of the total Brazilian Amazonian soy production. Moreover, in table IV.A.30 we excluded 5% of the municipalities which exhibit the lowest deforestation rates and in table IV.A.31 we exclude the 5% municipalities with the highest deforestation rates. Both tables show that our results are robust to these modifications.

**Land use** The municipalities in our sample differ in terms of how much of the area is already developed and the potential for further deforestation. In tables IV.A.32-IV.A.34, we control for the lagged areas allocated to agriculture or mining. These controls do not affect the conclusions of this study.

[19]Naturally, municipalities within a Brazilian state do not only share geographical proximity but also political, legislative and cultural commonalities.

## IV.4.5 Carbon Stock and Gross Domestic Product

In this section, we estimate the impacts of the three policies on municipal GDPs and carbon stocks. The question is whether there is a trade-off between local economic development and the global public good of carbon storage.

*Table IV.5: GDP and Carbon*

| | GDP | | | Carbon | | |
|---|---|---|---|---|---|---|
| | Prio | Soy | CZs | Prio | Soy | CZs |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| PI ag | 0.334*** | 0.230** | 0.306*** | 1.743*** | 1.663*** | 3.242*** |
| | (0.104) | (0.104) | (0.102) | (0.411) | (0.387) | (0.426) |
| PI ag x Ever x Active | 0.020 | -0.021** | -0.005 | -0.228** | -0.021 | 0.111*** |
| | (0.017) | (0.008) | (0.006) | (0.094) | (0.031) | (0.027) |
| PI ag x Ever | -0.031 | 0.041*** | 0.115*** | 0.077 | 0.055 | -0.311* |
| | (0.130) | (0.009) | (0.045) | (0.518) | (0.035) | (0.162) |
| Ever x Active | | 0.002 | 0.002 | | -0.077** | -0.098** |
| | | (0.009) | (0.009) | | (0.035) | (0.042) |
| L.ln Stock | | | | 0.116** | 0.141*** | 0.308*** |
| | | | | (0.048) | (0.046) | (0.051) |
| PI ag x ln Stock | -0.029*** | -0.024** | -0.027*** | -0.053** | -0.062*** | -0.148*** |
| | (0.010) | (0.010) | (0.009) | (0.024) | (0.022) | (0.025) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.87 | 0.87 | 0.86 | 0.19 | 0.19 | 0.19 |
| Total(mean) | 0.02 | -0.01 | 0.13 | 0.75 | 0.70 | 0.69 |
| Total(p25) | 0.04 | 0.01 | 0.16 | 0.82 | 0.79 | 0.77 |
| Total wo(mean) | -0.00 | 0.01 | 0.14 | 0.97 | 0.72 | 0.56 |
| Total wo(p25) | 0.02 | 0.03 | 0.16 | 1.05 | 0.81 | 0.77 |

Note: Columns (1)-(3) have municipal GDP as the dependent variable. Since there is no time lag between the annual GDP and the policies, variables are not lagged in the regression but the regression is run from 2003-2013 to keep results comparable. The GDP in 2002 works as the stock variable here to account for the heterogeneity in size and economic power between the municipalities. Columns (4)-(5) display the policy effects on the carbon flow. Carbon flow is measured as the difference in carbon stock in year $t-1$ and year $t$. It includes the carbon stock variable to account for heterogeneity in carbon storage in a municipality.

Columns 1-3 of table IV.5 present estimates of models analog to table IV.2, but with municipal GDP as the dependent variable. The estimation considers logged GDP from 2003 to 2013 and takes GDP in 2002 as the stock variable to account for heterogeneity in size of the municipal economy. Note that the regressor is not time lagged in this specification, since there is no time gap between the policy implementation and the GDP production as it is the case for the deforestation and carbon variable.
Table IV.A.35 shows the full baseline estimation with GDP as dependent variable and

reveals the higher agricultural prices are positively related to municipal income if one takes the heterogeneity that increasing prices have on different sizes of economy across the municipalities. Column (1) shows that coefficients of agricultural price and its interaction with the priority municipality policy is small and not significant. For the soy moratorium policy in column (2) we find that GDP declines about 3800 R$ in average which is only 1.1% of the average GDP across the municipalities in our period. A reason for this decline could be that the moratorium forces farmers to shift part of their production away from soy to less profitable crops, as the expansion of soy fields is limited to the land which was already deforested before 2006. Column (3) indicates that the conservation zone policy does not affect the effect of agricultural prices on GDP, which is negative but not significant.

Table IV.5 includes carbon results for all three policies in column (4)-(6). Table IV.A.36 is the counterpart of table IV.2 with carbon loss as a dependent variable. Our data measures the total amount carbon which is stored in the forest of a municipality for each year. This amount depends, naturally, on the forest area of the municipality but also on the type of vegetation, the age of the trees etc. To make our estimates comparable to the deforestation estimations we take the natural logarithm of carbon loss per year as the dependent variable. This means that we compute the differences in the carbon stock between year $t$ and year $t+1$ to get the amount of carbon which is no longer stored in the forest due to deforestation. In order to control for heterogeneity in the dependent variable we include the carbon stock as a control and let the price index vary across different sizes of this carbon stock. The total carbon stock lost by deforestation in the Brazilian Amazon in our period of observation is 2.5 Pg, which could result in $CO_2$ emissions of about 9 Pg C.[20] If this amount of carbon would have been turned into carbon dioxide[21] it would be comparable to the amount of global $CO_2$ emissions from fossil fuels in 2010 (Le Quéré et al., 2016). Using the coefficient from column (1) of table IV.A.36 and the total carbon loss of 2.5 Pg C, we find that the total amount of carbon emissions due to agricultural price increases in our period is 0.96 Pg C.[22] Column (4) reports a negative effect of the blacklist policy, suggesting that this policy reduced the

[20]The conversion of carbon into carbon dioxide is based on the following consideration: One carbon molecule combines with two oxygen molecules. $C + O_2 = CO_2$. The mass of a carbon molecule is 12.0069 and the mass of a oxygen molecule is 15.999. Consequentially, one molecule of $CO_2$ has a mass of 44.0076. Thus, 12.0096 grams of carbon turn into 44.0076 gram of carbon dioxide.

[21]Note that the loss of 2.5 Pg of carbon does not necessarily mean that the entire biomass is turned into $CO_2$. This would only be true if the total carbon stock was burned without any remaining. Naturally, if trees are harvested and used for furniture or in construction, the carbon would not be emitted into the atmosphere. Thus, the total emission of $CO_2$ depends how the timber is used and if trees could grow back or the forest loss results in a land use change.

[22]This is calculated as: $2.5 - \frac{2.5}{e^{0.609 \cdot 0.8}} = 0.96$ Pg C.

agricultural price pressure and avoided the loss of 0.02 Pg C.[23] The coefficient of interest for the Soy Moratorium, presented in column (5), is not significant.
Interpreting the results on conservation zone policy considered in column (6) brings two insights. First, carbon density is in average 17% higher in municipalities with conservation zones than in the control group. This is probably due to the fact that an objective of this policy is to protect especially those areas that contain high forest density and biodiversity. Second, this high forest density results in a loss of stored carbon of around 0.08 Pg C in the affected municipalities.[24] As explained in section IV.4.1 this loss is mainly due to deforestation outside of protected areas, which increased after the implementation of zones. We interpret this as leakage triggered by the limited size of land available after establishment of the conservation zone.

These results reveal that the avoided deforestation as well as the leakage of the conservation zones policy can be translated into a loss of carbon storage in consideration of different forest densities in the affected municipalities. If the avoidance of further $CO_2$ emissions due to deforestation and especially forest fires is the main goal of deforestation policies, more focus should be set on preventing this form of leakage in carbon rich environments. Regarding simultaneously effects on economic growth the policies do not show a negative effect except of the case of Soy Moratorium.

[23]The total carbon loss in the priority municipalities over 2008-2013 was 0.23 Pg. The mean of the price index was in these municipalities 1.2 for 2002-2007 and 2.0 for 2008-2013, a 66% increase. The total price effect with the policy was 0.75 and without 0.97, as reported in the lower part of table 2, and suggests that the price increase of 66% lead to a loss of 0.09 Pg C: $0.23 - \frac{e^{1 \cdot 0.75}}{e^{1.66 \cdot 0.75}} = 0.09$ Without the policy, the loss would instead have been 0.11 Pg C: $0.23 - \frac{e^{1 \cdot 0.97}}{e^{(0.97 * 1.66)}} = 0.11$. This implies that the policy saved $0.11 - 0.09 = 0.02$ Pg C.

[24]The total carbon loss in the zone municipalities over the entire period was 1.27 Pg. The price index in the zone affected municipalities increased by 79% between 2003 and 2013. The total price effect with the policy was 0.69, as reported in the lower part of table 2, and suggests that the price increase of 79% lead to a loss of 0.534 Pg Carbon: $1.27 - \frac{e^{0.69 \cdot 1}}{e^{(0.69 * 1.79)}} = 0.534$. Without the policy, the loss would instead have been 0.454 Pg C Carbon:$1.27 - \frac{e^{0.56 \cdot 1}}{e^{(0.56 * 1.79)}} = 0.454$. This implies that the policy saved $0.454 - 0.534 = -0.08$ Pg C.

## IV.5 Conclusion

We investigated the effectiveness of three command-and-control policies in reducing the pressure from international agriculture commodity prices on deforestation. We studied the Brazilian Legal Amazon, home of the world's largest forest and a key supplier of agriculture commodities such as soy and corn, on the world market. We presented empirical evidence that increases in commodity prices are directly related to at least 13 % of total deforestation in the Amazon. With respect to the policies, our results showed that within-municipality leakage made policies targeting specific areas (conservation zones) ineffective in reducing the pressure from international agriculture commodity prices. The effectiveness of a policy targeting one crop (Soy Moratorium) is limited by the compensation farmers could create by planting other crops on recently deforested land. In contrast, a policy of blacklisting entire municipalities, irrespective of the source of deforestation, leads to a reduction in deforestation related to agricultural prices.

By examining the effects of policies on GDP and carbon stocks, we contribute to the debate on the relationship between economic growth and the environment. Even though our estimates cover neither all costs nor all benefits, these estimates provide lower bounds estimates of observable costs (in terms of lost GDP) and direct estimates of the benefits for climate change mitigation. We find that policies do not have a negative effect on economic growth except in the case of Soy Moratorium. Potentially, a switch away from soy beans towards less valuable crops has caused this small decrease in total GDP. In terms of effects on carbon stock, and consistent with the results of leakage induced by these policies, the blacklisting municipalities policy helps to avoid carbon emissions, whilst conservation zones policy results in leakage in emissions. If the avoidance of further $CO_2$ emissions due to deforestation and forest fires in particular is the main goal of deforestation policies, our results suggest that more focus should be set on preventing this form of leakage in carbon-rich environments.

# IV.A Appendix

## Extra Graphs and Tables

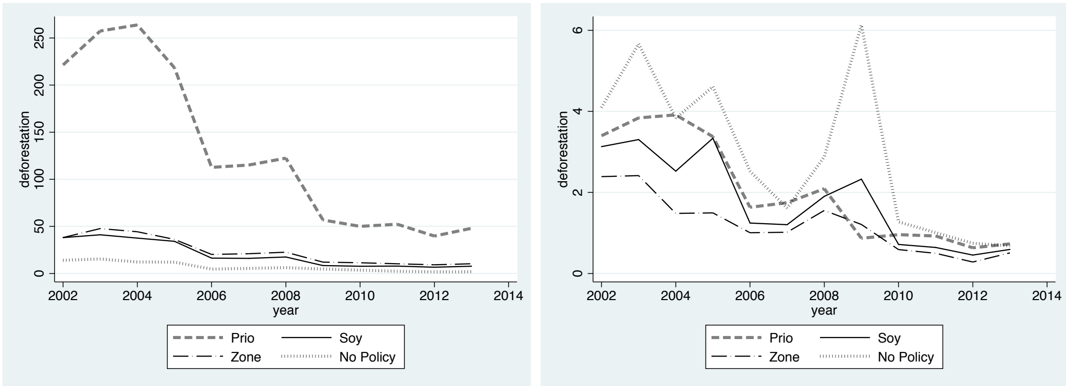



*Figure IV.A.4: Average Deforestation in Municipalities*

Left panel shows mean deforestation in $km^2$ in municipalities affected by different policy measures. The horizontal dashed line shows the deforestation rates in municipalities which are not treated by any policy.Right panel shows the deforestation in % of forest cover left in the municipality.

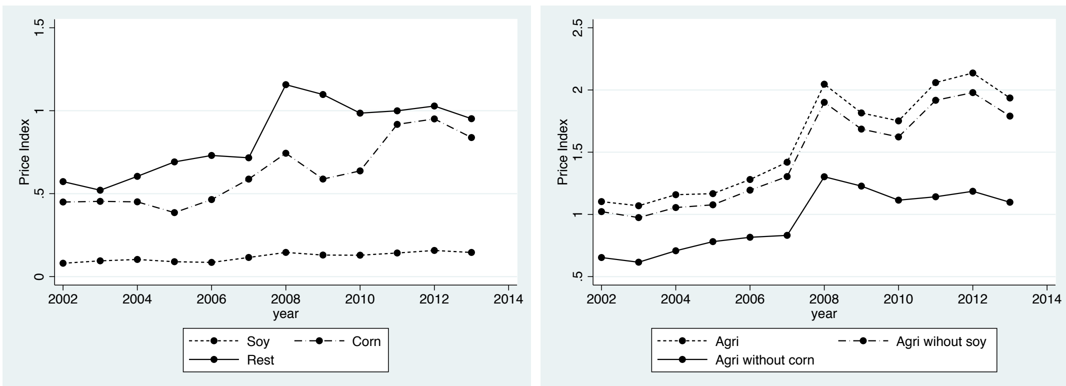



*Figure IV.A.5: Average Price Index Over Time*

Left panel shows the average price index of soy, corn and other crops. The right panel the aggregated price of all price indexes and without the main crops soy and corn.

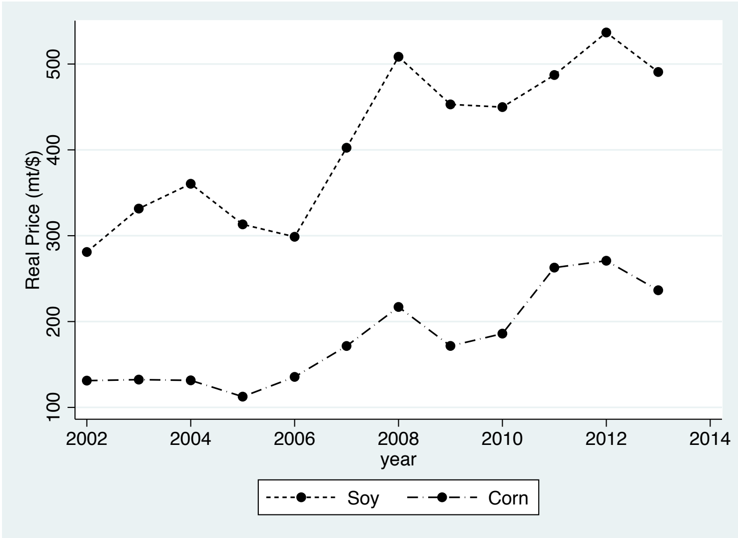



*Figure IV.A.6: Real Market Prices over Time and Mean PI over Time*
The panel shows real market price developments for corn and soy prices in US $ per metric ton.

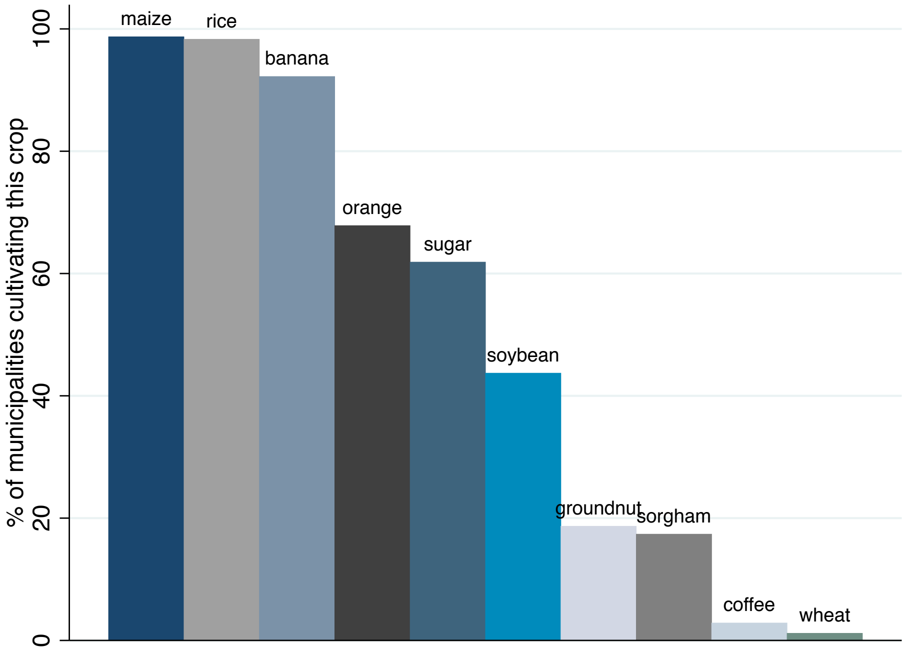



*Figure IV.A.7: Crops' Frequency Across Municipalities*
Shows the percentage of municipalities which report to plant the ten intentionally traded crops included in the price index.

## Descriptives

*Table IV.A.1: Data Description and Sources*

| Abbreviation | Description | Unit | Source |
|---|---|---|---|
| Sum df | Annual deforestation on municipal level | $km^2$ | INPE(2016) |
| Sum forest | Area in a municipality which is covered by forest | $km^2$ | INPE(2016) |
| 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 | % | World Bank |
| Area Agriculture | Area in a municipality used for agricultural harvest | $km^2$ | IGBE/PAM (2016) |
| Area in zone | Area in a municipality which is part of a protection zone | $km^2$ | INPE(2016) |
| Soy fields | Spatial reference for soy fields | $km^2$ | Gibbs et al. (2015) |
| Sectoral GDP | Gross Domestic Product divided in three main sectors: agriculture, industry and services | 1000R$ | IBGE/PIB(2016) |
| Carbon storage | Annual change in carbon mass stored in municipal forest area | tons | INPE (2017) |
| Soil constraints | Soil quality measured in retention capacity, nutrient constraints, workability constraints, oxygen constrains | 1-6 | FAO (2017) |
| Access | Access to municipality measured in average travel time to closest city with more tham 50,000 inhabitants | 1-6 | FAO (2017) |

*Table IV.A.2: Descriptive Statistics*

| Variable | Mean | Std. Dev. | Min. | Max. | Obs. |
|---|---|---|---|---|---|
| Log Deforestation | 1.56 | 1.51 | 0 | 7.17 | 7260 |
| Log Rest Forest Cover | 5.88 | 2.62 | 0 | 11.91 | 7260 |
| Log Carbon Mass | 9.19 | 2.1 | 0 | 14.45 | 7260 |
| Log Carbon Flow | 3.81 | 2.37 | 0 | 9.67 | 7260 |
| Log GDP | 11.33 | 1.20 | 8.34 | 17.52 | 7254 |
| Log GDP Agriculture | 9.99 | 1.09 | 6.87 | 13.80 | 7254 |
| Log GDP Industry | 9.01 | 1.52 | 5.54 | 16.82 | 7254 |
| Log GDP Service | 10.70 | 1.23 | 7.66 | 16.92 | 7254 |
| Price Index Agri | 1.55 | 0.47 | 0 | 2.49 | 7260 |
| Price Index Soy | 0.11 | 0.33 | 0 | 1.96 | 7260 |
| Price Index Corn | 0.61 | 0.42 | 0 | 2.49 | 7260 |
| PI without Soy | 1.44 | 0.56 | 0 | 2.49 | 7260 |
| PI without Corn | 0.94 | 0.45 | 0 | 2.38 | 7260 |
| Log Area Zone | 2.73 | 3.50 | 0 | 11.13 | 7260 |
| Dummy Prio | 0.03 | 0.17 | 0 | 1 | 7260 |
| Log Soy Area 2005 | 2.36 | 3.94 | 0 | 13.27 | 7260 |
| Labour | 4183.76 | 25479.40 | 1 | 535702 | 7243 |
| Wage | 2529.63 | 1463.74 | 195 | 16237.38 | 7243 |
| Agricultural Area | 16712.35 | 59464.25 | 0 | 1015955 | 7260 |
| Agricultural Value | 27427.59 | 104194.59 | 0 | 2066094 | 7260 |
| Productivity | 1883.31 | 1282.19 | 0 | 8087.94 | 7260 |
| Soy Value | 13802.39 | 68008.57 | 0 | 1420207 | 7260 |

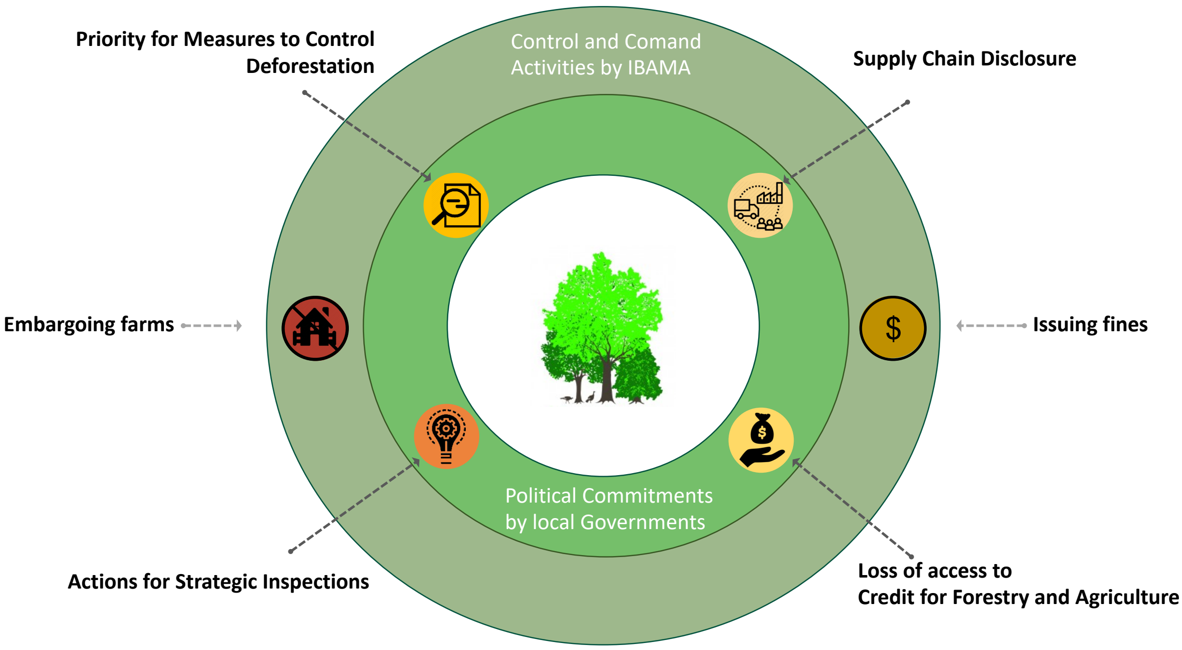
*Table IV.A.3: Descriptives Forest and Carbon*

| | Deforestation | Forest | Carbon Stock | Carbon Loss |
|---|---|---|---|---|
| Total | 162648.60 | 2873407 | 43.71 | 2.5 |
| Total 2002-2007 | 135986.30 | 2905376 | 44.23 | 1.93 |
| Total 2008-2013 | 26662.33 | 2828649 | 42.98 | 0.59 |
| | | | | |
| Prio | 82563.03 | 647261.30 | 8.55 | 1.07 |
| Prio 2002-2007 | 62995.50 | 668394.50 | 8.84 | 0.84 |
| Prio 2008-2013 | 19567.53 | 626128 | 8.24 | 0.23 |
| | | | | |
| Zones | 87516.84 | 2364519 | 35.70 | 1.27 |

*Table IV.A.4: Descriptives Prices*

| Variable | Total | Prio | Zone |
|---|---|---|---|
| PI agri 2002 | 1.10 | 1.07 | 1.11 |
| PI agri 2013 | 1.94 | 1.94 | 1.90 |
| PI agri 2002-2007 | 1.20 | 1.18 | 1.19 |
| PI agri 2008-2013 | 1.96 | 1.97 | 1.92 |

*Figure IV.A.8: Consequences for Municipalities Being on the Blacklist*



## Maps

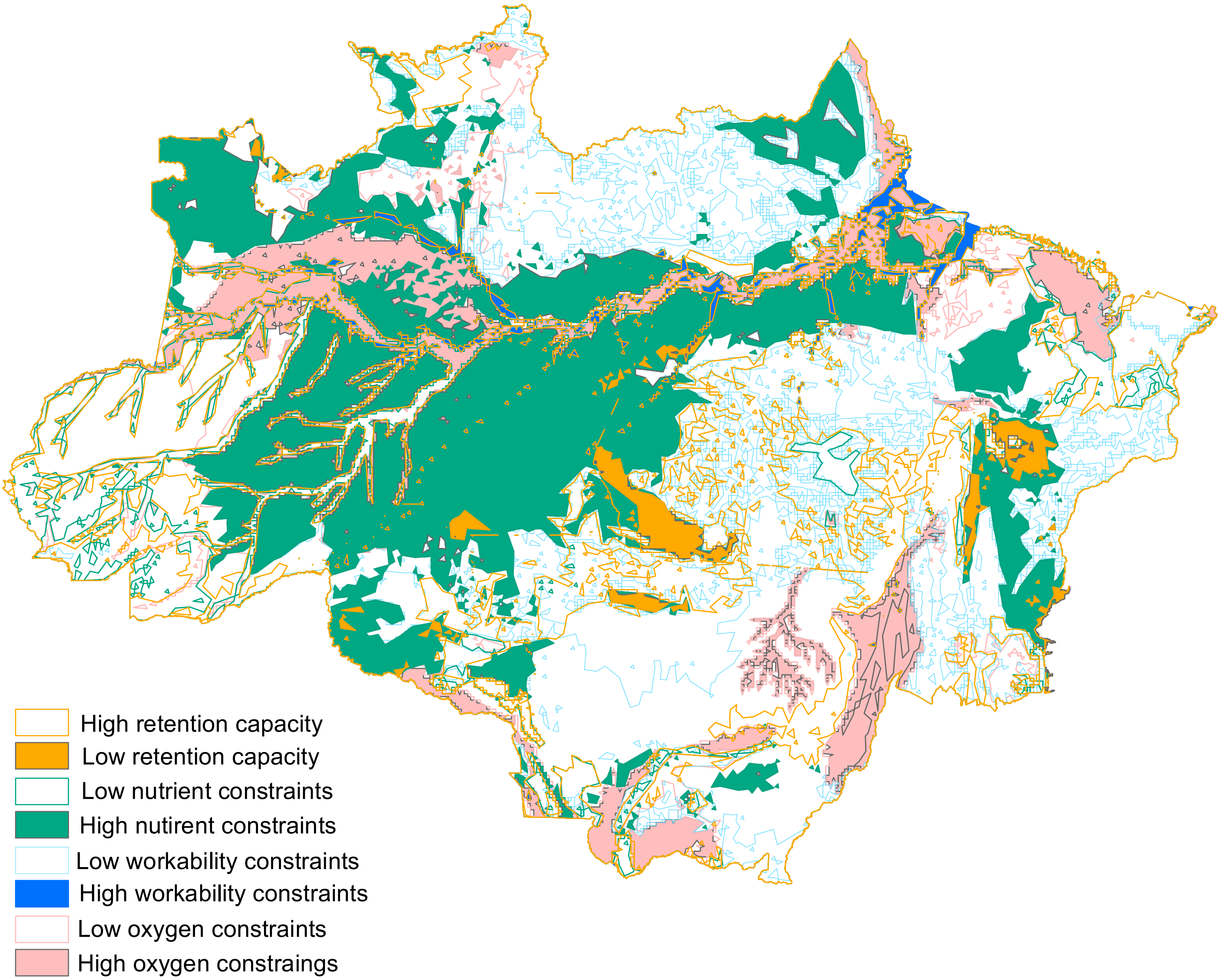



*Figure IV.A.9: FAO Soil Constraints*
Map shows FAO GAEZ soil constraints in the Brazilian Amazon for 4 types of soil quality measure: Retention capacity, nutrient, workability and oxygen

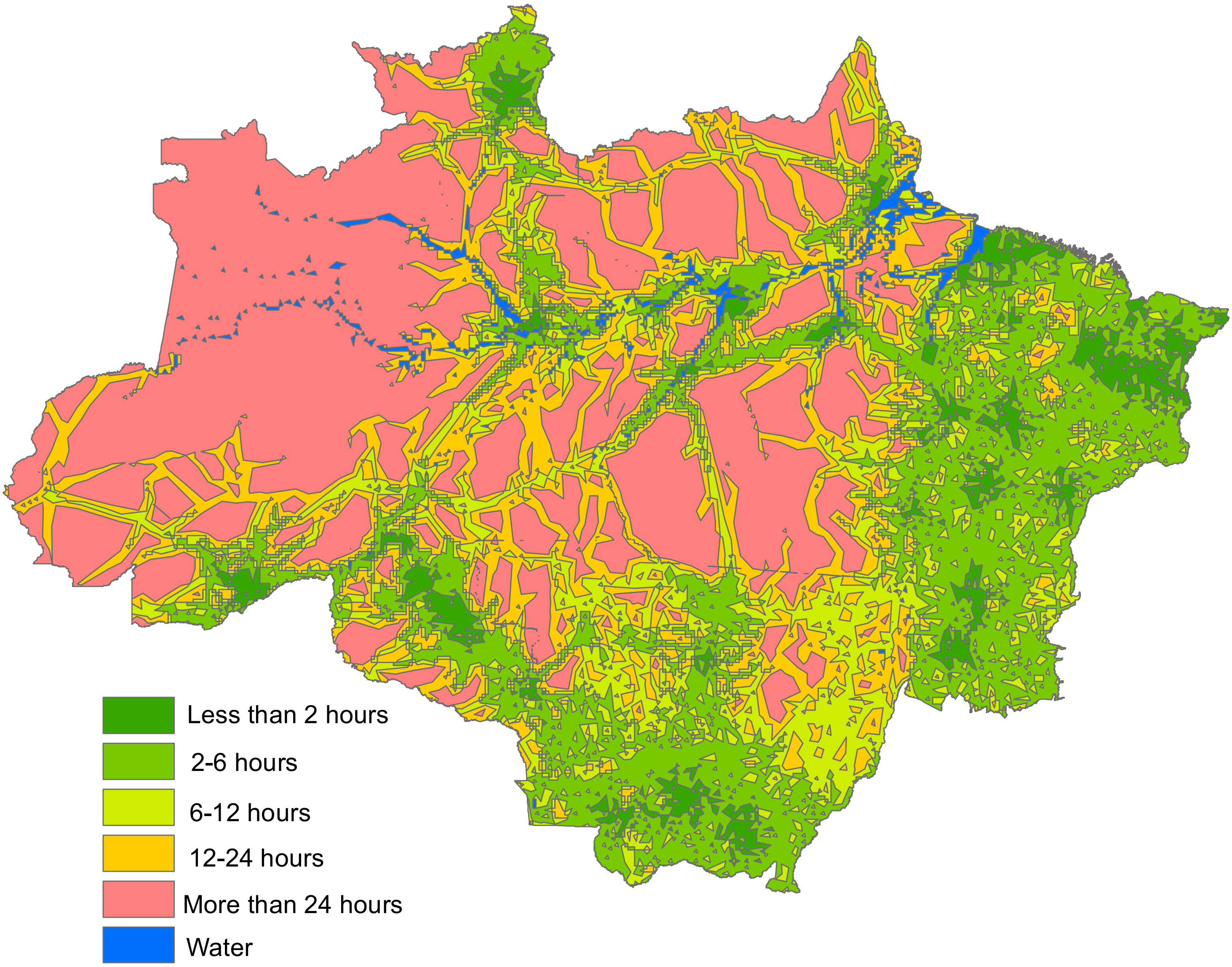



*Figure IV.A.10: FAO Access Measure*
Map shows limitation of access by FAO GAEZ in the Brazilian Amazon. Access is measured as average travel time from the closest city with more than 50,000 habitants.

# Additional Tables

## Soy Moratorium

*Table IV.A.5: Baseline with Soy Price Index*

| | (1)<br>Baseline 1 | (2)<br>Baseline 2 | (3)<br>Baseline 3 | (4)<br>Prio | (5)<br>Soy | (6)<br>CZs |
|---|---|---|---|---|---|---|
| L.PI ag | -0.674*** | -0.736*** | 2.154*** | 4.169*** | 3.358*** | 4.601*** |
| | (0.186) | (0.184) | (0.207) | (0.612) | (0.885) | (0.634) |
| L.PI ag x Ever x Active | | | | -0.621** | -0.165*** | 0.007 |
| | | | | (0.248) | (0.038) | (0.030) |
| L.PI ag x Ever | | | | 2.577*** | 0.255*** | -0.142 |
| | | | | (0.667) | (0.088) | (0.306) |
| L.Ever x Active | | | | | -0.061*** | 0.016** |
| | | | | | (0.016) | (0.007) |
| L.ln RF | | 0.267*** | 0.271*** | 0.275*** | 0.269*** | 0.250*** |
| | | (0.088) | (0.089) | (0.091) | (0.091) | (0.088) |
| L.PI ag x ln RF | | | -0.535*** | -0.521*** | -0.492*** | -0.552*** |
| | | | (0.034) | (0.041) | (0.040) | (0.039) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.34 | 0.36 | 0.39 | 0.38 | 0.38 |
| Total(mean) | | | | 3.06 | 0.55 | 1.21 |
| Total(p25) | | | | 4.02 | 1.46 | 2.23 |
| Total wo(mean) | | | -1.00 | 3.68 | 0.71 | 1.21 |
| Total wo(p25) | | | -0.01 | 4.64 | 1.62 | 2.23 |

Note: As table IV.2 but $PIag$ is substituted by the a weighted soy price index.

*Table IV.A.6: Baseline with Corn Price Index*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | -0.188 | -0.149 | 1.344*** | 7.143*** | 7.310*** | 7.537*** |
| | (0.115) | (0.114) | (0.164) | (1.498) | (1.508) | (1.509) |
| L.PI ag x Ever x Active | | | | -0.505* | 0.100*** | 0.075*** |
| | | | | (0.299) | (0.032) | (0.020) |
| L.PI ag x Ever | | | | 2.861*** | -0.071* | -0.045 |
| | | | | (0.656) | (0.038) | (0.172) |
| L.Ever x Active | | | | | -0.091*** | -0.005 |
| | | | | | (0.011) | (0.012) |
| L.ln RF | | 0.228*** | 0.560*** | 0.531*** | 0.575*** | 0.571*** |
| | | (0.083) | (0.102) | (0.100) | (0.103) | (0.097) |
| L.PI ag x ln RF | | | -0.273*** | -0.253*** | -0.275*** | -0.330*** |
| | | | (0.024) | (0.025) | (0.024) | (0.026) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.33 | 0.35 | 0.37 | 0.38 | 0.36 |
| Total(mean) | | | | 8.01 | 5.72 | 5.64 |
| Total(p25) | | | | 8.48 | 6.23 | 6.16 |
| Total wo(mean) | | | -0.26 | 8.52 | 5.62 | 5.55 |
| Total wo(p25) | | | 0.24 | 8.98 | 6.13 | 6.16 |

Note: As table IV.2 but $PIag$ is substituted by the a weighted soy price index.

*Table IV.A.7: Baseline with Agricultural Price Index excluding Soy*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.291*** | 0.317*** | 1.106*** | 0.828*** | 0.976*** | 1.166*** |
| | (0.089) | (0.088) | (0.091) | (0.095) | (0.095) | (0.101) |
| L.PI ag x Ever x Active | | | | -0.294*** | 0.050*** | 0.085*** |
| | | | | (0.088) | (0.019) | (0.018) |
| L.PI ag x Ever | | | | 1.535*** | -0.076*** | -0.058 |
| | | | | (0.274) | (0.023) | (0.114) |
| L.Ever x Active | | | | | -0.077*** | -0.091*** |
| | | | | | (0.018) | (0.026) |
| L.ln RF | | 0.255*** | 0.741*** | 0.699*** | 0.758*** | 0.787*** |
| | | (0.087) | (0.111) | (0.111) | (0.116) | (0.103) |
| L.PI ag x ln RF | | | -0.156*** | -0.144*** | -0.155*** | -0.204*** |
| | | | (0.010) | (0.011) | (0.010) | (0.012) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.33 | 0.37 | 0.39 | 0.39 | 0.40 |
| Total(mean) | | | | 1.22 | 0.04 | 0.01 |
| Total(p25) | | | | 1.48 | 0.32 | 0.28 |
| Total wo(mean) | | | 0.19 | 1.51 | -0.01 | -0.09 |
| Total wo(p25) | | | 0.48 | 1.78 | 0.27 | 0.28 |

Note: As table IV.2 but $PIag$ excludes the soy price.

## Conservation Zones

*Table IV.A.8: Including Zones' Area*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) PAs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.196** | 0.215** | 0.977*** | 0.941*** | 1.028*** | 1.368*** |
| | (0.089) | (0.087) | (0.090) | (0.095) | (0.092) | (0.100) |
| L.PI ag x Ever x Active | | | | -0.275*** | 0.020 | 0.089*** |
| | | | | (0.093) | (0.023) | (0.019) |
| L.PI ag x Ever | | | | 1.699*** | -0.029 | -0.002 |
| | | | | (0.398) | (0.024) | (0.123) |
| L.Ever x Active | | | | | -0.069*** | -0.092*** |
| | | | | | (0.026) | (0.028) |
| L.lfr_sum | | 0.243*** | 0.739*** | 0.678*** | 0.771*** | 0.794*** |
| | | (0.087) | (0.114) | (0.111) | (0.121) | (0.099) |
| L.PI ag x ln RF | | | -0.155*** | -0.137*** | -0.153*** | -0.213*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 7271 | 7271 | 7271 | 7271 | 7271 | 7271 |
| R-sq | 0.33 | 0.33 | 0.37 | 0.39 | 0.39 | 0.39 |
| Total mean | 0.20 | 0.22 | 0.05 | 1.66 | 0.23 | 0.19 |
| Total 25 | | | 0.34 | 1.92 | 0.52 | 0.49 |
| Total wo mean | | | | 1.93 | 0.21 | 0.08 |
| Total wo 25 | | | | 2.20 | 0.50 | 0.49 |

Note: As table IV.2 but includes also the area within conservation zones.

*Table IV.A.9: Inside Conservation Zones*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) PAs |
|---|---|---|---|---|---|---|
| L.PI ag | -0.185*** | -0.162*** | 0.165*** | 0.176** | 0.158 | 0.154* |
| | (0.060) | (0.060) | (0.062) | (0.086) | (0.097) | (0.084) |
| L.PI ag x Ever x Active | | | | -0.241** | -0.007 | -0.010 |
| | | | | (0.096) | (0.035) | (0.012) |
| L.PI ag x Ever | | | | 0.289 | 0.018 | 0.132 |
| | | | | (0.393) | (0.036) | (0.085) |
| L.Ever x Active | | | | | -0.004 | 0.006 |
| | | | | | (0.044) | (0.018) |
| L.lfr_sum | | 0.586** | 0.933*** | 0.919*** | 0.934*** | 0.926*** |
| | | (0.245) | (0.292) | (0.297) | (0.306) | (0.298) |
| L.PI ag x ln RF | | | -0.072*** | -0.067*** | -0.072*** | -0.074*** |
| | | | (0.008) | (0.007) | (0.008) | (0.010) |
| Observations | 3179 | 3179 | 3179 | 3179 | 3179 | 3179 |
| R-sq | 0.13 | 0.13 | 0.17 | 0.19 | 0.17 | 0.18 |
| Total mean | -0.18 | -0.16 | -0.21 | -0.10 | -0.18 | -0.12 |
| Total 25 | | | -0.06 | 0.06 | -0.01 | 0.05 |
| Total wo mean | | | | 0.14 | -0.18 | -0.10 |
| Total wo 25 | | | | 0.30 | 0.00 | 0.05 |

Note: As table IV.2 but includes only the area within conservation zones.

*Table IV.A.10: Including Only Indigenous Lands*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.180** | 0.200** | 0.981*** | 0.945*** | 1.025*** | 1.162*** |
| | (0.089) | (0.087) | (0.090) | (0.094) | (0.090) | (0.098) |
| L.PI ag x Ever x Active | | | | -0.275*** | 0.019 | 0.025 |
| | | | | (0.093) | (0.023) | (0.029) |
| L.PI ag x Ever | | | | 1.735*** | -0.027 | 0.173 |
| | | | | (0.398) | (0.024) | (0.143) |
| L.Ever x Active | | | | | -0.069*** | -0.011 |
| | | | | | (0.026) | (0.047) |
| L.ln RF | | 0.239*** | 0.745*** | 0.686*** | 0.775*** | 0.759*** |
| | | (0.085) | (0.112) | (0.109) | (0.119) | (0.106) |
| L.PI ag x ln RF | | | -0.160*** | -0.143*** | -0.158*** | -0.181*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 7271 | 7271 | 7271 | 7271 | 7271 | 7271 |
| R-sq | 0.33 | 0.33 | 0.38 | 0.39 | 0.40 | 0.39 |
| Total(mean) | | | | 1.55 | 0.08 | 0.27 |
| Total(p25) | | | | 1.82 | 0.37 | 0.59 |
| Total wo(mean) | | | 0.03 | 1.83 | 0.06 | 0.25 |
| Total wo(p25) | | | 0.33 | 2.09 | 0.35 | 0.59 |

Note: As table IV.2 takes indigenous lands as the only type conservation zone. Other types of conservation zones are not considered as part of the policy.

*Table IV.A.11: Including Only Sustainable Use Zones*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.188** | 0.207** | 0.978*** | 0.941*** | 1.024*** | 1.237*** |
| | (0.090) | (0.088) | (0.091) | (0.095) | (0.092) | (0.103) |
| L.PI ag x Ever x Active | | | | -0.276*** | 0.020 | 0.075*** |
| | | | | (0.093) | (0.022) | (0.028) |
| L.PI ag x Ever | | | | 1.721*** | -0.029 | -0.011 |
| | | | | (0.392) | (0.024) | (0.188) |
| L.Ever x Active | | | | | -0.069*** | -0.072** |
| | | | | | (0.026) | (0.037) |
| L.ln RF | | 0.243*** | 0.742*** | 0.682*** | 0.772*** | 0.760*** |
| | | (0.086) | (0.112) | (0.109) | (0.119) | (0.105) |
| L.PI ag x ln RF | | | -0.156*** | -0.140*** | -0.155*** | -0.183*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.33 | 0.37 | 0.39 | 0.39 | 0.38 |
| Total(mean) | | | | 1.55 | 0.09 | 0.19 |
| Total(p25) | | | | 1.82 | 0.38 | 0.48 |
| Total wo(mean) | | | 0.05 | 1.83 | 0.07 | 0.14 |
| Total wo(p25) | | | 0.34 | 2.09 | 0.36 | 0.48 |

Note: As table IV.2 takes sustainable-use zones as the only type conservation zone. Other types of conservation zones are not considered as part of the policy.

*Table IV.A.12: Including Only Strictly Protected Zones*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.194** | 0.213** | 0.976*** | 0.945*** | 1.031*** | 1.196*** |
| | (0.089) | (0.088) | (0.091) | (0.095) | (0.092) | (0.097) |
| L.PI ag x Ever x Active | | | | -0.274*** | 0.021 | 0.032* |
| | | | | (0.094) | (0.023) | (0.019) |
| L.PI ag x Ever | | | | 1.706*** | -0.030 | -0.048*** |
| | | | | (0.401) | (0.024) | (0.007) |
| L.Ever x Active | | | | | -0.070*** | -0.019 |
| | | | | | (0.026) | (0.029) |
| L.ln RF | | 0.244*** | 0.741*** | 0.680*** | 0.772*** | 0.786*** |
| | | (0.087) | (0.114) | (0.110) | (0.121) | (0.119) |
| L.PI ag x ln RF | | | -0.155*** | -0.138*** | -0.154*** | -0.163*** |
| | | | (0.010) | (0.010) | (0.010) | (0.010) |
| Observations | 7271 | 7271 | 7271 | 7271 | 7271 | 7271 |
| R-sq | 0.33 | 0.33 | 0.37 | 0.39 | 0.39 | 0.39 |
| Total(mean) | | | | 1.55 | 0.10 | 0.18 |
| Total(p25) | | | | 1.81 | 0.39 | 0.48 |
| Total wo(mean) | | | 0.05 | 1.82 | 0.08 | 0.17 |
| Total wo(p25) | | | 0.34 | 2.08 | 0.37 | 0.48 |

Note: As table IV.2 takes strictly protected zones as the only type conservation zone. Other types of conservation zones are not considered as part of the policy.

## Threats to identification

### Non-random policy assignment

*Table IV.A.13: Testing for Different Pre-trends*

| | (1) Deforestation | (2) Forest | (3) Labour | (4) Wage | (5) GDP | (6) Mining | (7) Zone | (8) A.Area | (9) A.Value | (10) Product. | (11) Soy V. | (12) Logs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prio | -0.006 | 0.001 | -0.035* | -0.006 | 0.008 | -0.010 | 0.013 | 0.033 | 0.022 | 0.004 | 0.137 | 0.044 |
| | (0.029) | (0.004) | (0.018) | (0.007) | (0.008) | (0.010) | (0.058) | (0.039) | (0.037) | (0.010) | (0.089) | (0.051) |
| Observations | 3,960 | 3,960 | 3,960 | 3,954 | 3,960 | 3,960 | 3,960 | 3,960 | 3,960 | 3,960 | 3,960 | |
| Soy | 0.048* | 0.010*** | -0.036* | 0.013 | 0.051*** | -0.013 | -0.068*** | 0.298*** | 0.261*** | 0.008 | 1.239*** | -0.044 |
| | (0.026) | (0.004) | (0.021) | (0.009) | (0.007) | (0.010) | (0.026) | (0.037) | (0.037) | (0.006) | (0.078) | (0.065) |
| Observations | 2,640 | 2,640 | 2,640 | 2,640 | 2,634 | 2,640 | 2,640 | 2,640 | 2,640 | 2,640 | 2,640 | 2,640 |
| CZ | 0.116 | 0.015* | 0.061 | 0.015 | -0.003 | -0.003 | 0.056** | 0.001 | -0.070 | -0.030** | -0.191* | -0.125 |
| | (0.102) | (0.008) | (0.045) | (0.022) | (0.010) | (0.004) | (0.026) | (0.041) | (0.044) | (0.012) | (0.104) | (0.092) |
| Observations | 660 | 660 | 660 | 660 | 660 | 660 | 660 | 660 | 660 | 660 | 660 | 660 |

Note: The independent variable is an interaction between the a dummy that becomes one if a municipality is ever affected by the studied policy and a trend variable (*Trend x Treated*). The observation period here is the pre-policy period, years before the policy was established. Note that fo the municipalities with conservation zones the year 2005 is the threshold for the policy to be implemented since most zones were implemented in 2006 or later. The dependent variables are: *Forest* left forest cover in a municipality; *labour* number of workers employed; *wage* average wage paid; *GDP* GDP per capita; *mining* area occupied by mines or mining activity; *A.Area* area used for the plantation of agricultural goods; *A.value* monetary value generated by cultivation of crops; *Productivity* average productivity in the production of crops (kg per ha); *soy v.* monetary value generated by the production of soybeans; *logs* quantity of logs produced in $m^3$.

*Table IV.A.14: Interaction between Continuous Treatment and Time Dummies*

| | (1)<br>Soy | (2)<br>Soy | (3)<br>CZs | (4)<br>CZs |
|---|---|---|---|---|
| L.PI ag | 0.847*** | 0.923*** | 0.980*** | 0.983*** |
| | (0.079) | (0.077) | (0.095) | (0.091) |
| L.PI ag x Ever x Active | 0.016 | 0.015 | 0.059*** | 0.066*** |
| | (0.022) | (0.022) | (0.008) | (0.008) |
| L.PI ag x Ever | 0.001 | -0.023 | -0.058 | 0.016 |
| | (0.036) | (0.024) | (0.565) | (0.259) |
| L.Ever x Active | | -0.065*** | | -0.086*** |
| | | (0.024) | | (0.018) |
| L.ln RF | 0.790*** | 0.800*** | 0.778*** | 0.774*** |
| | (0.125) | (0.125) | (0.107) | (0.105) |
| L.PI ag x ln RF | -0.154*** | -0.153*** | -0.188*** | -0.191*** |
| | (0.009) | (0.009) | (0.010) | (0.010) |
| Observations | 7260 | 7260 | 7260 | 7260 |
| Municipalities | 660 | 660 | 660 | 660 |
| R-sq | 0.40 | 0.39 | 0.38 | 0.38 |
| Total mean | -0.03 | 0.01 | 0.04 | 0.04 |
| Total 25 | 0.26 | 0.34 | 0.40 | 0.41 |
| Total wo mean | -0.06 | -0.01 | -0.13 | -0.14 |
| Total wo 25 | 0.24 | 0.32 | 0.24 | 0.23 |

Note: Standard errors are clustered at the municipality level. Variables not shown include municipality fixed effects, year fixed effects and, in column 1 and 3, interaction between year fixed effects and the "ever-treated" variable, i.e. ln (soy area in 2005) in the case of Soy and mean expansion of conservation zones in the case of CZs. Note that these "ever" variables are continuous and give treatment intensity, in contrast to the ever-dummy in the case of the priority list. Column 2 and 4 present our standard specification, where "ever" x "treated" represents the policy directly instead of "ever" interacted with the time dummies.

## Alternative Specifications

*Table IV.A.15: Baseline: Without Controls for Remaining Forest*

| | (1)<br>Baseline 1 | (2)<br>Prio | (3)<br>Soy | (4)<br>CZs |
|---|---|---|---|---|
| L.PI ag | 0.170* | 0.246*** | 0.238*** | 0.302*** |
| | (0.089) | (0.090) | (0.088) | (0.095) |
| L.PI ag x Ever x Active | | -0.298*** | 0.031 | 0.045** |
| | | (0.093) | (0.022) | (0.021) |
| L.PI ag x Ever | | 1.265*** | -0.045* | -0.335** |
| | | (0.397) | (0.025) | (0.132) |
| L.Ever x Active | | | -0.077*** | -0.033 |
| | | | (0.025) | (0.030) |
| Observations | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.36 | 0.35 | 0.33 |
| Total(mean) | | 1.21 | 0.22 | 0.02 |
| Total wo(mean) | | 1.51 | 0.19 | -0.03 |

Note: As table IV.2 but without including remaining forest cover and the interaction of remaining forest cover with the price index ($PI\ ag \times RF$) into the regression

*Table IV.A.16: Baseline: Deforestation in % of Remaining Forest*

| | (1) Baseline 1 | (2) Prio | (3) Soy | (4) CZs |
|---|---|---|---|---|
| L.PI ag | 1.956*** | 1.460** | 1.590** | 1.730*** |
| | (0.626) | (0.637) | (0.710) | (0.652) |
| L.PI ag x Ever x Active | | -0.336* | 0.050 | 0.238*** |
| | | (0.185) | (0.120) | (0.050) |
| L.PI ag x Ever | | -1.115 | -0.152 | -1.410** |
| | | (0.998) | (0.139) | (0.561) |
| L.Ever x Active | | | -0.061 | -0.106 |
| | | | (0.135) | (0.065) |
| Observations | 7260 | 7260 | 7282 | 7260 |
| R-sq | 0.06 | 0.06 | 0.06 | 0.07 |
| Total(mean) | | 0.01 | 1.49 | 0.60 |
| Total(p25) | | 0.35 | 1.44 | 0.32 |

Note: As table IV.2 but dependent variable is deforestation in % of forest cover of the previous period.

*Table IV.A.17: Baseline deforestation in % of municipal area*

| | (1) Baseline 1 | (2) Baseline 3 | (3) Prio | (4) Soy | (5) CZs |
|---|---|---|---|---|---|
| L.PI ag | 0.170* | 1.343*** | 1.062*** | 1.188*** | 2.227*** |
| | (0.089) | (0.179) | (0.180) | (0.175) | (0.204) |
| L.PI ag x Ever x Active | | | -0.283*** | 0.029 | 0.090*** |
| | | | (0.095) | (0.023) | (0.020) |
| L.PI ag x Ever | | | 1.462*** | -0.029 | -0.165 |
| | | | (0.401) | (0.025) | (0.124) |
| L.Ever x Active | | | | -0.078*** | -0.088*** |
| | | | | (0.025) | (0.029) |
| L.PI ag x ln Area | | -0.160*** | -0.113*** | -0.133*** | -0.263*** |
| | | (0.022) | (0.022) | (0.022) | (0.025) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.34 | 0.36 | 0.36 | 0.36 |
| Total(mean) | | | 1.35 | 0.13 | 0.08 |
| Total(p25) | | | 1.46 | 0.27 | 0.25 |
| Total wo(mean) | | 0.07 | 1.63 | 0.10 | -0.02 |
| Total wo(p25) | | 0.24 | 1.75 | 0.24 | 0.25 |

Note: As table IV.2 but with deforestation in percent of the entire municipal area.

*Table IV.A.18: Inverse Hyperbolic Sine of Deforestation*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.250** | 0.277*** | 1.037*** | 0.928*** | 1.015*** | 1.079*** |
| | (0.101) | (0.099) | (0.101) | (0.097) | (0.091) | (0.103) |
| L.PI ag x Ever x Active | | | | -0.297*** | 0.005 | 0.073*** |
| | | | | (0.095) | (0.023) | (0.009) |
| L.PI ag x Ever | | | | 1.709*** | -0.014 | 0.010 |
| | | | | (0.382) | (0.026) | (0.291) |
| L.Ever x Active | | | | | -0.056** | -0.093*** |
| | | | | | (0.026) | (0.020) |
| L.ln RF | | 0.318*** | 0.831*** | 0.789*** | 0.877*** | 0.850*** |
| | | (0.107) | (0.136) | (0.135) | (0.145) | (0.122) |
| L.PI ag x ln RF | | | -0.158*** | -0.145*** | -0.157*** | -0.199*** |
| | | | (0.011) | (0.011) | (0.010) | (0.011) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| Municipalities | 660 | 660 | 660 | 660 | 660 | 660 |
| R-sq | 0.32 | 0.32 | 0.35 | 0.36 | 0.37 | 0.37 |
| Total mean | | | | 1.49 | 0.08 | 0.11 |
| Total 25 | | | | 1.77 | 0.40 | 0.49 |
| Total wo mean | | | 0.11 | 1.78 | 0.07 | -0.09 |
| Total wo 25 | | | 0.41 | 2.07 | 0.39 | 0.29 |

Note: As table IV.2, but dependent variable is the inverse hyperbolic sine of deforestation. This allows us to include municipality-years with zero deforestation without adding 1 before taking logs.

*Table IV.A.19: Price Index Weighted by Mean Area Planted*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) PAs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.430*** | 0.449*** | 1.080*** | 1.036*** | 0.964*** | 1.436*** |
| | (0.100) | (0.098) | (0.096) | (0.101) | (0.094) | (0.105) |
| L.PI ag x Ever x Active | | | | -0.316*** | -0.142*** | 0.080*** |
| | | | | (0.089) | (0.037) | (0.018) |
| L.PI ag x Ever | | | | 1.940*** | 0.129*** | -0.002 |
| | | | | (0.576) | (0.038) | (0.121) |
| L.Ever x Active | | | | | 0.124*** | -0.080*** |
| | | | | | (0.044) | (0.026) |
| L.PI ag x ln RF | | | -0.151*** | -0.131*** | -0.151*** | -0.205*** |
| | | | (0.009) | (0.010) | (0.009) | (0.011) |
| L.ln RF | | 0.260*** | 0.753*** | 0.679*** | 0.782*** | 0.792*** |
| | | (0.088) | (0.118) | (0.113) | (0.124) | (0.102) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.32 | 0.33 | 0.37 | 0.39 | 0.39 | 0.39 |
| Total(mean) | | | | 1.89 | 0.06 | 0.33 |
| Total(p25) | | | | 2.14 | 0.35 | 0.63 |
| Total wo(mean) | | | 0.19 | 2.21 | 0.20 | 0.23 |
| Total wo(p25) | | | 0.49 | 2.46 | 0.50 | 0.63 |

Note: As table IV.2 but the price index is weighted by the average planted area for a crop over the whole period. This weights are aggregated as in the main specification with initial weights.

*Table IV.A.20: Price Index Weighted by Potential Yield*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.191*** | 0.186*** | 0.764*** | 0.879*** | 0.994*** | 1.110*** |
| | (0.050) | (0.051) | (0.083) | (0.143) | (0.158) | (0.155) |
| L.PI ag x Ever x Active | | | | -0.323*** | 0.021 | 0.060*** |
| | | | | (0.071) | (0.016) | (0.018) |
| L.PI ag x Ever | | | | 1.158** | -0.040** | 0.028 |
| | | | | (0.478) | (0.018) | (0.122) |
| L.Ever x Active | | | | | -0.070*** | -0.074** |
| | | | | | (0.026) | (0.031) |
| L.ln RF | | 0.232*** | 0.657*** | 0.714*** | 0.813*** | 0.850*** |
| | | (0.084) | (0.116) | (0.126) | (0.137) | (0.122) |
| L.PI ag x ln RF | | | -0.117*** | -0.128*** | -0.143*** | -0.195*** |
| | | | (0.010) | (0.013) | (0.012) | (0.014) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.33 | 0.33 | 0.36 | 0.39 | 0.39 | 0.39 |
| Total(mean) | | | | 0.96 | 0.13 | 0.06 |
| Total(p25) | | | | 1.20 | 0.40 | 0.35 |
| Total wo(mean) | | | 0.07 | 1.28 | 0.11 | -0.01 |
| Total wo(p25) | | | 0.29 | 1.52 | 0.38 | 0.35 |

Note: As table IV.2 but potential yields weighting. The price index is contructed analogously to the price index with initial price index as described in section IV.2 but uses the share of potential yields for 7 crops; Rice, Soybeans, Corn, Sugar cane, Banana, Citrus fruits and Cotton. Potential Yields are defined as the total production capacity (t/ha) and are available at the FAO GAEZ data base on a pixel level. We aggregated the pixel information on the municipality level with a GIS software.

## Correlation across Policies

*Table IV.A.21: Overlapping of Policies*

| | (1) Prio Soy | (2) Prio CZs | (3) Soy CZs | (4) All |
|---|---|---|---|---|
| L.PI ag | 0.972*** | 1.242*** | 1.229*** | 1.177*** |
| | (0.091) | (0.099) | (0.094) | (0.094) |
| L.PI ag x Ever x Active (Prio) | -0.218*** | -0.226*** | | -0.228*** |
| | (0.068) | (0.069) | | (0.066) |
| L.PI ag x Ever x Active (Soy) | 0.022 | | 0.020 | 0.021 |
| | (0.022) | | (0.021) | (0.021) |
| L.PI ag x Ever x Active (Zones) | | 0.080*** | 0.069*** | 0.070*** |
| | | (0.019) | (0.019) | (0.019) |
| L.PI ag x Ever (Prio) | 0.151 | 0.107 | | 0.195 |
| | (0.171) | (0.163) | | (0.158) |
| L.PI ag x Ever (Soy) | -0.026 | | -0.022 | -0.020 |
| | (0.024) | | (0.023) | (0.023) |
| L.Ever x Active (Soy) | -0.072*** | | -0.067*** | -0.069*** |
| | (0.026) | | (0.024) | (0.024) |
| L.Ever x Active (Zone) | | -0.081*** | -0.071*** | -0.073*** |
| | | (0.028) | (0.027) | (0.027) |
| L.ln RF | 0.745*** | 0.741*** | 0.809*** | 0.777*** |
| | (0.115) | (0.096) | (0.106) | (0.105) |
| L.PI ag x ln RF | -0.149*** | -0.191*** | -0.199*** | -0.188*** |
| | (0.010) | (0.011) | (0.010) | (0.011) |
| L.PI ag x Ever(Zones) | | -0.054 | -0.017 | -0.024 |
| | | (0.115) | (0.112) | (0.111) |
| Observations | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.40 | 0.40 | 0.41 | 0.41 |
| Total mean | 0.09 | 0.21 | -0.03 | -0.05 |
| Total 25 | 0.36 | 0.56 | 0.34 | 0.30 |
| Total wo mean | 0.10 | 0.12 | 0.05 | 0.26 |
| Total wo 25 | 0.37 | 0.47 | 0.42 | 0.61 |

Note: As table IV.2 but the price index is weighted by the average planted area for a crop over the whole period. This weights are aggregated as in the main specification with initial weights.

### Geographical Characteristics and Spatial Autocorrelation

*Table IV.A.22: Priority List: Time invariant Soil quality and Access Measures*

| | (1) nutrient1 | (2) nutrient2 | (3) oxygen | (4) roots | (5) workability | (6) access |
|---|---|---|---|---|---|---|
| L.PI ag | 0.721*** | 0.597*** | 0.812*** | 0.776*** | 0.695*** | 0.689*** |
| | (0.132) | (0.113) | (0.094) | (0.091) | (0.091) | (0.105) |
| L.PI ag x Active x Post | -0.269*** | -0.266*** | -0.267*** | -0.289*** | -0.288*** | -0.286*** |
| | (0.093) | (0.093) | (0.093) | (0.092) | (0.092) | (0.094) |
| L.ln RF | 0.707*** | 0.710*** | 0.714*** | 0.763*** | 0.762*** | 0.740*** |
| | (0.105) | (0.101) | (0.102) | (0.094) | (0.095) | (0.095) |
| L.PI ag x ln RF | -0.158*** | -0.163*** | -0.173*** | -0.173*** | -0.171*** | -0.197*** |
| | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.012) |
| L.PI ag x characteristic | 0.100** | 0.174*** | 0.187*** | 0.192*** | 0.212*** | 0.224*** |
| | (0.041) | (0.036) | (0.027) | (0.025) | (0.028) | (0.038) |
| L.PI ag x Ever | 1.736*** | 1.781*** | 1.834*** | 1.710*** | 1.681*** | 1.712*** |
| | (0.401) | (0.396) | (0.394) | (0.410) | (0.408) | (0.409) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.40 | 0.40 | 0.41 | 0.40 | 0.40 |
| Total (mean) | 1.26 | 1.15 | 1.36 | 1.18 | 1.08 | 0.96 |
| Total (p25) | 1.55 | 1.45 | 1.68 | 1.50 | 1.40 | 1.32 |
| Total wo (mean) | 1.53 | 1.42 | 1.63 | 1.47 | 1.37 | 1.24 |
| Total wo (p25) | 1.82 | 1.72 | 1.95 | 1.79 | 1.68 | 1.61 |

Note: As column 4 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The mean of the time-invariant characteristics is used in the calculations of the total effect.

*Table IV.A.23: Soy Moratorium: Time invariant Soil Quality and Access Measures*

| | (1) nutrient1 | (2) nutrient2 | (3) oxygen | (4) roots | (5) workability | (6) access |
|---|---|---|---|---|---|---|
| L.PI ag | 0.750*** | 0.658*** | 0.888*** | 0.847*** | 0.786*** | 0.749*** |
| | (0.130) | (0.112) | (0.092) | (0.089) | (0.091) | (0.101) |
| L.PI ag x Active | 0.022 | 0.023 | 0.024 | 0.024 | 0.023 | 0.021 |
| | (0.022) | (0.022) | (0.022) | (0.022) | (0.022) | (0.022) |
| L.Ever x Active | -0.071*** | -0.072*** | -0.072*** | -0.071*** | -0.071*** | -0.070*** |
| | (0.026) | (0.025) | (0.025) | (0.025) | (0.025) | (0.026) |
| L.ln RF | 0.794*** | 0.789*** | 0.787*** | 0.828*** | 0.828*** | 0.827*** |
| | (0.114) | (0.110) | (0.111) | (0.103) | (0.104) | (0.104) |
| L.PI ag x ln RF | -0.173*** | -0.175*** | -0.182*** | -0.182*** | -0.181*** | -0.212*** |
| | (0.010) | (0.010) | (0.010) | (0.010) | (0.010) | (0.012) |
| L.PI ag x characteristic | 0.120*** | 0.180*** | 0.175*** | 0.176*** | 0.186*** | 0.238*** |
| | (0.040) | (0.036) | (0.026) | (0.024) | (0.028) | (0.037) |
| L.PI ag x Ever | -0.032 | -0.033 | -0.030 | -0.026 | -0.023 | -0.032 |
| | (0.024) | (0.024) | (0.024) | (0.024) | (0.024) | (0.024) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.40 | 0.40 | 0.40 | 0.41 | 0.41 | 0.40 |
| Total (mean) | -0.28 | -0.38 | -0.19 | -0.22 | -0.28 | -0.51 |
| Total (p25) | 0.04 | -0.06 | 0.15 | 0.11 | 0.05 | -0.12 |
| Total wo (mean) | -0.30 | -0.40 | -0.21 | -0.25 | -0.30 | -0.53 |
| Total wo (p25) | 0.02 | -0.08 | 0.12 | 0.09 | 0.03 | -0.14 |

Note: As column 5 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The mean of the time-invariant characteristics is used in the calculations of the total effect.

*Table IV.A.24: CZs: Time invariant Soil Quality and Access Measures*

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | nutrient1 | nutrient2 | oxygen | roots | workability | access |
| L.PI ag | 1.156*** | 0.976*** | 1.150*** | 1.095*** | 1.033*** | 1.094*** |
| | (0.138) | (0.121) | (0.101) | (0.096) | (0.096) | (0.115) |
| L.PI ag x Ever x Active | 0.076*** | 0.074*** | 0.067*** | 0.070*** | 0.074*** | 0.078*** |
| | (0.020) | (0.019) | (0.019) | (0.020) | (0.020) | (0.019) |
| L.Ever x Active | -0.077*** | -0.075*** | -0.063** | -0.070** | -0.074*** | -0.078*** |
| | (0.029) | (0.028) | (0.028) | (0.029) | (0.029) | (0.028) |
| L.ln RF | 0.786*** | 0.787*** | 0.784*** | 0.828*** | 0.834*** | 0.805*** |
| | (0.097) | (0.094) | (0.095) | (0.088) | (0.088) | (0.091) |
| L.PI ag x ln RF | -0.211*** | -0.215*** | -0.219*** | -0.220*** | -0.221*** | -0.234*** |
| | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.012) |
| L.PI ag x characteristic | 0.059 | 0.148*** | 0.155*** | 0.175*** | 0.197*** | 0.155*** |
| | (0.040) | (0.036) | (0.027) | (0.024) | (0.027) | (0.040) |
| L.PI ag x Ever | -0.037 | -0.027 | -0.041 | -0.065 | -0.076 | -0.105 |
| | (0.117) | (0.114) | (0.114) | (0.117) | (0.118) | (0.117) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.40 | 0.40 | 0.41 | 0.41 | 0.40 |
| Total (mean) | 0.06 | -0.06 | 0.09 | 0.06 | 0.01 | -0.04 |
| Total (p25) | 0.45 | 0.34 | 0.50 | 0.46 | 0.42 | 0.39 |
| Total wo (mean) | -0.03 | -0.14 | 0.02 | -0.02 | -0.07 | -0.13 |
| Total wo (p25) | 0.36 | 0.25 | 0.42 | 0.38 | 0.34 | 0.30 |

Note: As column 6 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The mean of the time-invariant characteristics is used in the calculations of the total effect.

*Table IV.A.25: Priority List: States and the Forest Frontier*

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | PA | MA | MT | RO | TO | RR | AC | AM | AP | Old | New |
| L.PI ag | 0.951*** | 0.595*** | 1.071*** | 0.957*** | 0.903*** | 0.953*** | 0.981*** | 1.092*** | 0.959*** | 1.292*** | 0.970*** |
| | (0.094) | (0.098) | (0.091) | (0.094) | (0.100) | (0.094) | (0.095) | (0.104) | (0.095) | (0.116) | (0.101) |
| L.PI ag x Active x Post | -0.274*** | -0.263*** | -0.253*** | -0.260*** | -0.275*** | -0.272*** | -0.273*** | -0.268*** | -0.274*** | -0.271*** | -0.273*** |
| | (0.094) | (0.089) | (0.082) | (0.093) | (0.093) | (0.094) | (0.094) | (0.092) | (0.093) | (0.093) | (0.093) |
| L.ln RF | 0.693*** | 0.702*** | 0.726*** | 0.674*** | 0.674*** | 0.695*** | 0.710*** | 0.711*** | 0.695*** | 0.749*** | 0.703*** |
| | (0.109) | (0.115) | (0.116) | (0.107) | (0.104) | (0.106) | (0.106) | (0.101) | (0.107) | (0.097) | (0.106) |
| L.PI ag x ln RF | -0.147*** | -0.113*** | -0.140*** | -0.136*** | -0.142*** | -0.149*** | -0.156*** | -0.165*** | -0.148*** | -0.166*** | -0.152*** |
| | (0.011) | (0.011) | (0.010) | (0.010) | (0.011) | (0.010) | (0.011) | (0.012) | (0.010) | (0.010) | (0.012) |
| L.PI ag x characteristic | -0.016 | 0.489*** | -0.586*** | -0.567*** | 0.110** | 0.371*** | 0.464*** | 0.655*** | 0.177 | -0.349*** | 0.051 |
| | (0.075) | (0.053) | (0.068) | (0.069) | (0.051) | (0.116) | (0.131) | (0.125) | (0.168) | (0.059) | (0.087) |
| L.PI ag x Ever | 1.771*** | 1.767*** | 1.906*** | 1.712*** | 1.773*** | 1.767*** | 1.815*** | 1.811*** | 1.775*** | 1.725*** | 1.761*** |
| | (0.397) | (0.375) | (0.363) | (0.397) | (0.395) | (0.400) | (0.396) | (0.392) | (0.397) | (0.410) | (0.398) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.40 | 0.41 | 0.40 | 0.39 | 0.39 | 0.39 | 0.40 | 0.39 | 0.40 | 0.39 |
| Total (mean) | 1.58 | 1.44 | 1.90 | 1.61 | 1.57 | 1.57 | 1.60 | 1.66 | 1.59 | 1.77 | 1.56 |
| Total (p25) | 1.85 | 1.64 | 2.16 | 1.86 | 1.83 | 1.84 | 1.89 | 1.97 | 1.86 | 2.07 | 1.84 |
| Total wo (mean) | 1.86 | 1.70 | 2.15 | 1.87 | 1.84 | 1.84 | 1.88 | 1.93 | 1.86 | 2.04 | 1.84 |
| Total wo (p25) | 2.13 | 1.91 | 2.41 | 2.12 | 2.10 | 2.12 | 2.16 | 2.24 | 2.13 | 2.34 | 2.12 |

Note: As column 6 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The value 1 is used for the time-invariant characteristic dummy in the calculations of the total effect (the effect is for the state or arc in question). The headings are defined as following: *PA* State of Pará, *MA* State of Maranhão, *MT* State of Mato Grosso, *RO* state of Rôndonia, *TO* State of Tocantis, *RR* State of Roraima, *AC* State of Acre, *AM* state of Amazonia, *AP* State of Amapá, *Old* old agricultural frontier, *New* new agricultural frontier.

*Table IV.A.26: Soy Moratorium: States and the forest frontier*

| | (1)<br>PA | (2)<br>MA | (3)<br>MT | (4)<br>RO | (5)<br>TO | (6)<br>RR | (7)<br>AC | (8)<br>AM | (9)<br>AP | (10)<br>Old | (11)<br>New |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L.PI ag | 1.300*** | 0.953*** | 1.354*** | 1.290*** | 1.250*** | 1.304*** | 1.325*** | 1.382*** | 1.303*** | 1.535*** | 1.278*** |
| | (0.100) | (0.100) | (0.095) | (0.100) | (0.105) | (0.100) | (0.100) | (0.104) | (0.100) | (0.118) | (0.104) |
| L.PI ag x Ever x Active | 0.080*** | 0.081*** | 0.067*** | 0.072*** | 0.079*** | 0.080*** | 0.079*** | 0.074*** | 0.080*** | 0.061*** | 0.084*** |
| | (0.019) | (0.019) | (0.019) | (0.019) | (0.019) | (0.020) | (0.019) | (0.020) | (0.020) | (0.020) | (0.020) |
| L.Ever x Active | -0.080*** | -0.082*** | -0.066** | -0.071** | -0.079*** | -0.080*** | -0.078*** | -0.074*** | -0.080*** | -0.058** | -0.085*** |
| | (0.028) | (0.028) | (0.028) | (0.028) | (0.028) | (0.029) | (0.028) | (0.029) | (0.029) | (0.029) | (0.029) |
| L.ln RF | 0.776*** | 0.785*** | 0.786*** | 0.765*** | 0.757*** | 0.781*** | 0.789*** | 0.783*** | 0.781*** | 0.817*** | 0.768*** |
| | (0.100) | (0.106) | (0.106) | (0.099) | (0.095) | (0.098) | (0.097) | (0.095) | (0.098) | (0.092) | (0.099) |
| L.PI ag x ln RF | -0.205*** | -0.171*** | -0.186*** | -0.195*** | -0.200*** | -0.206*** | -0.212*** | -0.213*** | -0.206*** | -0.216*** | -0.198*** |
| | (0.011) | (0.011) | (0.010) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.012) |
| L.PI ag x characteristic | -0.029 | 0.470*** | -0.525*** | -0.436*** | 0.121** | -0.011 | 0.493*** | 0.508*** | -0.016 | -0.274*** | -0.095 |
| | (0.070) | (0.052) | (0.065) | (0.065) | (0.053) | (0.132) | (0.107) | (0.132) | (0.184) | (0.059) | (0.083) |
| L.PI ag x Ever | -0.049 | -0.081 | -0.060 | -0.038 | -0.041 | -0.047 | -0.063 | -0.052 | -0.047 | 0.014 | -0.061 |
| | (0.117) | (0.113) | (0.113) | (0.112) | (0.116) | (0.117) | (0.117) | (0.116) | (0.117) | (0.117) | (0.117) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.40 | 0.41 | 0.40 | 0.39 | 0.39 | 0.40 | 0.40 | 0.39 | 0.40 | 0.39 |
| Total (mean) | 0.16 | 0.51 | -0.19 | -0.21 | 0.28 | 0.17 | 0.66 | 0.72 | 0.17 | 0.06 | 0.11 |
| Total (p25) | 0.54 | 0.83 | 0.15 | 0.15 | 0.65 | 0.55 | 1.05 | 1.11 | 0.55 | 0.46 | 0.48 |
| Total wo (mean) | 0.06 | 0.42 | -0.27 | -0.29 | 0.19 | 0.08 | 0.57 | 0.63 | 0.07 | -0.01 | 0.01 |
| Total wo (p25) | 0.44 | 0.73 | 0.07 | 0.07 | 0.56 | 0.46 | 0.96 | 1.03 | 0.45 | 0.39 | 0.38 |

Note: As column 6 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The value 1 is used for the time-invariant characteristic dummy in the calculations of the total effect (the effect is for the state or arc in question). The headings are defined as following: *PA* State of Pará, *MA* State of Maranhão, *MT* State of Mato Grosso, *RO* state of Rôndonia, *TO* State of Tocantis, *RR* State of Roraima, *AC* State of Acre, *AM* state of Amazonia, *AP* State of Amapá, *Old* old agricultural frontier, *New* new agricultural frontier.

*Table IV.A.27: CZs: States and the Forest Frontier*

| | (1)<br>nutrient1 | (2)<br>nutrient2 | (3)<br>oxygen | (4)<br>roots | (5)<br>workability | (6)<br>access | (7)<br>area ag | (8)<br>area min | (9)<br>est9 | (10)<br>est10 | (11)<br>est11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L.PI ag | 1.300*** | 0.953*** | 1.354*** | 1.290*** | 1.250*** | 1.304*** | 1.325*** | 1.382*** | 1.303*** | 1.535*** | 1.278*** |
| | (0.100) | (0.100) | (0.095) | (0.100) | (0.105) | (0.100) | (0.100) | (0.104) | (0.100) | (0.118) | (0.104) |
| L.PI ag x Ever x Active | 0.080*** | 0.081*** | 0.067*** | 0.072*** | 0.079*** | 0.080*** | 0.079*** | 0.074*** | 0.080*** | 0.061*** | 0.084*** |
| | (0.019) | (0.019) | (0.019) | (0.019) | (0.019) | (0.020) | (0.019) | (0.020) | (0.020) | (0.020) | (0.020) |
| L.PI ag x Ever | -0.049 | -0.081 | -0.060 | -0.038 | -0.041 | -0.047 | -0.063 | -0.052 | -0.047 | 0.014 | -0.061 |
| | (0.117) | (0.113) | (0.113) | (0.112) | (0.116) | (0.117) | (0.117) | (0.116) | (0.117) | (0.117) | (0.117) |
| L.Ever x Active | -0.080*** | -0.082*** | -0.066** | -0.071** | -0.079*** | -0.080*** | -0.078*** | -0.074*** | -0.080*** | -0.058** | -0.085*** |
| | (0.028) | (0.028) | (0.028) | (0.028) | (0.028) | (0.029) | (0.028) | (0.029) | (0.029) | (0.029) | (0.029) |
| L.ln RF | 0.776*** | 0.785*** | 0.786*** | 0.765*** | 0.757*** | 0.781*** | 0.789*** | 0.783*** | 0.781*** | 0.817*** | 0.768*** |
| | (0.100) | (0.106) | (0.106) | (0.099) | (0.095) | (0.098) | (0.097) | (0.095) | (0.098) | (0.092) | (0.099) |
| L.PI ag x ln RF | -0.205*** | -0.171*** | -0.186*** | -0.195*** | -0.200*** | -0.206*** | -0.212*** | -0.213*** | -0.206*** | -0.216*** | -0.198*** |
| | (0.011) | (0.011) | (0.010) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.011) | (0.012) |
| L.PI ag x characteristic | -0.029 | 0.470*** | -0.525*** | -0.436*** | 0.121** | -0.011 | 0.493*** | 0.508*** | -0.016 | -0.274*** | -0.095 |
| | (0.070) | (0.052) | (0.065) | (0.065) | (0.053) | (0.132) | (0.107) | (0.132) | (0.184) | (0.059) | (0.083) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.40 | 0.41 | 0.40 | 0.39 | 0.39 | 0.40 | 0.40 | 0.39 | 0.40 | 0.39 |
| Total (mean) | 0.16 | 0.51 | -0.19 | -0.21 | 0.28 | 0.17 | 0.66 | 0.72 | 0.17 | 0.06 | 0.11 |
| Total (p25) | 0.54 | 0.83 | 0.15 | 0.15 | 0.65 | 0.55 | 1.05 | 1.11 | 0.55 | 0.46 | 0.48 |
| Total wo (mean) | 0.06 | 0.42 | -0.27 | -0.29 | 0.19 | 0.08 | 0.57 | 0.63 | 0.07 | -0.01 | 0.01 |
| Total wo (p25) | 0.44 | 0.73 | 0.07 | 0.07 | 0.56 | 0.46 | 0.96 | 1.03 | 0.45 | 0.39 | 0.38 |

Note: As column 6 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The value 1 is used for the time-invariant characteristic dummy in the calculations of the total effect (the effect is for the state or arc in question). The headings are defined as following: *PA* State of Pará, *MA* State of Maranhão, *MT* State of Mato Grosso, *RO* state of Rôndonia, *TO* State of Tocantis, *RR* State of Roraima, *AC* State of Acre, *AM* state of Amazonia, *AP* State of Amapá, *Old* old agricultural frontier, *New* new agricultural frontier.

*Table IV.A.28: Baseline: Standard Errors Adjusted for Spatial Autocorrelation*

| | (1)<br>Baseline 1 | (2)<br>Baseline 2 | (3)<br>Baseline 3 | (4)<br>Prio | (5)<br>Soy | (6)<br>PAs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.170 | 0.189 | 0.983*** | 0.952*** | 1.026*** | 1.303*** |
| | (0.198) | (0.199) | (0.251) | (0.244) | (0.237) | (0.243) |
| L.PI ag x Ever x Active | | | | -0.274** | 0.020 | 0.080*** |
| | | | | (0.110) | (0.033) | (0.028) |
| L.PI ag x Ever | | | | 1.769*** | -0.028 | -0.047 |
| | | | | (0.424) | (0.037) | (0.139) |
| L.Ever x Active | | | | | -0.070* | -0.080* |
| | | | | | (0.042) | (0.041) |
| L.ln RF | | 0.242 | 0.752*** | 0.695*** | 0.780*** | 0.781*** |
| | | (0.187) | (0.209) | (0.202) | (0.215) | (0.192) |
| L.PI ag x ln RF | | | -0.163*** | -0.147*** | -0.161*** | -0.206*** |
| | | | (0.026) | (0.025) | (0.024) | (0.026) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.83 | 0.83 | 0.84 | 0.84 | 0.85 | 0.85 |
| Total mean | | | | 1.58 | 0.07 | 0.14 |
| Total 25 | | | | 1.85 | 0.37 | 0.52 |
| Total wo mean | | | | 1.85 | 0.05 | 0.04 |
| Total wo 25 | | | | 2.13 | 0.35 | 0.42 |

Note: Standard errors are clustered at the municipality and state-year level. Variables not shown include municipality-state fixed effects and year fixed effects.

## Excluding potential outliers

*Table IV.A.29: Baseline: Without Biggest Soy Producers*

| | (1)<br>Baseline 1 | (2)<br>Baseline 2 | (3)<br>Baseline 3 | (4)<br>Prio | (5)<br>Soy | (6)<br>PAs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.137 | 0.156* | 0.944*** | 0.907*** | 1.017*** | 1.260*** |
| | (0.088) | (0.086) | (0.090) | (0.093) | (0.091) | (0.099) |
| L.PI ag x Ever x Active | | | | -0.275*** | 0.030 | 0.079*** |
| | | | | (0.093) | (0.023) | (0.019) |
| L.PI ag x Ever | | | | 1.786*** | -0.041* | -0.050 |
| | | | | (0.389) | (0.025) | (0.117) |
| L.Ever x Active | | | | | -0.073*** | -0.080*** |
| | | | | | (0.026) | (0.028) |
| L.ln RF | | 0.246*** | 0.751*** | 0.694*** | 0.777*** | 0.780*** |
| | | (0.086) | (0.111) | (0.108) | (0.117) | (0.099) |
| L.PI ag x ln RF | | | -0.162*** | -0.145*** | -0.160*** | -0.204*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 7205 | 7205 | 7205 | 7205 | 7205 | 7205 |
| R-sq | 0.32 | 0.33 | 0.37 | 0.39 | 0.39 | 0.39 |
| Total mean | 0.14 | 0.16 | -0.01 | 1.56 | 0.07 | 0.23 |
| Total 25 | | | 0.29 | 1.83 | 0.36 | 0.54 |
| Total wo mean | | | | 1.84 | 0.04 | 0.01 |
| Total wo 25 | | | | 2.11 | 0.33 | 0.39 |

Note: Baseline regression without the municipalities that have the highest mean production value in the considered period. Those municipalities are: Campo Novo do Parecis, Sorriso, Nova Mutum, Sapezal, Diamantino. Standard errors are clustered at the municipality level Variables not shown include municipality fixed effects and year fixed effects.

*Table IV.A.30: Without Lowest 5%*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.177* | 0.193** | 1.016*** | 0.962*** | 1.021*** | 1.363*** |
| | (0.091) | (0.090) | (0.098) | (0.103) | (0.098) | (0.108) |
| L.PI ag x Ever x Active | | | | -0.274*** | 0.011 | 0.080*** |
| | | | | (0.093) | (0.023) | (0.019) |
| L.PI ag x Ever | | | | 1.720*** | -0.018 | -0.043 |
| | | | | (0.395) | (0.025) | (0.117) |
| L.Ever x Active | | | | | -0.066** | -0.077*** |
| | | | | | (0.026) | (0.029) |
| L.ln RF | | 0.195** | 0.735*** | 0.671*** | 0.747*** | 0.780*** |
| | | (0.076) | (0.110) | (0.107) | (0.115) | (0.099) |
| L.PI ag x ln RF | | | -0.162*** | -0.144*** | -0.155*** | -0.210*** |
| | | | (0.011) | (0.012) | (0.011) | (0.013) |
| Observations | 6941 | 6941 | 6941 | 6941 | 6941 | 6941 |
| R-sq | 0.34 | 0.34 | 0.38 | 0.39 | 0.40 | 0.40 |
| Total(mean) | | | | 1.53 | 0.07 | 0.14 |
| Total(p25) | | | | 1.79 | 0.35 | 0.42 |
| Total wo(mean) | | | 0.03 | 1.80 | 0.06 | 0.04 |
| Total wo(p25) | | | 0.33 | 2.07 | 0.34 | 0.42 |

Note: As table IV.2 but without the 5% municipalities that had lowest deforestation rates in the regarded period

*Table IV.A.31: Without Highest 5%*

| | (1) Baseline 1 | (2) Baseline 2 | (3) Baseline 3 | (4) Prio | (5) Soy | (6) CZs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.141* | 0.161** | 0.901*** | 0.981*** | 0.997*** | 1.254*** |
| | (0.083) | (0.081) | (0.084) | (0.095) | (0.090) | (0.098) |
| L.PI ag x Ever x Active | | | | -0.460*** | 0.008 | 0.066*** |
| | | | | (0.121) | (0.024) | (0.018) |
| L.PI ag x Ever | | | | 1.242* | -0.018 | 0.024 |
| | | | | (0.647) | (0.026) | (0.118) |
| L.Ever x Active | | | | | -0.051* | -0.055** |
| | | | | | (0.028) | (0.026) |
| L.ln RF | | 0.245*** | 0.733*** | 0.701*** | 0.763*** | 0.759*** |
| | | (0.084) | (0.109) | (0.107) | (0.116) | (0.097) |
| L.PI ag x ln RF | | | -0.158*** | -0.151*** | -0.157*** | -0.200*** |
| | | | (0.010) | (0.010) | (0.010) | (0.011) |
| Observations | 6897 | 6897 | 6897 | 6897 | 6897 | 6897 |
| R-sq | 0.31 | 0.32 | 0.36 | 0.37 | 0.38 | 0.38 |
| Total(mean) | | | | 0.90 | 0.09 | 0.20 |
| Total(p25) | | | | 1.16 | 0.36 | 0.48 |
| Total wo(mean) | | | -0.00 | 1.36 | 0.08 | 0.13 |
| Total wo(p25) | | | 0.27 | 1.62 | 0.35 | 0.48 |

Note: As table IV.2 but without the 5% municipalities that had highest deforestation rates in the regarded period

## Land use

*Table IV.A.32: Priority List: Controlling for Lagged Time Variant Land Use*

| | (1) | (2) | (3) |
|---|---|---|---|
| | area ag | area min | area non-act |
| L.PI ag | 1.162*** | 0.953*** | 1.070*** |
| | (0.145) | (0.094) | (0.097) |
| L.PI ag x Active x Post | -0.274*** | -0.271*** | -0.267*** |
| | (0.092) | (0.095) | (0.097) |
| L.PI ag x Ever | 1.720*** | 1.783*** | 1.860*** |
| | (0.396) | (0.399) | (0.394) |
| L.ln RF | 0.675*** | 0.687*** | 0.672*** |
| | (0.106) | (0.107) | (0.110) |
| L.PI ag x ln RF | -0.144*** | -0.144*** | -0.127*** |
| | (0.010) | (0.011) | (0.011) |
| L.Characteristic | -0.025 | -0.040 | 0.053 |
| | (0.033) | (0.041) | (0.047) |
| L.PI ag x Characteristic | -0.027* | -0.010 | -0.035*** |
| | (0.015) | (0.009) | (0.006) |
| Observations | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.39 | 0.40 |
| Total (mean) | 1.56 | 1.60 | 1.69 |
| Total (p25) | 1.83 | 1.86 | 1.92 |
| Total wo (mean) | 1.83 | 1.87 | 1.95 |
| Total wo (p25) | 2.10 | 2.13 | 2.19 |

Note: As column 4 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The sample mean of the time-invariant characteristics is used in the calculations of the total effect.

*Table IV.A.33: Soy Moratorium: Controlling for Lagged Time Variant Land Use*

| | (1) | (2) | (3) |
|---|---|---|---|
| | area ag | area min | area non-act |
| L.PI ag | 0.920*** | 0.946*** | 1.045*** |
| | (0.130) | (0.079) | (0.084) |
| L.PI ag x Ever x Active | 0.003 | 0.016 | 0.015 |
| | (0.025) | (0.022) | (0.022) |
| L.PI ag x Ever | -0.011 | -0.023 | -0.017 |
| | (0.026) | (0.024) | (0.024) |
| L.Ever x Active | -0.050* | -0.065*** | -0.065*** |
| | (0.029) | (0.024) | (0.024) |
| L.ln RF | 0.788*** | 0.783*** | 0.760*** |
| | (0.116) | (0.117) | (0.119) |
| L.PI ag x ln RF | -0.161*** | -0.158*** | -0.142*** |
| | (0.010) | (0.010) | (0.010) |
| L.Characteristic | -0.028 | -0.049 | 0.037 |
| | (0.030) | (0.039) | (0.047) |
| L.PI ag x Characteristic | 0.003 | -0.005 | -0.030*** |
| | (0.015) | (0.009) | (0.006) |
| Observations | 7260 | 7260 | 7260 |
| R-sq | 0.39 | 0.39 | 0.40 |
| Total (mean) | -0.02 | -0.01 | 0.01 |
| Total (p25) | 0.29 | 0.32 | 0.30 |
| Total wo (mean) | -0.02 | -0.03 | -0.01 |
| Total wo (p25) | 0.29 | 0.29 | 0.27 |

Note: As column 5 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The sample mean of the time-invariant characteristics is used in the calculations of the total effect.

*Table IV.A.34: CZs: Controlling for Lagged Time Variant Land Use*

| | (1)<br>area ag | (2)<br>area min | (3)<br>area non-act |
|---|---|---|---|
| L.PI ag | 1.462*** | 1.303*** | 1.439*** |
| | (0.139) | (0.100) | (0.102) |
| L.PI ag x Ever x Active | 0.078*** | 0.082*** | 0.078*** |
| | (0.019) | (0.020) | (0.019) |
| L.PI ag x Ever | -0.044 | -0.061 | -0.006 |
| | (0.115) | (0.117) | (0.113) |
| L.Ever x Active | -0.080*** | -0.083*** | -0.077*** |
| | (0.028) | (0.029) | (0.028) |
| L.ln RF | 0.758*** | 0.769*** | 0.752*** |
| | (0.097) | (0.098) | (0.101) |
| L.PI ag x ln RF | -0.201*** | -0.200*** | -0.183*** |
| | (0.011) | (0.012) | (0.011) |
| L.Characteristic | -0.033 | -0.025 | 0.075 |
| | (0.031) | (0.041) | (0.047) |
| L.PI ag x Characteristic | -0.022 | -0.013 | -0.039*** |
| | (0.014) | (0.009) | (0.006) |
| Observations | 7260 | 7260 | 7260 |
| R-sq | 0.40 | 0.39 | 0.40 |
| Total (mean) | 0.16 | 0.13 | 0.18 |
| Total (p25) | 0.47 | 0.43 | 0.69 |
| Total wo (mean) | 0.07 | 0.03 | 0.09 |
| Total wo (p25) | 0.47 | 0.43 | 0.69 |

Note: As column 6 in table IV.2, except the interaction term between the price and the characteristic indicated in the column headings. The sample mean of the time-invariant characteristics is used in the calculations of the total effect.

## GDP and Carbon

*Table IV.A.35: Dependent Variable: Total GDP*

| | (1)<br>Baseline 1 | (2)<br>Baseline 2 | (3)<br>Prio | (4)<br>Soy | (5)<br>CZs |
|---|---|---|---|---|---|
| PI ag | 0.030 | 0.282*** | 0.334*** | 0.230** | 0.306*** |
| | (0.024) | (0.097) | (0.104) | (0.104) | (0.102) |
| PI ag x Ever x Active | | | 0.020 | -0.021** | -0.005 |
| | | | (0.017) | (0.008) | (0.006) |
| PI ag x Ever | | | -0.031 | 0.041*** | 0.115*** |
| | | | (0.130) | (0.009) | (0.045) |
| Ever x Active | | | | 0.002 | 0.002 |
| | | | | (0.009) | (0.009) |
| PI ag x ln Stock | | -0.023*** | -0.029*** | -0.024** | -0.027*** |
| | | (0.009) | (0.010) | (0.010) | (0.009) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.86 | 0.86 | 0.87 | 0.87 | 0.86 |
| Total(mean) | | | 0.02 | -0.01 | 0.13 |
| Total(p25) | | | 0.04 | 0.01 | 0.16 |
| Total wo(mean) | | 0.03 | -0.00 | 0.01 | 0.14 |
| Total wo(p25) | | 0.05 | 0.02 | 0.03 | 0.16 |

Note: As table IV.2 but the dependent variable is the total municipality GDP.

*Table IV.A.36: Dependent Variable: Carbon Loss*

| | (1)<br>Baseline 1 | (2)<br>Baseline 2 | (3)<br>Baseline 3 | (4)<br>Prio | (5)<br>Soy | (6)<br>PAs |
|---|---|---|---|---|---|---|
| L.PI ag | 0.607*** | 0.608*** | 1.582*** | 1.743*** | 1.663*** | 3.242*** |
| | (0.137) | (0.137) | (0.377) | (0.411) | (0.387) | (0.426) |
| L.PI ag x Ever x Active | | | | -0.228** | -0.021 | 0.111*** |
| | | | | (0.094) | (0.031) | (0.027) |
| L.PI ag x Ever | | | | 0.077 | 0.055 | -0.311* |
| | | | | (0.518) | (0.035) | (0.162) |
| L.Ever x Active | | | | | -0.077** | -0.098** |
| | | | | | (0.035) | (0.042) |
| L.ln Carbon Stock | | 0.005 | 0.142*** | 0.116** | 0.141*** | 0.308*** |
| | | (0.007) | (0.046) | (0.048) | (0.046) | (0.051) |
| L.PI ag x ln Carbon Stock | | | -0.064*** | -0.053** | -0.062*** | -0.148*** |
| | | | (0.022) | (0.024) | (0.022) | (0.025) |
| Observations | 7260 | 7260 | 7260 | 7260 | 7260 | 7260 |
| R-sq | 0.27 | 0.27 | 0.27 | 0.28 | 0.29 | 0.28 |
| Total mean | | | | 0.75 | 0.70 | 0.69 |
| Total 25 | | | | 0.82 | 0.79 | 0.77 |
| Total wo mean | | | 0.55 | 0.97 | 0.72 | 0.56 |
| Total wo 25 | | | 0.64 | 1.05 | 0.81 | 0.77 |

Note: As table IV.2 but the dependent variable is total carbon dioxide bounded in the forest left in a municipality.

# Chapter V

# Bibliography

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