Industrial Activity and Land Degradation: Evidence from Slaughterhouse Openings in Brazil

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Abstract

We study the effects of industrial plant openings on livestock production and deforestation. Using a staggered difference-in-differences approach, we show that opening a slaughterhouse in a given region increases pastureland at the cost of forest area and increases land degradation. Moreover, after the introduction of certification-like, legally-enforced commitments between slaughterhouses and prosecutors in the Amazon region, we show that opening new plants led to positive impacts on forest area and higher productivity. Our results suggest that agreeable-enforcement can generate positive production and environmental impacts.

Key-words: slaughterhouse, deforestation, degradation, industrial plants.

JEL Codes: Q12, Q24, Q28, L10, I15, Q51, Q56, Q54

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1 Introduction

Industrial activity and environmental preservation are often two opposing forces in modern economies. Although industrial plants create jobs and spur economic growth, they also generate local and global externalities, such as local air pollution and greenhouse gas emissions. Some of these externalities have been extensively studied, including their negative impacts on human health and "non-health" outcomes such as cognitive performance and productivity (e.g., Graff-Zivin and Neidell, 2013; Aguilar-Gomez et al., 2022). In contrast, changes in land cover and land use accompanying industrial activity have been overlooked.

Can new industrial plants lead to land degradation? We examine this question in the Brazilian context, leveraging the opening of about 150 cattle slaughterhouses around the country since the early 1990s. Land degradation can arise from forest conversion, overgrazing, over-cultivation, and other factors associated with the pressures of livestock production. Like the United States, Brazil has become a major player in beef markets, accounting for roughly 20% of all world beef exports (OECD/FAO, 2022). Extensive cattle ranching has been the dominant production system in Brazil, with more than 155 million hectares converted to pastureland — an area larger than France, Germany, and Spain altogether.

Brazil also holds some of the most important biomes still preserved in the world: the Amazon rain-forest and the Cerrado (a savanna-type biome in central Brazil). Both have been considerably impacted by the expansion of agricultural and cattle production over the past three decades (Vale et al., 2022). Given the increasing demand for animal protein around the world, especially from Asia, the opening of new slaughterhouses followed by increasing beef production may be causing land-use changes and other forms of land degradation in surrounding areas.

To investigate the impacts of industrial activity on cattle production and environmental outcomes, we explore the staggered timing of slaughterhouse openings using comprehensive municipality level data for Brazil. Slaughterhouses usually purchase cattle from an area around them, often up to about 200 kilometers (Franco, 2013). Hence, the opening of a slaughterhouse affects ranchers across several municipalities via the increasing demand for cattle after the beginning of plant operations. This may generate different responses by ranchers. Some might choose to expand production intensively or extensively, with different externalities emerging from their choices. As the response of ranchers is conceptually ambiguous, accurately assessing the impact of these externalities requires empirical analysis to determine their effects.

We also investigate how areas under the influence of a certification-like, legally-enforced commitment — known as *TAC* (in Portuguese: *Termo de Ajustamento de Conduta*) — respond to the opening of new slaughterhouses after prosecutors indicted existing plants for buying cattle from illegally deforested farms. In late 2009, slaughterhouses in the Amazon region signed agreements with the federal government to avoid prosecution by committing not to acquire cattle from such farms. The unique characteristics of this commitment, which is neither pure law-enforcement nor purely voluntary, yields an interesting setting for studying the impacts of government-and-market-led efforts to control externalities from economic activities.

We use the recent developments by Callaway and Sant'Anna (2021) to identify the relationship between slaughterhouse openings and our outcomes of interest. Over the period of our analysis (1992-2019), Brazil has over 4,000 municipalities impacted by slaughterhouse openings — or approximately 80% of all municipalities in the country.[1] By exploring the staggered timing of openings and not-yet-treated municipalities as our control group, we are able to find consistent estimates of the impacts of slaughterhouse openings on cattle production and environmental outcomes.

Our work yields three main contributions. First, we examine land-use cover and land degradation stemming from industrial activity. We document that slaughterhouse openings lead to more cattle-raising activities in nearby areas, thus increasing the demand for pastureland. As a consequence, pasture areas augment by about 2.4% after a new opening. Notice that this is not a mechanical effect: cattle supply could respond intensively if ranchers chose to increase their productivity substantially. However, our results suggest that was not the case — i.e., bovine productivity increased marginally as a response to a new slaughterhouse in the surroundings, while the increase in area for bovine production was more relevant.

Apart from land-use cover, we also analyze land degradation by looking at the effects on pasture quality. Consistent with low productivity changes, we find that pasture degradation increased as a response to new openings. In particular, severely and intermediately degraded pasture areas increased by as much as 17% and 10% in exposed localities, respectively. Taken together, our results suggest that the immediate production response by ranchers to this type of demand shock is to raise more cattle extensively.

Our second contribution relates closely to the results above: we analyze the impacts of industrial openings on land-use change. In theory, the expansion of cattle-raising activities could take place over existing cleared areas — such as cropland or natural pasture areas — or over native forests. Our results show a significant reduction in natural forest areas after

[1] Brazil's municipalities are autonomous administrative entities roughly equivalent to U.S. counties.

a new slaughterhouse opening, thus suggesting the latter hypothesis holds. This means ranchers are satisfying their demand for more pastureland via the conversion of natural forest areas into pastures through deforestation.

The implication of our findings is that industrial activities which are dependent on land-intensive operations may lead to relevant land-use changes. Over the period we analyze, more 25 million hectares were added to the stock of pastureland in Brazil — almost all of which used to be native vegetation. Intrigued by whether this strong land-conversion may be context-specific, we also investigate if the institutional setting may influence economic decisions as to lead to different outcomes in terms of land allocation. To better understand whether that is the case, we study the effects of new slaughterhouse openings in areas of Brazil under the influence of certification-like, legally-enforced commitments (or *TAC*s) — located mainly in the Amazon region.

After signing no-deforestation commitments in 2009, then-existing slaughterhouses increased their monitoring over ranchers to avoid acquiring cattle possibly raised in illegally deforested areas. Such monitoring may have influenced ranchers decisions on land-use changes. Our third contribution is to show that this certification-like, legally-enforced commitment by plants has positive production and environmental effects for subsequent slaughterhouse openings in nearby areas. In fact, we find that new openings after the signature of *TAC* agreements lead to less pasture degradation, higher cattle productivity, and no further forest loss. At the same time, areas of the country which were not impacted by *TAC*s experienced exactly the opposite.

We associate our work with several branches of the economics literature. We first connect to the extensive literature on the impacts of economic activity on the environment. In particular, our paper relates to the literature on the effects of industrial activity on human health (e.g., Chay and Greenstone, 2003; Greenstone et al., 2010; Beach and Hanlon, 2018; Clay et al., 2022) and on the impacts of new infrastructure on environmental preservation (e.g., Asher et al., 2020; Garg and Shenoy, 2021). Our investigation furthers this literature by being the first to examine land-use changes and degradation stemming from industrial activities. Despite its importance, especially under the current context of climate change and increasing human-pressure on the environment, the relationship between environmental conservation — in particular, deforestation — and industrial plants has been overlooked in the economics literature.

Moreover, our investigation is also linked to the broad literature on the determinants of deforestation, especially with the branches which focus on illegal activities as drivers of forest loss (e.g., Chimeli and Soares, 2017; Andela et al., 2017; Menezes et al., 2021) and on the effects of agricultural activities on the environment (e.g., Assunção et al., 2017). Our approach advances this literature by providing evidence that industrial plants may be causing deforestation via agricultural-related activities (i.e., cattle-raising). Additionally, we also connect with the literature investigating the effects of demand (e.g., Bragança, 2018; Harding et al., 2020; Da Mata and Dotta, 2022) and technological (e.g., Dias et al., 2023 , Da Mata et al., 2023) shocks on environmental variables. To the best of our knowledge, we are the first to show that opening new plants lead to more demand for cattle, attracting ranchers to clear more land for pasture.

Finally, our paper relates to previous work on policies to address deforestation. There exists two grand sets of literature on this issue. First, we are associated with the command and control branch which shows that placing constraints (e.g., Assunção et al., 2020) and increasing enforcement (e.g., Burgess et al., 2019, Ferreira, 2021, Assunção et al., 2022) can prevent further forest loss. Second, we are also linked with the literature on market incentives to avoid deforestation, especially with the branch on payment for eco-services (e.g., Alix-Garcia et al., 2015; Börner et al., 2017; Jayachandran et al., 2017). Although not exactly as traditional as the settings above, the *TAC* agreements provide us with a unique context to study how a mixture of both command-and-control and market-incentives mechanisms may impact deforestation, yielding a novel contribution on how government-and-market-led efforts may prevent further environmental damages.

This article proceeds as follows. Section 2 details the background on Brazil's slaughterhouses and the certification-like, legally-enforced agreements. Section 3 describes the empirical strategy. Section 4 presents the data, while Section 5 reports the results. Section 6 concludes.

2 Background

2.1 Slaughterhouse Openings in Brazil

There are over 140 municipalities in Brazil which currently host more than 180 federally-inspected slaughterhouse plants operating within their borders.[2] Such industries acquire beef cattle from rural areas usually within a 200 kilometer-radius (Franco, 2013), so that a plant in a given locality often buy animals from ranchers located in several neighboring

[2]Federally-inspected plants are explained with more detail in the subsequent paragraph. There also exists other types of inspections, at the state and local levels. However, they only allow slaughterhouses to sell their products within state or local boundaries. Hence, their sizes are considerably smaller than the federally-inspected plants.

municipalities. Taking into account the average operating radius of a given slaughterhouse in the Brazilian territory, we find that 4,086 municipalities have been impacted by plant openings over the past three decades across the country.

Federally-inspected plants are allowed to commercialize their meat-packed products over all of the national territory, while some of them also have exporting licenses. The Brazilian national inspection service (*Serviço de Inspeção Federal—SIF*) from the Ministry of Agriculture and Livestock (*Ministério da Agricultura e da Pecuária—MAP*) is responsible for overseeing animal-product plants and authorizing their operations via licensing. The bureaucratic process to open a new slaughterhouse can be burdensome and take time — anecdotal evidence indicates over a year from construction to being fully operational (e.g., Reuters, 2022; TO, 2007; MG, 2008). There exists a series of requirements which a plant must fulfil and documents that must be provided to the SIF department, including detailed plant footprints, the implementation of residue treatment infrastructure, and even an in-house office for SIF inspectors to work from when they visit plants for oversight (SIF, 2023).

Once slaughterhouses are fully built and equipped, the SIF department has a final say on the authorization to operate. Plants may then start their commercial operations, which includes buying cattle from surrounding areas and selling products to urban centers. The slaughter capacity of federally-inspected plants may vary considerably, from about 500 to 2,000 heads of beef cattle a day. Given Brazil's average bovine productivity in the last decades (approximately 0.85 animals per hectare), back-of-the-envelope calculations suggest that such plants influence an area up to 116 million hectares of pastureland — or 74% of all pastures in the country. This is consistent with the fact that a little over 75% of all commercial slaughtered animals in Brazil have been processed by federally-inspected plants (IBGE, 2023).[3]

Historically, the location of these plants have been changing toward the North region of Brazil, from the West of the state of *São Paulo* and Southern *Goiás* and *Mato Grosso do Sul* to the Southern Amazon region, including the states of *Pará*, *Rondônia* and Northern *Mato Grosso* (Vale et al., 2022). Cattle production in those areas has been increasing, and the latter three states have accounted for 80% of deforestation and 80% of cattle production since year 2000 in the Amazon region (Skidmore et al., 2021).

Figure 1 below displays information on the location of slaughterhouses in Brazil. Panel (a) shows the municipalities which host federally-inspected slaughterhouses and panel (b) presents municipalities impacted by plants within a 200-kilometer radius. As one may no-

[3]The remaining 25% of slaughtered animals are processed for local consumption by considerably smaller, local plants.

tice, except for areas deep into the Amazon forest and areas in the Brazilian Northeast (known for its semi-arid climate, not suitable for traditional agriculture), almost all municipalities in the country contain a plant within a 200-kilometer radius.

2.2 The Certification-Like, Legally-Enforced Commitments

Governments worldwide have been attempting to implement policies to counteract the costs associated with economic externalities, such as deforestation (UNEP, 2021). In particular, a series of government policies and agreements have been carried out in Brazil during the 2000s and early 2010s to stop further forest loss, especially in the Amazon region. Efforts included policies such as black-listing high-deforestation municipalities and restrictions to rural credit access by farmers who were not up to date with environmental documentation.[4] They also included private sector initiatives, such as the soy moratorium — according to which commodity trading companies committed not to acquire soybeans from areas deforested after 2006 (ABIOVE, 2014).

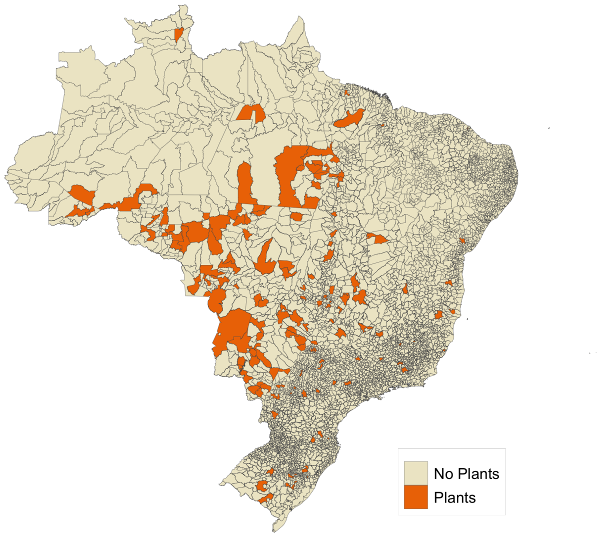
In a similar fashion, Greenpeace launched a campaign in May 2009 to raise consumer awareness about the links between Brazilian beef products and deforestation in the Amazon region (Reuters, 2009). The campaign was based on satellite data suggesting beef companies were acquiring cattle from illegally deforested farms. After the campaign, Brazilian federal prosecutors sued slaughterhouses and other market participants (e.g., supermarkets, tanneries, and factories) for buying products derived from environmental crimes, which could lead to severe legal penalties (Barreto et al., 2017).

In order to avoid lawful measures, slaughterhouses operating in the Amazon region signed paralegal agreements with federal prosecutors in which they committed to stop buying cattle from farms that (i) had deforested areas after October 2009, (ii) had been partially embargoed by IBAMA (Brazil's Environment and Natural Resources Institute) due to irregular deforestation, and (iii) were not registered in the Environmental Rural Registry (*Cadastro Ambiental Rural—CAR*) (Barreto and Araújo, 2012).[5] These agreements were named *Termo de Ajustamento de Conduta* (TAC), freely translated as Conduct Adjustment Agreement. If signatory slaughterhouses failed to fulfil the pledge, then prosecutors were able to apply penalties without involving the justice system.

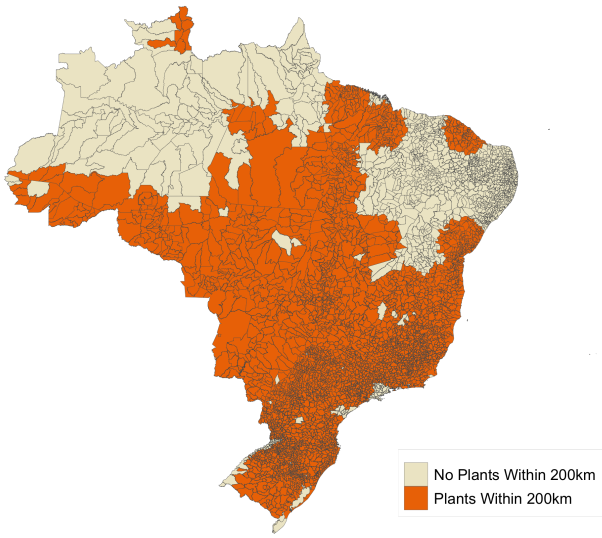
[4] The economics literature has shown these policies have been effective in lowering deforestation (e.g., Assunção et al., 2015, and Assunção et al., 2020)

[5] The Environmental Rural Registry (or CAR) consists of an environmental registration all farmland-owners must have with state governments. In the registration process, farmers have to provide detailed geo-referenced information about forests, reserves, and protected areas inside their farms, and the perimeter of their properties.

Figure 1: Municipalities with at least one Slaughterhouses Plant and within a 200-kilometer radius from a Slaughterhouse Plant in Brazil



(a) Municipalities with at least one Slaughterhouse Plant



(b) Municipalities within a 200-kilometer radius from a Slaughterhouse Plant

Notes. The figure above displays the geographical location of slaughterhouses across Brazilian municipalities. Panel (a) shows municipalities which host at least one federally-inspected slaughterhouse plant. Panel (b) presents municipalities which have a slaughterhouse within a 200-kilometer radius.

Since these agreements have been partially originated from market-led pressure (e.g., Greenpeace marketing campaign) and partially from government-related enforcement (e.g., federal prosecution), we name them certification-like, legally-enforced commitments. Such commitments have influenced major beef companies since 2009 in the Amazon region, with approximately 70% of all slaughtered animals in 2016 being processed in plants which were signatories of TACs (Barreto et al., 2017). As a consequence, ranchers operating in the surrounding areas of these plants may have been influenced by their new policies — and thus made different decisions in terms of land-use than their counterparts elsewhere in the country.

In the previous section we mentioned that federally-inspected slaughterhouses buy cattle within a 200-kilometer radius, on average. However, according to Barreto et al. (2017), plants can acquire bovines from farms up to 350-kilometers away in the Amazon region — where the *TAC* signatory slaughterhouses are located. We thus consider the 350-kilometer radius of such plants to be the area of influence of the certification-like, legally-enforced commitments. Figure 2 below displays municipalities which have at least one signatory plant and municipalities within a 350-kilometer radius from a signatory plant. Since the 2009 Greenpeace campaign focused almost exclusively in the Amazon region, notice that impacted municipalities are solely located in that part of the country.

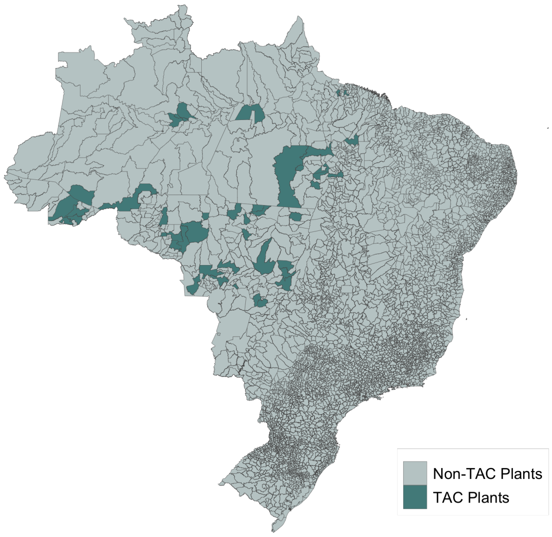
3 Empirical Strategy

Given the staggered nature of slaughterhouse openings across Brazilian municipalities, we utilize the estimator proposed by Callaway and Sant'Anna (2021) to identify the impacts of slaughterhouse openings on our outcomes of interest. This estimator is a staggered difference-in-differences (DiD) and it takes into account heterogeneous effects in treated units for different years. More precisely, we estimate the following specification:

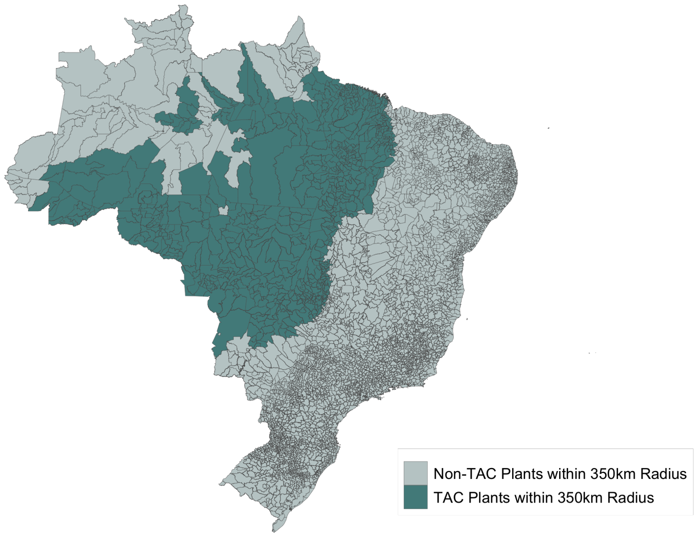
$$y_{it} = \sum_{g \in \mathcal{G}} \beta_g \mathbf{1}\{t - E_i = g\} + \eta_t W_i + \alpha_i + \gamma_t + \varepsilon_{it} \tag{1}$$

where y_{it} is the dependent variable of interest (e.g., production and environmental variables) for municipality i in time t, and E_i represents the first year municipality i was treated (that is, received a slaughterhouse plant within a 200-kilometer distance). Hence, β_g captures the average treatment effect t periods after the beginning of treatment for municipalities treated for the first time in year g, where $\mathcal{G}$ collects disjoint sets g of relative periods t

Figure 2: Municipalities with Certification-like, Legally-Enforced Commitment Slaughterhouse Plants and within a 350-kilometer radius from a TAC-Plant in Brazil



(a) Municipalities with at least one TAC-signatory Slaughterhouse Plant



(b) Municipalities within a 350-kilometer radius of a TAC-signatory Slaughterhouse Plant

Notes. The figure above displays the geographical locations of TAC-signatory slaughterhouses in Brazilian municipalities. Panel (a) shows municipalities which host at least one federally-inspected slaughterhouse plant which signed a TAC. Panel (b) presents municipalities which have a signatory slaughterhouse within a 350-kilometer radius.

$\in$ [-T,T]. Finally, α_i is the municipality fixed effects and γ_t is time fixed effects. We use the $log + 1$ transformation on our dependent variables, which yield an elasticity-like interpretation for values of y_{it}.[6]

Our main identification hypothesis is that municipalities with or without slaughterhouse plants would present a similar trends in terms of outcome variables in the absence of such plants. In our main specification, control groups are given by the geographical locations which were not-yet-treated in the data panel. This translates into comparing units which received a plant within a 200-kilometer radius with units which, at that point in time, had not yet received a plant within the same distance — but would be impacted by an opening in the following years. By selecting municipalities that were eventually influenced by a nearby plant, we can create treatment and control groups that are better suited for comparison.

A possible source of concern in DiD settings is the validity of the parallel trends assumption. In our staggered design, we condition parallel trends on covariates so that comparison groups are controlled for the influence of variables that could affect the trajectory of our outcomes of interest. Variables such as livestock production and environmental preservation could be impacted by the amount of people (population) and by average rain and temperature in a given municipality, making the hypothesis of conditional parallel trends more credible than its unconditional counterpart. Moreover, ignoring the presence of covariate-specific trends may result in relevant biases in estimating causal effects (Callaway and Sant'Anna, 2021).

A central aspect of our research design is that the main channel through which slaughterhouse openings affect our outcomes of interest is via ranchers who respond differently to higher cattle demand. As mentioned before, some farmers may choose to expand their production more extensively while others may decide to raise cattle intensively, with different externalities stemming from such choices. This means the opening of new plants only impact our dependent variables through farmers' production and environmental decisions, which are made based on their exposure to new demand for cattle (i.e., a new plant opening). Given that ranchers are not able to systematically influence the location of slaughterhouses across the Brazilian territory, let alone influence their commercial decisions outside the farm gate, our staggered timing approach yields a causal relationship between plant openings and our outcomes of interest.

We use two types of estimators proposed by Callaway and Sant'Anna (2021) derived

[6]Although recent studies have shown that problems might emerge with this type of variable transformation (e.g., Chen and Roth, 2022; Mullahy and Norton, 2022), we run several robustness checks in Section 5.5 which reassure the resilience of our approach.

from Equation (1). First, we estimate the group aggregate treatment effects of slaughterhouse openings. This yields an equivalent parameter to the traditional DiD estimator for staggered settings, considering the whole period of analysis. In particular, our estimations compute the average treatment effect across different groups of municipalities which were treated at a given period. Second, we also estimate the event-study coefficients to compare periods before and after treatment. In this latter case, we restrict our sample to municipalities which were exposed to treatment for at least 6 periods.[7] We then compute the average effect of receiving a slaughterhouse within a 200-kilometer radius for different lengths of exposure, relative to a base year (one period before receiving treatment).

Our specification also allows for limited treatment anticipation. Recall the context described in Section 2 on the time it usually takes to build a new slaughterhouse plant (at least one year). Given that ranchers may choose to expand their production when they receive a clear signal that a new plant will be constructed within a 200-kilometer radius, we view the start of construction as a strong indicator for them. As such, we consider the initiation of the plant's construction to be the critical event that prompts ranchers to decide whether to increase their operations. As a consequence, we allow for one period of anticipation in Equation (1): farmers decide whether and how to expand their cattle production upon the beginning of the construction of a new plant.

We also run several robustness checks to verify the validity of our design. We test, for instance, for alternative dependent variable transformations and different radius distances for impacted areas. Another important check we perform is the use of alternative estimators, such as those by Sun and Abraham (2021) and Borusyak et al. (2021), to understand how results might change with estimators which depend on different hypotheses. We also check whether a distinct control group ("never-treated" municipalities) may influence our outcomes. In general, as we discuss with more detail in Section 5.5, our results remain largely unchanged to such and other robustness exercises.

4 Data

Our analysis' time frame is 27 years, from 1992 to 2019. We work with novel publicly available data to build a comprehensive municipality-year level dataset. We describe the data in three parts: (i) outcome variables, (ii) treatment variables, and (iii) additional variables. Summary statistics is provided in Appendix Table A.1.

[7] We performed several exercises with less and more exposure periods. Outcomes remain very similar.

4.1 Outcome Variables

Cattle Heads. We collect data on the number of bovines from *Pesquisa Pecuária Municipal* (PPM) by IBGE (*Instituto Brasileiro de Geografia e Estatística* — the Brazilian Bureau of Statistics) from 1992 to 2019. PPM is a survey conducted yearly at the municipality level and compiles the number of animals of various species which are raised commercially. The survey does not take into account animal age or sex, which is why we also collect data from the Brazilian agricultural censuses of 2006 and 2017 to estimate a weighted average of the quantity of animal units municipalities host yearly.[8]

Pasture Quality. We collect satellite-derived data on pasture quality for all Brazilian municipalities from *Atlas das Pastagens* — an initiative from LAPIG-UFG.[9] Data is gathered for years 2000 to 2019 and contain a three-level granularity on pasture degradation: (i) severely degraded areas, (ii) intermediately degraded areas, and (iii) non-degraded areas. The degree of degradation is classified via a method known as enhanced vegetation index (EVI), using the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Earth Observing System-Terra platform (Huete et al., 2002; LAPIG, 2022). The EVI may vary between 0 and 1. An index higher than 0.6 translates into non-degraded areas; between 0.4 and 0.6 is an intermediately degraded area; and below 0.4 translates into a severely degraded area. Qualitatively, the EVI yields the degree of degradation of pastureland according to five main variables in a given area: (i) the height of vegetation; (ii) the number of termite nests; (iii) the degree of vegetation homogeneity in the area; (iv) the number of weed invaders; and (v) the amount of exposed bare soil. For example, the degree of degradation is higher if the height of vegetation is lower, and/or the number of termite nests is higher, and/or the degree of homogeneity in the area is lower, and/or the number of weed invaders is higher, and/or the amount of bare soil is higher.

Land-Cover and Land-Use. We utilize annual data on land-cover and land-use from MapBiomas from 1992 to 2019. MapBiomas processes 30-meter-by-30-meter LandSat-8 satellite images to document and classify land-use change and land-cover in Brazil (MapBiomas, 2022).[10] In particular, we collect municipality-year-level data on the stock of natural forest

[8] An animal unit is a unified measure for animal size and weight. For cattle, one animal unit corresponds to 450 kilos of live weight.

[9] LAPIG-UFG stands for *Laboratório de Processamento de Imagens e Geoprocessamento* at *Universidade Federal de Goiás* (Laboratory for Image Processing and Geo-processing at the Federal University of Goiás).

[10] MapBiomas is a Brazilian collaborative network composed by NGOs, universities and startup companies which map land-use and land-cover change in Brazil using satellite data from 1985 to 2021 (MapBiomas, 2022). By using machine-learning techniques to process each pixel-image, the tool developed by MapBiomas is able to classify land into several uses and detect its changes across time (e.g., it provides information on areas for (i) pasture, (ii) agriculture, (iii) urbanization, (iv) forests etc.).

area, pastureland, and agricultural area. Natural forest area corresponds to the amount of land covered by forests and native vegetation — it does not include planted forests for commercial purposes. Pastureland and agricultural area relate to areas covered by crops and pastures (the latter can be either planted or natural). MapBiomas data is measured in hectares and matches the period of January through December of each year.

Number of fires. Data on fires is collected from *Banco de Dados de Queimadas* (INPE, 2020a) by the National Institute for Space Research (INPE). INPE gathers and processes images from reference satellites which generate detailed daily pictures of fires with a minimum size of 30-by-1-meter for each 1-square-kilometer pixel.[11] The satellite data is harmonized to allow for comparisons among municipalities over time.[12] We aggregate the pixel-level fire counts to calculate the number of fires at the municipality-year level, following Da Mata and Dotta (2022).

4.2 Treatment Variables

Slaughterhouse Openings. We collected yearly data from the Ministry of Agriculture and Livestock (MAP) on federally-inspected bovine-slaughterhouses from 1992 to 2019. Data comprises of location, opening dates, and plants slaughter capacity for all regions in Brazil for a total of 181 slaughterhouses across the country. Since our unit of analysis is at the municipality level — and some municipalities have more than one plant —, we consider the opening date of the first slaughterhouse for treatment purposes. In our data aggregation, we display openings for 147 municipalities which host at least one plant. Moreover, we also consider that each new plant buys cattle up to 200-kilometers away from its location (Franco, 2013). Given that our unit of analysis is at the municipality level, we estimate which municipalities are impacted by the 200-kilometer radius from the centroid of each host municipality. As a consequence, from our initial 147 localities which host slaughterhouses, we find that 4,086 municipalities were eventually impacted (treated) by plant openings when considering the 200-kilometer radius.

Certification-like, legally-enforced commitments. Data on slaughterhouses which signed TACs — the certification-like, legally-enforced commitments — in 2009 and after come

[11] A fire inside a pixel is counted as “one fire" whether its size is equal to the minimum detectable area (30 meters length by 1 meter width), one large fire of about one square kilometer, or several medium-sized fires. If a fire surpasses one square kilometer, the fire count will equal the number of pixels it occupies (INPE, 2020b).

[12] Between June 1998 and July 2002, the reference satellite was NOAA-12 with sensor AVHRR, which captured images at the end of the afternoon. From July 2002, the reference satellite was the AQUA_M-T with sensor MODIS, which captured images at the beginning of the afternoon.

from Barreto et al. (2017). Their work gathered satellite-and-field-collect data on particular plants which committed to the agreements. Based on their research, we proceeded with the following approach to determine which municipalities are under TAC influence: we selected a radius up to 350 kilometers from the centroid of municipalities which host TAC-signatory federally-inspected plants.[13] We classify this region as under TAC influence because farmers were subjected to selling their cattle to TAC-signatory slaughterhouses. We then separate Brazilian municipalities into two parts: (i) localities under the influence of TACs (certification-like, legally-enforced commitments); and (ii) the rest of the country. Upon this separation, in Section 5 we utilize each part to compare how new openings after 2009 impacted our outcomes of interest in each region. We use the same empirical design as before, but restrict the time frame from 2009 onward.

4.3 Additional Data

Socio-economic covariates. We collect data on population, illiteracy and poverty rates for 1991 from *Atlas dos Municípios* database, by the United Nations. Notice that data is preperiod because our main specification depends on conditional parallel trends, as mentioned in Section 3.

Geo-climatic covariates. Data on rain and temperature at the municipality level comes from Da Mata and Resende (2020). For the same reason as described above, we calculate the average of each variable from 1960 to 1991 to estimate pre-period rain and temperature averages and use them as covariates.

5 Results

We divide our results into four parts: (i) we first show the effects of slaughterhouse openings on production variables — cattle heads, pasture areas, and bovine productivity; (ii) we then analyze the impacts on land degradation — we check the effects on severely, intermediately, and non-degraded pastureland; (iii) we then proceed in showing the responses of deforestation-related variables — that is, natural forest areas and the number of fires; finally, (iv) we compare the effects of slaughterhouse openings for areas under and outside the influence of certification-like, legally-enforced commitments (*TAC*s). After showing the results, we proceed to describing the robustness checks performed to assess the resilience of our methodology choice.

[13]See Section 2 as to understand why we utilize 350-kilometers for TAC-signatory plants.

Our main results are shown in Tables 1 through 4 and Figures 3 through 6. Notice that we display results in a similar format. As mentioned in Section 3, we first show the group aggregated average treatment effects on tables and, subsequently, we present figures with event-study results. This allows us to show the consistency of our results and alleviate concerns about the choice of our research design.

5.1 Effects on Cattle Production and Productivity

We begin by showing the effects of slaughterhouse openings on production variables, particularly on cattle heads, pasture areas and bovine productivity. Table 1 below displays the group aggregate average treatment effects from 1992 to 2019 for 4,086 Brazilian municipalities. After a new opening, the average treated municipality presents a 31% increase in the number of cattle heads raised in its circumscription. In addition, it also shows an increase of approximately 2,4% in pasture areas. Results are shown in columns (i) and (ii) below.

Table 1: Effects on Cattle Heads, Pasture Area, and Bovine Productivity

	Dependent Variable		
	Cattle Heads	Pasture Area	Bovine Productivity
	(i)	(ii)	(iii)
1{Slaughterhouse}	0.3154^{***}	0.0247^{***}	0.0353^{***}
	(0.0756)	(0.0095)	(0.0133)
Year FE	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes
Socioeconomic Covariates	Yes	Yes	Yes

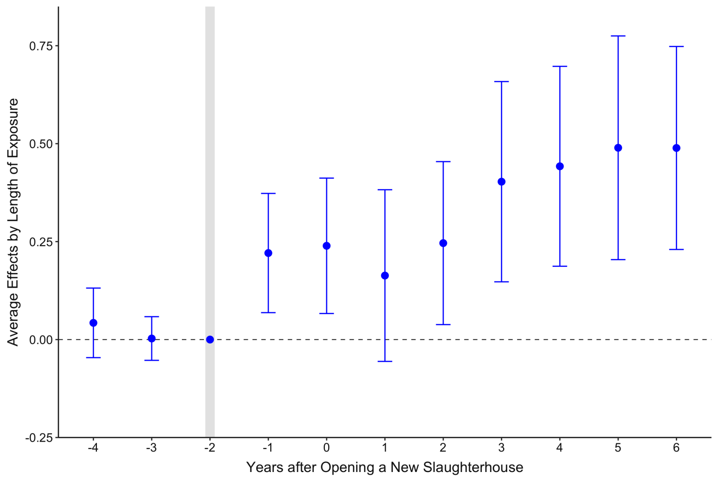
Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", and "Bovine Productivity". All dependent variables were transformed using $log+1$. Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Moreover, since both the amount of raised cattle and pastureland increased as a response to a new opening in a given region, notice that bovine productivity — that is, the amount of heads raised per hectare of pastureland — is also affected: column (iii) in Table 1 displays a marginal increase in bovine productivity. Given Brazil's low starting point in terms of animals per hectare, a 3,5% increase in productivity — though not negligible — is not substantial. In fact, this outcome is consistent with the history of bovine productivity in the country, which has remained relatively low over the past 30 years due to extensive production systems adopted in several regions.

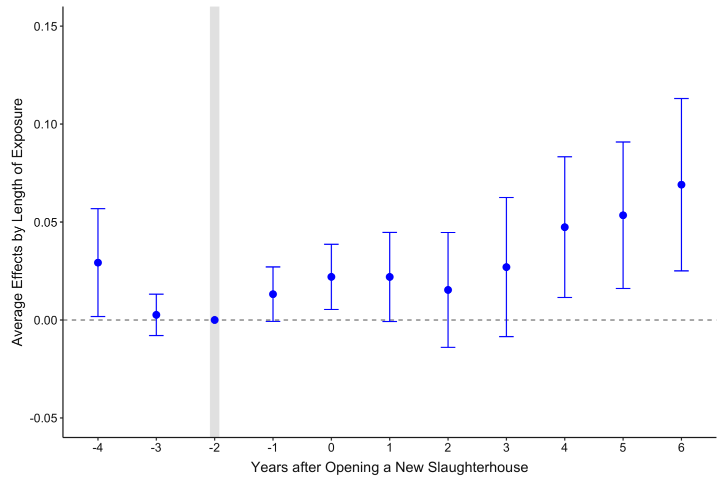
In addition to the group average treatment effects shown in Table 1 above, we also estimate the event-study results which display the average treatment effects by length of exposure. Figure 3 below shows such results. Notice that after a new plant opening, both the number of cattle heads and pasture area present important increases. Take for example the number of cattle heads in panel (a): after 7 years of the beginning of the construction of a new plant, ranchers within 200-kilometers from a municipality which hosts a plant increased their number of cattle heads by approximately 50% relative to the year before construction started. Given the amount of bovines in Brazil over the period of our analysis, this represents over 15,000 heads of cattle in addition to previously existing bovines. Furthermore, the cumulative impact of the increase in pastureland is also significant — see panel (b).

Reinforcing the results in Table 1, the event-study on bovine productivity shows relatively lower and weaker effects of plant openings. This is consistent with an increase in both the number of heads and pasture area. As a consequence, one may conclude that ranchers, when faced with higher demand for cattle, expanded production substantially more on the extensive margin and did not seek to improve productivity in a similar fashion.

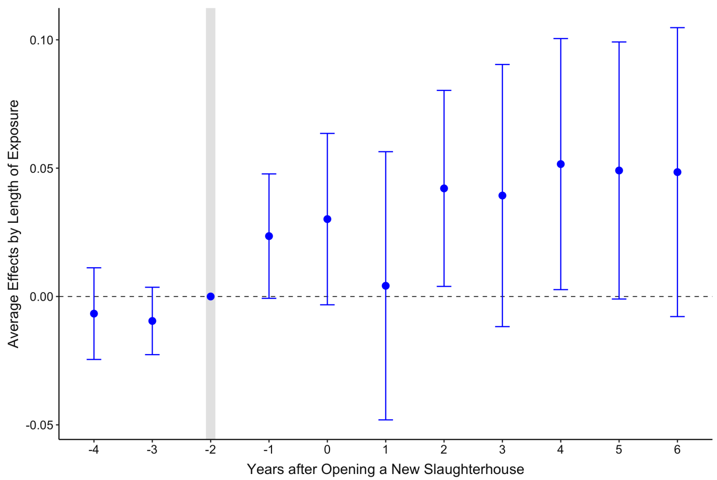
Figure 3: Production Responses to Slaughterhouse Openings: Cattle Heads, Pasture Areas and Bovine Productivity



(a) Cattle Heads



(b) Pasture Area



(c) Bovine Productivity

Notes: This figure presents the results of Equation (1) using the dynamic effects for production variables. Panel (a) displays the effects on the number of cattle heads. Panel (b) shows the impacts on pastureland, measured in hectares. Finally, panel (c) presents the response of bovine productivity, measured by number of heads per hectare. Period -1 is the first treatment period due to anticipation.

5.2 Effects on Land Degradation

Next we show the impacts of slaughterhouse openings on land degradation. In particular, we focus on the degree of pastureland degradation. We begin by displaying the group aggregate effects for severely, intermediately, and non-degraded areas in Table 2 below. Notice that both severely and intermediately degraded pasture areas increased substantially while opening a new plant had no statistical effects on non-degraded pastureland.

Table 2: Effects on the Degrees of Degradation for Pastureland

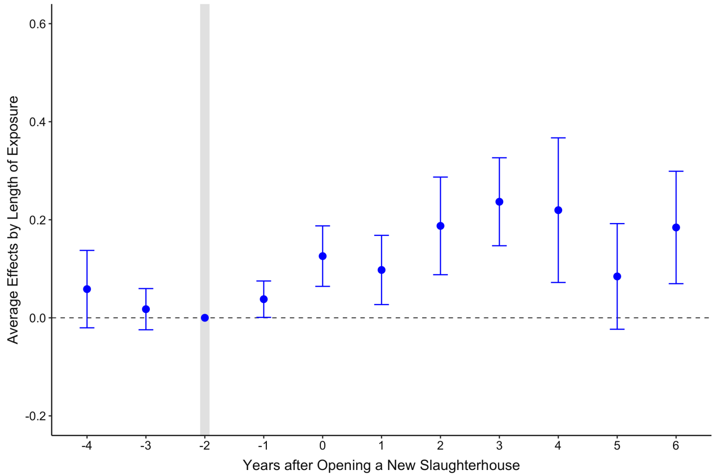
	Dependent Variable			
	Severely Degraded	Intermediately Degraded	Degraded (Total)	Non-Degraded
	(i)	(ii)	(iii)	
1 {Slaughterhouse}	0.1769***	0.1012***	0.0843***	-0.0399
	(0.0273)	(0.0265)	(0.0243)	(0.0252)
Year FE	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes
Socioeconomic Covariates	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Severely Degraded Pastureland", "Intermediately Degraded Pastureland", and "Non-Degraded Pastureland". All dependent variables were transformed into $log+1$. Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

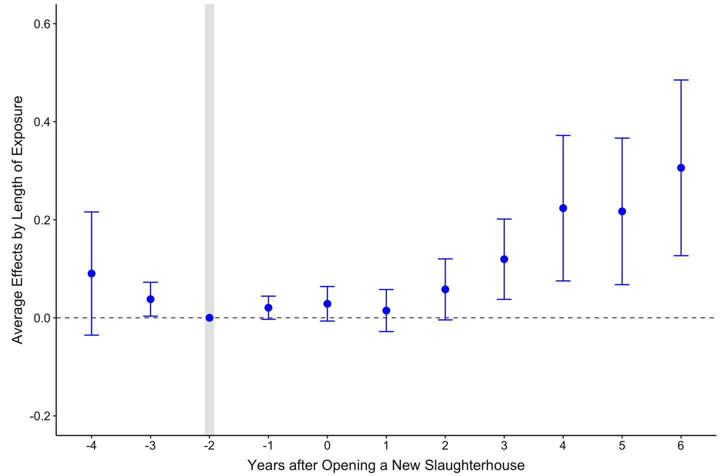
As seen the previous section, ranchers chose to increase the number of cattle heads and the amount of pasture areas as a response to new openings — without substantially augmenting cattle productivity. Together with the results from Table 2 above, we also suggest that ranchers made another relevant choice: to overgraze pasture areas, leading to increased pasture degradation. Since one cannot place more cattle heads in a degraded pasture area, a greater amount of degraded lands is both a consequence and a cause of stagnant bovine productivity.

We also estimate the event-study results for land degradation and display them in Figure 4 below. One may notice in panels (a) and (b) that there is a substantial and consistent increase in degraded areas after a new plant opening. In contrast, we find no clear pattern on non-degraded pasture areas, as one may notice on panel (c). As mentioned in the paragraph above, new openings lead to more relative land degradation in the form of degraded pastureland. Our estimations suggest that the combined cumulative increase in degradation is approximately equal to the increase in pastureland from the previous section — in other words, almost an equivalent area to the newly added pastureland becomes degraded after a new plant opening.

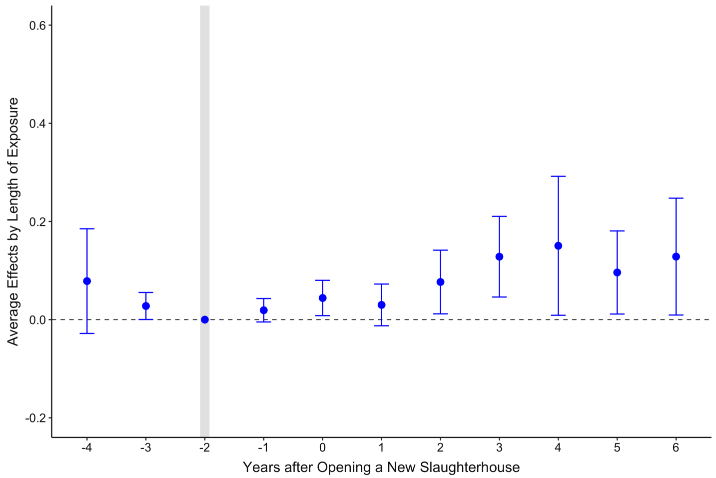
Figure 4: Pasture Degradation Responses to Slaughterhouse Openings: Severely, Intermediately, Total and non-Degraded Pasture Areas



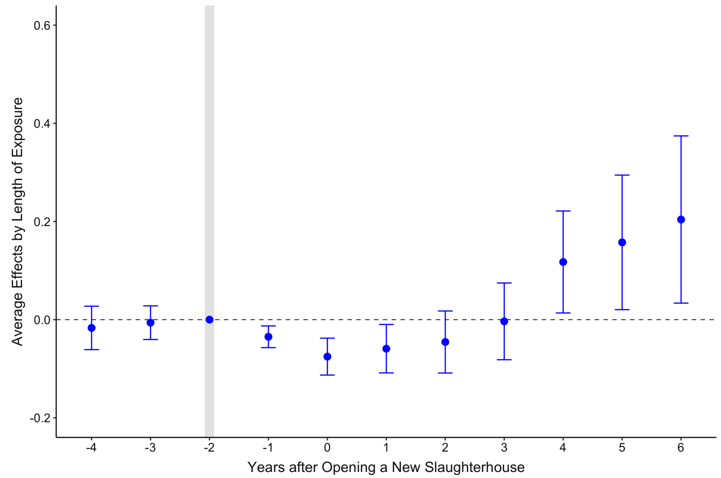
(a) Severe Degradation



(b) Intermediate Degradation



(a) Total Degradation



(c) Non-Degradation

Notes: This figure presents the results of Equation (1) using the dynamic effects for pasture degradation variables. Panel (a) displays the effects on severely degraded areas. Panel (b) shows the impacts on intermediately degraded areas. Finally, panel (c) presents the response of non-degraded areas. All areas are measured in hectares. Period -1 is the first treatment period due to anticipation.

5.3 Effects on Land-Use

Our results so far suggest that ranchers increased cattle production by augmenting pasture areas and at the cost of its quality. However, the increase in pastureland may have come at an even higher cost: either from the conversion of previous agricultural areas or by the clearing of native vegetation. In Table 3 below we display the group aggregate average treatment effects of slaughterhouse openings on natural forest areas and the number of fires in the average municipality.

Notice that natural forest areas present an average decrease of around 3,6% — that is, more deforestation is taking place as a response to new slaughterhouse openings across the country. Moreover, this decrease in natural forest areas is consistent with the choice of ranchers to increase their pastureland. It is also sound with the high rates of forest loss experienced in Brazil during our period of analysis.

Although deforestation has often being associated with fires (e.g., Menezes et al., 2021), we find the opposite: the number of fires present a strong negative response after a new opening. On average, the number of fires fall by approximately 24%. This may be counter-intuitive at first, since fires have been used as a land-clearing method for centuries. However, there are several reasons why that might be the case, including two relevant ones: (i) we find that degraded pasture areas increased after a new plant openings, which could lower the subsequent number of fires due to less organic matter above soil subjected to burning; and (ii) new and more efficient land-clearing techniques have been introduced over the past decades, avoiding unnecessary fires and the risk of spreading them uncontrollably.

In Figure 5 below we display the results of our event-study design for both natural forest areas and the number of fires — panels (a) and (b), respectively. We find that both outcome variables show a negative response to receiving a new plant within a 200-kilometer radius, consistent with the group aggregate effects we mentioned in the paragraphs above.

5.4 Certification-Like, Legally-Enforced Commitments

Our results so far suggest that slaughterhouse openings lead to more cattle demand. To satisfy this demand, ranchers increase their cattle numbers and pasture areas, as to raise more heads. This expansion takes place extensively: we have shown that bovine productivity did not augment as a response to new plant openings; in addition, pasture quality — as measured by the degree of degradation of pasture areas — has worsened; as a consequence, land-use change from natural forest areas to pastureland has taken place to increase the

Table 3: Effects on Natural Forest Area and Number of Fires

	Dependent Variable	
	Natural Forest Area	Number of Fires
	(i)	(ii)
1 {Slaughterhouse}	-0.0361***	-0.2423***
	(0.0028)	(0.0653)
Year FE	Yes	Yes
Municipality FE	Yes	Yes
Weather Covariates	Yes	Yes
Socioeconomic Covariates	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Natural Forest Area" and "Number of Fires". All dependent variables were transformed into $log+1$. Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

area of pasture for cattle.

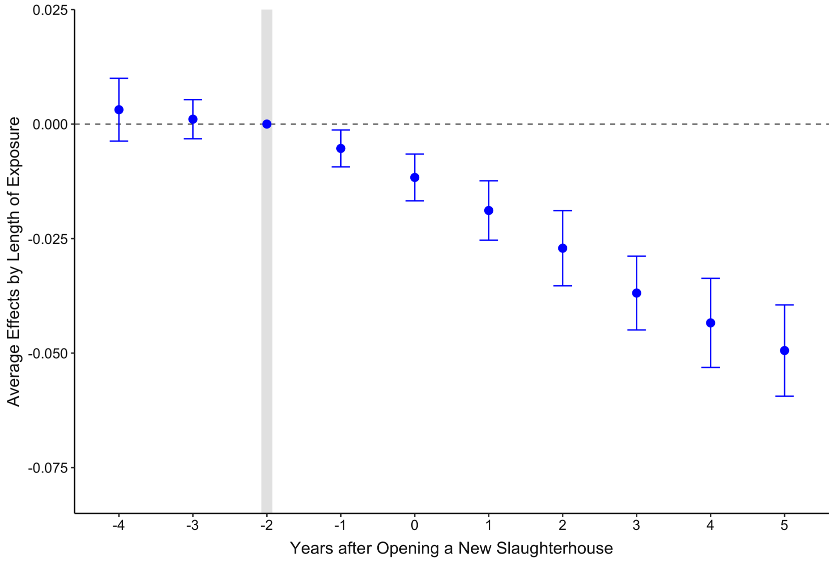
The story presented above supports the notion that there exists a trade-off between preserving the environment and promoting agricultural production in Brazil. Nonetheless, this trade-off may be influenced by contextual factors, such as the absence of available native lands for ranchers to expand onto or the enforcement of environmental regulations that forbid further land-use conversion. In such cases, ranchers would need to pursue alternative approaches to expanding production in order to meet the rising demand for cattle by slaughterhouses. With that in mind, we investigate how agreeable-enforcement might decouple land-dependent industrial activity from deforestation and degradation. In particular, we look into the certification-like, legally-enforced commitments (TACs) explained in Section 2.

In order to perform the analysis, we subset our data from 2009 onward and divide municipalities into categories: (i) those under the influence of TAC commitments; and (ii) those outside this influence area.[14] As mentioned in Section 2, the TAC area coincides massively with the Amazon region — mainly because slaughterhouses in that part of the country were the ones to sign the commitments. We then proceed by applying the same empirical design as described in Section 3 — that is, the staggered DiD with slaughterhouse openings with 200-kilometer radius —, but using our new subsets of the original data.[15] Re-

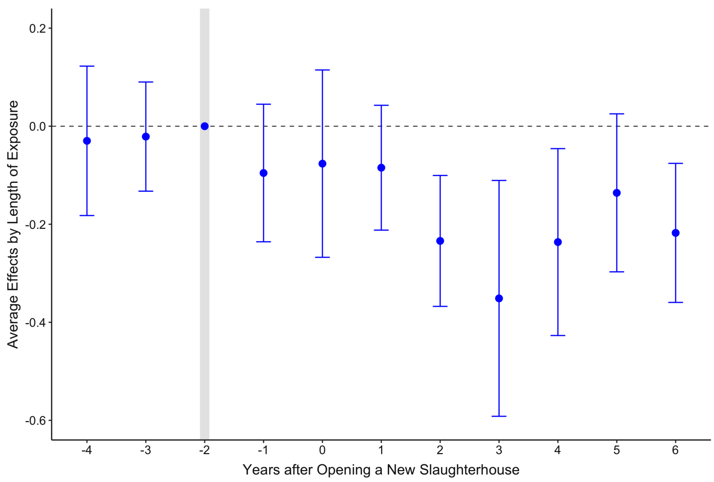
[14]Recall that an area under TAC influence is given by the buying radius of a signatory slaughterhouse. In other words, it encompasses the municipalities up to the 200-kilometer radius of the centroid of localities that host a slaughterhouse.

[15]Notice that in Section 2 we mention that slaughterhouses in the Amazon region have more distant buying radius, up to 350 kilometers. We thus consider the area under TAC influence to be municipalities within such radius from slaughterhouse plants. Nevertheless, in our baseline specification for identifying the impacts of new openings on our outcomes of interest in the TAC-influence region, we still use the 200-kilometer radius

Figure 5: Environmental Responses to Slaughterhouse Openings: Natural Forest Area and Number of Fires



(a) Natural Forest Areas



(b) Number of Fires

Notes: This figure presents the results of Equation (1) using the dynamic effects for environmental variables “Natural Forest Area" and “Number of Fires". Panel (a) displays the effects on natural forest areas, measured in hectares. Panel (b) shows the impacts on the number of fires, measure by the count of fires. Period -1 is the first treatment period due to anticipation.

sults are displayed in Table 4, showing the outcomes for each dependent variable in both TAC and non-TAC areas.

As one may notice below, bovine productivity increased in TAC areas and decreased in non-TAC areas. Consistently, our measure of degraded pastureland presented a sharp decrease in areas of TAC influence: that is, pasture quality improved in such areas and could support more animals per hectare. Non-TAC areas, on the other hand, showed an increase in degraded pastureland as a response to a new plant opening — consistent with the pattern we identified for the whole country in the previous sections.

Table 4: Effects on Bovine Productivity, Pasture Degradation, and Natural Forest Area

	Dependent Variable					
	Bovine Productivity		Degraded Pastureland		Natural Forest Area	
	TAC	Non-TAC	TAC	Non-TAC	TAC	Non-TAC
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
1 {Slaughterhouse}	0.0689***	-0.1385***	-0.2207***	0.1931***	0.0024	-0.0575***
	(0.0244)	(0.0481)	(0.0553)	(0.0494)	(0.0175)	(0.0186)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Socioeconomic Covariates	Yes	Yes	Yes	Yes	Yes	Yes

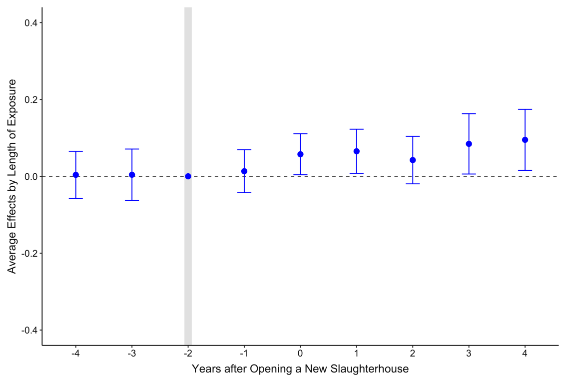
Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Bovine Productivity", "Degraded Pastureland", and "Natural Forest Area". All columns take covariates into account. All dependent variables were transformed into $log + 1$. Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Due to increased efficiency and less degradation on existing pastureland, the regions that were subject to TAC commitments did not exhibit any significant changes in their natural forest areas following new plant openings. In simpler terms, areas that fell under the influence of certification-like, legally-enforced agreements did not experience more deforestation. Instead, they displayed a boost in cattle productivity and a decline in pastureland degradation. In contrast, the non-TAC regions followed the same trend as in the previous sections, displaying a strong adverse impact on natural forests after new plant openings.

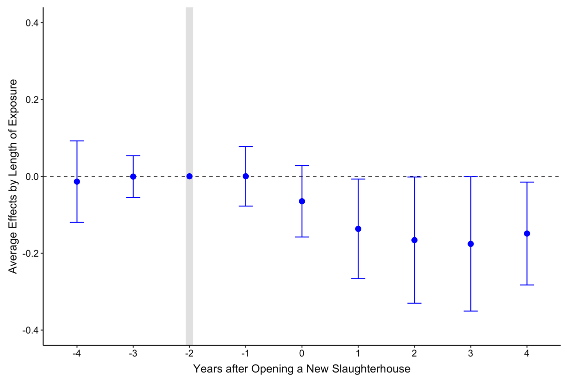
In Figure 6 below we display the event-study results for each of the variables above. We also divide our outcomes between TAC areas and non-TAC areas and show them in panels (a) through (f). Reassuringly, our story remains consistent when taking into account the latter approach as well.

to maintain consistency with previous results. In the interest of full disclosure, we also perform a robustness check in which we consider the treatment (opening a new plant) to be up to the 350-kilometer radius. See Section 5.5 for more details.

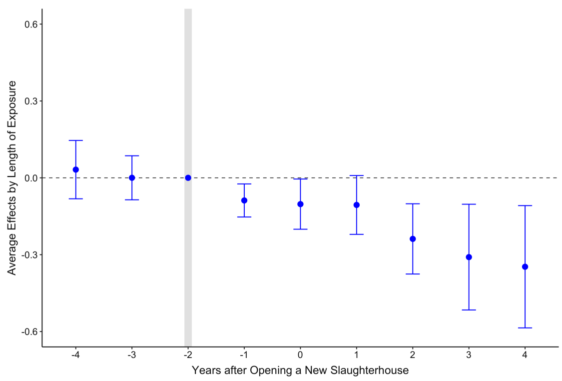
Figure 6: Responses of TAC and non-TAC Areas to Slaughterhouse Openings



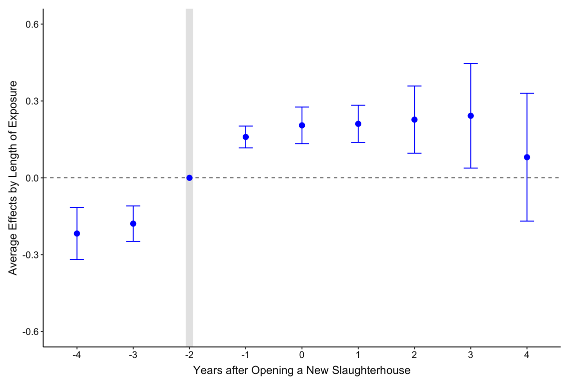
(a) TAC: Productivity



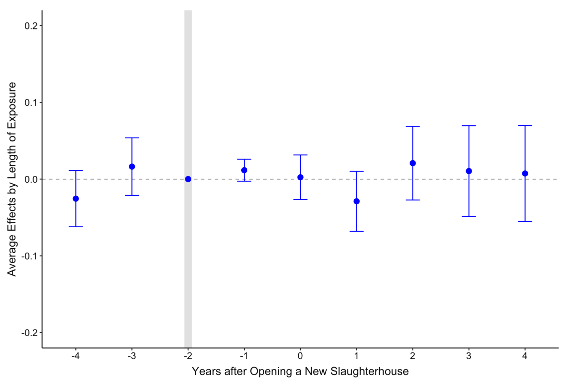
(b) Non-TAC: Productivity



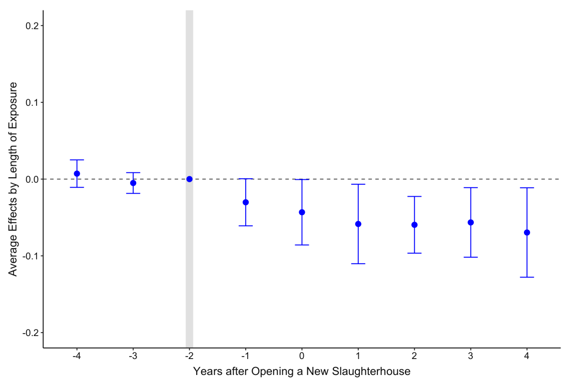
(c) TAC: Degraded Pastureland



(d) Non-TAC: Degraded Pastureland



(e) TAC: Natural Forest Area



(f) Non-TAC: Natural Forest Area

Notes: This figure presents the results of Equation (1) using the dynamic effects for areas under and outside the influence of TAC commitments. Panels (a) and (b) display the effects of slaughterhouse openings on bovine productivity for TAC and non-TAC areas, respectively. Panels (c) and (d) show the impacts on degraded pastureland (given by the sum of severely and intermediately degraded pasture areas) for TAC and non-TAC areas. Finally, panels (e) and (f) present the responses of natural forest areas for areas under TAC and non-TAC, respectively. Period -1 is the first treatment period due to anticipation.

5.5 Robustness Checks

We perform various robustness checks in order to verify the validity of our choice for research design. In the exercises below, we follow a similar format: we test results for cattle heads, pasture areas, degraded pastureland, and natural forest areas. In the Online Appendix, we first show the aggregate coefficients in Appendix Tables A.2 to A.7 and then display the study-event results from Appendix Figures A.1 to A.9.

Alternative Variable Transformations. We begin by showing our results with different transformations on dependent variables: we perform an analysis at level and using the inverse hyperbolic sine transformation.[16] Results are shown in Appendix Table A.2 and Appendix Figure A.1. As one may notice, our results remain qualitatively the same using these alternative variable transformations — though, in a few cases, pre-trends emerge. We also perform a robustness check following a recent recommendation by Chen and Roth (2022), according to which we use the logarithm transformation on observations greater than 0 and a constant for observations equal to 0. We display the results in Appendix Table A.4, and they remain largely robust to this transformation — one can interpret such results in terms of the intensive margin (that is, when one values the change between positive values of observations).

Alternative Radiuses from Plants. Our main specification makes use of the 200-kilometer radius from slaughterhouse plants to investigate the effects of new openings. Although well documented by Franco (2013), the distance for buying cattle for slaughterhouses could, in theory, vary. We test this hypothesis by changing the distances from slaughterhouses for treated municipalities using 100-kilometer and 300-kilometer radiuses. We display results on Appendix Table A.3 and Appendix Figure A.2. Notice that, in doing so, we take into account a lower number of municipalities for the sample with 100-kilometer radius — 2,558 localities — and a relatively higher number for the sample with 300-kilometer radius — 4,553. Reassuringly, our results remain robust to varying distances.

Alternative Control Group. Our baseline approach uses as control group “not-yet-treated" municipalities. By definition, localities which qualify as not-yet-treated are those which eventually receive treatment in the data panel — i.e., a new slaughterhouse opening within a 200-kilometer radius. For disclosure, we test our results using a different control group: never-treated municipalities. We display results in Appendix Table A.5 and Appendix Figure A.3. Once more, our results remain qualitatively the same under a different control group.

[16] Recall our baseline approach utilizes the $log + 1$ transformation.

Alternative Event-Study Estimators. Although we sustain the difference-in-differences approach by Callaway and Sant'Anna (2021) is best suited for our analysis of the effects of slaughterhouse openings on the environment, we also utilize alternative developments in the literature to assess the robustness of our results. We run Equation (1) *without* covariates to calculate several estimators introduced by Sun and Abraham (2021), Roth and Sant'Anna (2021), Gardner (2022), and Borusyak et al. (2021). These estimators utilize different hypotheses for estimating treatment effects and calculating standard errors.

Briefly, the latter two approaches are "imputation-based" estimators and rely on residualizing the outcome variable and then averaging it to estimate the event-study average treatment effect — their main difference is in their asymptotic approach to estimating standard errors. The former two approaches estimate average treatment effects based on group-pairs, using a two-period difference-in-differences estimator; moreover, they differ in their control groups, since Sun and Abraham (2021) utilize the last treated unit while Roth and Sant'Anna (2021) use not-yet-treated units as controls (Butts and Gardner, 2022).

For full disclosure, we also run our baseline approach based on Callaway and Sant'Anna (2021) (*without* covariates) and the Two-Way Fixed Effects (TWFE) event-study estimation.[17] We display the event-study results in Figures A.4 through A.7. Notice that we do not utilize universal base periods in this robustness check — instead, we use the estimated pseudo-treatment effects for pre-periods in each approach.

Qualitatively, all estimators point at the same direction, telling us a similar story as in our baseline results: cattle heads, pasture areas and pastureland degradation increased substantially as a response to new plant openings, while natural forest areas decreased.

Alternative Radius For Plants in the Amazon. Barreto et al. (2017) shows that slaughterhouse plants in the Amazon region may buy cattle up to 350 kilometers away. In fact, we utilize such radius to find the influence area of certification-like, legally-enforced commitments (TACs) in the Amazon. However, in our baseline results, to keep consistency, we still use the 200-kilometer radius to define the treated municipalities inside that influence area. In the interest of full disclosure, we perform the same analysis using the 350-kilometer radius as treatment for TAC regions. Our results are shown in Appendix Table A.6. In comparison with our baseline outcomes, results remain very close.

Placebo Test With Alternative Slaughterhouses. Our baseline results with treated municipalities given by slaughterhouse openings within a 200-kilometer radius yield an interesting story: after an opening of a new plant, nearby localities present an increase in the

[17] Although conceptually incorrect due to heterogeneous treatment effects, we choose to display TWFE results for comparison.

number of cattle heads raised, and pastureland increases at the cost of both natural forest areas and pasture quality. We now test if that story is dependent on the specific treatment we took into account: a *bovine*-slaughterhouse opening. We check whether another type of slaughterhouse opening, in particular those related to *swines*, had similar impacts on our outcomes of interest as their bovine counterparts.[18]

Recall that bovine production is a land-intensive activity in Brazil, currently using more than 155 million hectares to raise over 200 million heads of cattle. Differently from bovines, production systems for swines are intensive in capital and labor, not land (e.g., EMBRAPA, 2023a; EMBRAPA, 2023b). As a consequence, this placebo exercise with openings of swine-slaughterhouses instead of bovine-slaughterhouses should yield different outcomes than our baseline design. In particular, one should expect different results specially in terms of deforestation via pasture areas.

We show the effects of swine-slaughterhouse openings on cattle heads, pasture areas, pasture degradation and natural forest area in Appendix Table A.7. One may notice that our previous story about new openings does not hold with swine-related plants: there are no effects on pasture areas nor cattle heads. In particular, we also find no effects on natural forest areas.

As expected, substituting our baseline treatment with a different type of slaughterhouse opening — swine, in this case — yielded null results relative to our previous story. This reinforces our main hypothesis: land-intensive industries may lead to a trade-off between environmental preservation and production.

Placebo Test With Timing Randomization. We also create placebo exercises based on the concept of timing randomization inference. The concept is relatively simple: we shuffle the opening dates for slaughterhouses across Brazil first 50 and then 100 times and re-run our staggered regression by Callaway and Sant'Anna (2021) with these random dates. Subsequently, we plot the event-study median coefficients and standard errors, and build a density plot showing the distribution of group aggregate average treatment coefficients. We display results in Appendix Figures A.8 and A.9. Again, performing these placebo exercises reinforces the robustness of our baseline approach: all our analyses yielded null effects on our outcomes of interest.

[18]We collected data on federally-inspected swine-slaughterhouses using the same database and methodology as described for bovine-slaughterhouses in Section 4. We perform the same procedure for defining the 200-kilometer radius from the centroid of each host municipality, thus yielding the treated municipalities in our sample. Our baseline approach using bovine-slaughterhouse openings yields a total of 4,086 localities eventually impacted by plant openings. Swine-slaughterhouse openings impact 1,940 localities across the period we analyze.

6 Conclusion

This paper investigates how land-intensive industrial activity may impact local production and environmental variables — an overlooked issue by the economics literature. We show that opening new slaughterhouse industrial plants lead to extensive production responses by ranchers. In particular, we demonstrate that they respond to the higher demand for cattle by raising a greater number of heads and augmenting their pasture areas.

Moreover, we also investigate the effects of plant openings on a novel variable: land degradation. We show that the degree of degradation of pasture areas worsen after a new opening. Interestingly, this is consistent with the fact that bovine productivity does not change after a new slaughterhouse opening — a result we also find. As a consequence, the response of ranchers to a new slaughterhouse opening comes at the cost, at least partially, of the quality of their pasture areas.

Apart from the effects on production and land-cover described above, we study whether these new plant openings have any effects on land-use change. In particular, we analyze the impacts on natural forest areas and fires. In accordance with the previous result on production at the extensive margin, we find that new plant openings lead to a decrease in natural forest areas within the 200-kilometer. In essence, this translates into more deforestation of native areas to substitute away for pastureland. We also show that the number of fires presents a decrease, a result we attribute to more degraded pastureland which makes pasture areas less prone to catching on fire.

Given our story above, we dig deeper to understand whether it is possible to decouple industrial activity from deforestation and degradation. In order to comprehend the feasibility of this type of decoupling, we study how exposure to certification-like, legally-enforced commitments (or the TAC agreements) might influence our results. We separate Brazilian municipalities into two regions: one which was under the influence of TACs and another which was not.

Whilst for the latter region most our baseline results hold, we show that for regions under TAC influence new slaughterhouse openings lead to more bovine productivity and pasture quality. As a consequence, we also find that natural forest areas are not impacted by new openings. These outcomes suggest that agreeable-enforcement is boosting environmental conservation through improvements in the intensive margin: ranchers still increase production, but instead of doing so extensively — as in our baseline setting —, they do it intensively.

Policymakers can withdraw important lessons from our work. In settings with high supply of land and relatively low environmental enforcement, land-intensive industrial activity may have relevant impacts: from deforestation and degradation to low productivity changes. However, in cases in which there is government-and-market-led enforcement, outcomes may be the opposite: constraints on land-expansion may lead to more productive and less-degraded production systems.

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Industrial Activity and Land Degradation: Evidence from Slaughterhouse Openings in Brazil

Da Mata, Dotta and Severnini

Appendix A Additional Figures and Tables

Table A.1: Summary Statistics

Statistic	Unit	N	Mean	St. Dev.	Min	Max	Period	Source
Cattle Heads	Count	155,596	34,343.8	78,108.2	0	2,282,445	1992-2019	IBGE/PPM
Pastureland	Hectares	155,708	29,227.8	61,997.5	0.0	1,748,281.0	1992-2019	MapBiomas
Bovine Productivity	Heads/Hectare	155,471	13.7	715.9	0.0	242,263.8	1992-2019	IBGE and MapBiomas
Severe Deg. Past.	Hectares	109,895	7,618.3	27,987.5	0.1	1,374,166.0	2000-2019	LAPIG
Interm. Deg. Past.	Hectares	110,692	12,825.2	28,153.3	0.1	674,656.7	2000-2019	LAPIG
Non-Deg. Past.	Hectares	110,624	10,647.3	26,182.2	0.1	1,039,674.0	2000-2019	LAPIG
Natural Forest Area	Hectares	155,708	97,003.3	510,290.0	0.0	15,619,507.0	1992-2019	MapBiomas
Number of Fires	Count	83,669	53.3	204.7	1	13,079	2000-2019	INPE
Population	Count	154,924	26,401.3	168,515.5	555	9,652,391	1991	*Atlas dos Municípios*
Illiteracy Rate	Percentage	154,924	32.9	17.5	1.8	88.3	1991	*Atlas dos Municípios*
Poverty Rate	Percentage	154,924	56.7	23.6	2.8	98.3	1991	*Atlas dos Municípios*
Average Rain	Millimeters	155,568	1,348.3	424.0	0.0	3,623.7	1960-1991	Da Mata and Resende (2020)
Average Temp.	Celsius	155,568	22.0	3.6	0.0	29.4	1960-1991	Da Mata and Resende (2020)
$1\{\text{Slaughterhouse}_{0km}\}$	Count	155,708	147	-	0.0	1	1992-2019	Estimated
$1\{\text{Slaughterhouse}_{100km}\}$	Count	155,708	2,558	-	0.0	1	1992-2019	Estimated
$1\{\text{Slaughterhouse}_{200km}\}$	Count	155,708	4,086	-	0.0	1	1992-2019	Estimated
$1\{\text{Slaughterhouse}_{300km}\}$	Count	155,708	4,553	-	0.0	1	1992-2019	Estimated

Notes. This table presents the descriptive statistics of all relevant variables taken into account in the estimations. Observations range from 1992 to 2019. The subscripts in the indicator variables relate to the radius which slaughterhouses may acquire cattle and its count is in municipalities affected by such radius.

Table A.2: Robustness Check: using Levels and the Inverse Hyperbolic Sine (Asinh) on the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area

	Dependent Variable							
	Cattle Heads		Pasture Area		Degraded Pastureland		Natural Forest Area	
	Level	$Asinh$	Level	$Asinh$	Level	$Asinh$	Level	$Asinh$
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
1{Slaughterhouse}	7728***	0.3324***	3461***	0.0255***	800*	0.0854***	-4643***	-0.0361***
	(1466)	(0.0807)	(859)	(0.0100)	(414)	(0.0230)	(1096)	(0.00289)
Socioec. Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", "Degraded Pastureland", and "Natural Forest Area". Columns (i), (iii), (v), and (vii) present results following our baseline approach but with dependent variables at level. Columns (ii), (iv), (vi), and (viii) present results following our baseline approach but with dependent variables transformed using $asinh$. Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Table A.3: Robustness Check: using 100-kilometer and 300-kilometer Radiuses to Estimate the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area

	Dependent Variable							
	Cattle Heads		Pasture Area		Degraded Pastureland		Natural Forest Area	
	100km	300km	100km	300km	100km	300km	100km	300km
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
1{Slaughterhouse}	0.1023	0.3969***	-0.0095	0.0725***	0.0866***	0.1037	-0.0141***	-0.0414***
	(0.0547)	(0.0813)	(0.0065)	(0.0148)	(0.0133)	(0.0416)	(0.0027)	(0.0038)
Socioec. Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", "Degraded Pastureland", and "Natural Forest Area". Columns (i), (iii), (v), and (vii) present results following our baseline approach but with dependent variables at level. Columns (ii), (iv), (vi), and (viii) present results following our baseline approach but with dependent variables transformed using log — we remove values below 1 to avoid problems in our transformation, thus excluding some observations for cattle heads, pasture area, degraded pastureland, and natural forest area (we exclude 4,675, 2,856, 53, and 24 out of 155,708 original observations, respectively). Control group is "not-yet-treated" and anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Table A.4: Robustness Check: using Chen and Roth (2022)'s transformation on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area

	Dependent Variable			
	Cattle Heads	Pasture Area	Degraded Pastureland	Natural Forest Area
	(i)	(ii)	(iii)	(iv)
1{Slaughterhouse}	0.3399***	0.025**	0.0855***	-0.0361***
	(0.0822)	(0.0115)	(0.0249)	(0.0028)
Socioec. Covariates	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", "Degraded Pastureland", and "Natural Forest Area". Columns (i), (iii), (v), and (vii) present results following the transformation proposed by Chen and Roth (2022), according to which we apply log to observations greater than 0 and utilize a constant for observations equal to 0 (we use -1 for such observations). The anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Table A.5: Robustness Check: using "Never-Treated" Municipalities as Control Group to Estimate the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area

	Dependent Variable			
	Cattle Heads	Pasture Area	Degraded Pastureland	Natural Forest Area
	(i)	(ii)	(iii)	(iv)
1{Slaughterhouse}	0.3225	0.0429*	0.0737***	-0.0416***
	(0.1748)	(0.0224)	(0.0234)	(0.0042)
Socioec. Covariates	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", "Degraded Pastureland", and "Natural Forest Area". Columns (i), (iii), (v), and (vii) present results following our baseline approach but with a different control group: "never-treated" municipalities. The anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Table A.6: Robustness Check: using the 350-kilometer Radius to Estimate the Effects on Bovine Productivity, Degraded Pastureland, and Natural Forest Area in the Region of Influence of Certification-Like, Legally-Enforced Commitments

	Dependent Variable		
	Bovine Productivity	Degraded Pastureland	Natural Forest Area
	(i)	(ii)	(iii)
1{Slaughterhouse}	0.0245*	-0.1046**	0.0244***
	(0.0141)	(0.0472)	(0.0055)
Socioec. Covariates	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

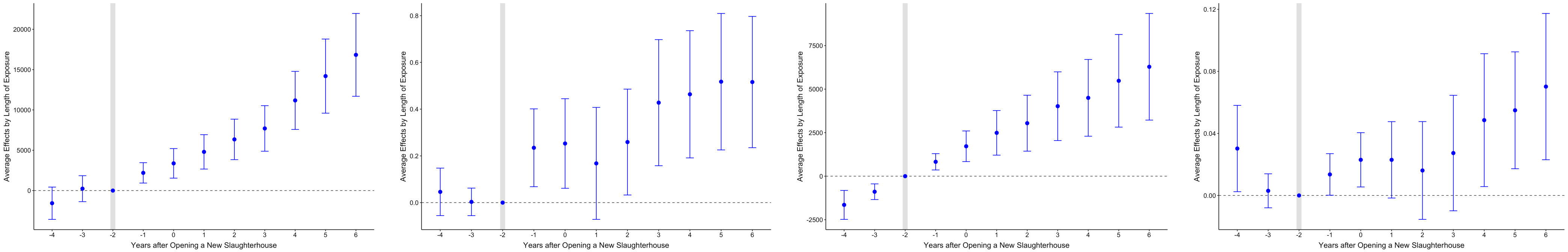
Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Bovine Productivity", "Degraded Pastureland", and "Natural Forest Area". All columns take into account covariates. The anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Table A.7: Robustness Check: using *Swine* Slaughterhouse Openings to Estimate the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area

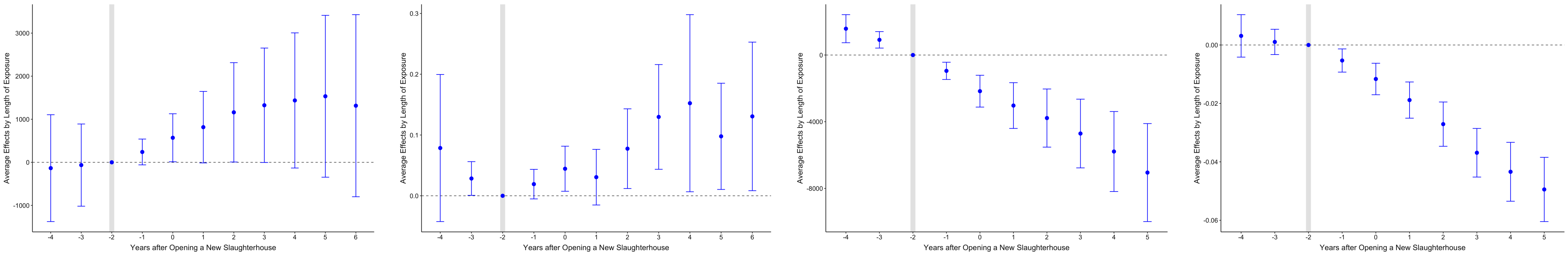
	Dependent Variable			
	Cattle Heads	Pasture Area	Degraded Pastureland	Natural Forest Area
	(i)	(ii)	(iii)	(iv)
1{Slaughterhouse}	-0.0098	-0.00004	0.0551***	-0.0021
	(0.0473)	(0.0065)	(0.0173)	(0.0022)
Socioec. Covariates	Yes	Yes	Yes	Yes
Weather Covariates	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Notes. This table presents the overall summary of ATT's based on group aggregation according to Callaway and Sant'Anna (2021) for the following dependent variables: "Cattle Heads", "Pasture Area", "Degraded Pastureland", and "Natural Forest Area". In this robustness check, we utilize *swine* slaughterhouse openings as treatment for municipalities up to 200-kilometer from the centroid of municipalities which host swine plants. Columns (i), (iii), (v), and (vii) present results following our baseline approach with control group "not-yet-treated" municipalities. The anticipation period equals 1. Statistical significance is given by *p<0.1; **p<0.05; ***p<0.01.

Figure A.1: Robustness Check: using Levels and *Asinh* on the Effects on Cattle Heads and Pasture Area



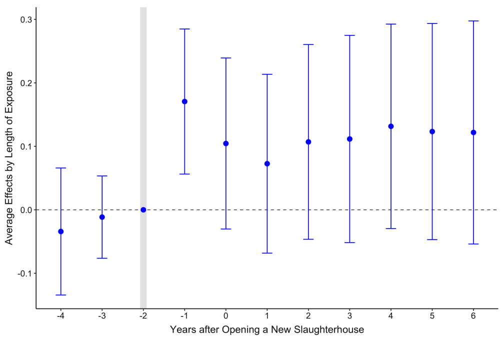
(a) Cattle Heads (Level) (b) Cattle Heads (Asinh) (c) Pasture Area (Level) (d) Pasture Area (Asinh)



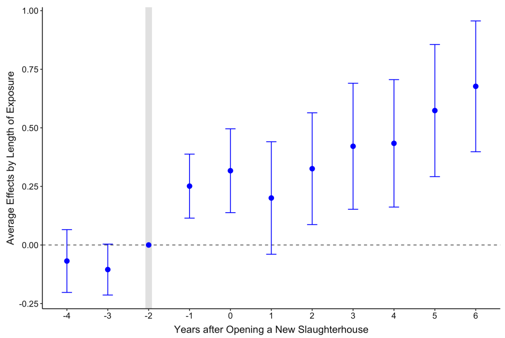
(e) Degraded Pastureland (Level) (f) Degraded Pastureland (Asinh) (g) Natural Forest Area (Level) (h) Natural Forest Area (Asinh)

Notes: This figure presents the results of Equation (1) using dynamic effects for different dependent variable transformations. Panels (a) and (b) display results for cattle heads in levels and *Asinh*, respectively. Panels (c) and (d) show results for pasture area in levels and *Asinh*, respectively. Panels (e) and (f) display results for degraded pastureland in levels and *Asinh*, respectively. Panels (g) and (h) show results for natural forest area area in levels and *Asinh*, respectively. Period -1 is the first treatment period due to anticipation.

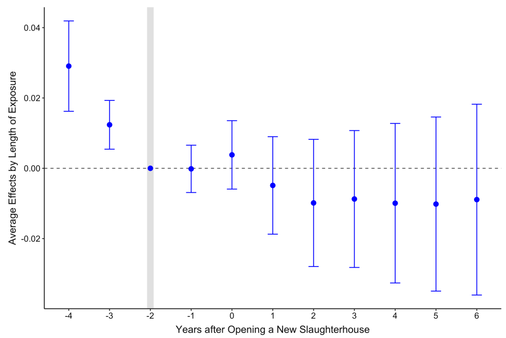
Figure A.2: Robustness Check: using Different Radiuses to Estimate the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area



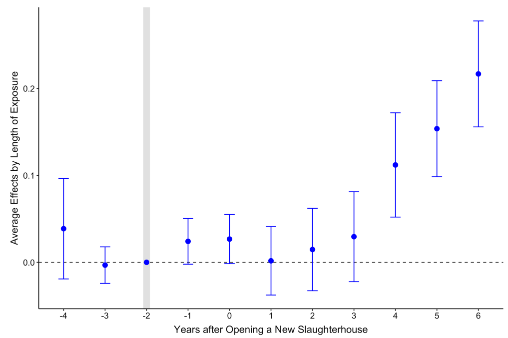
(a) Cattle Heads (100km)



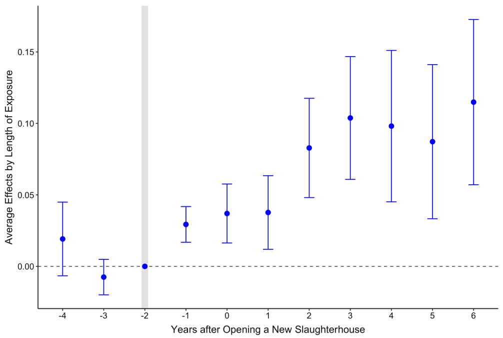
(b) Cattle Heads (300km)



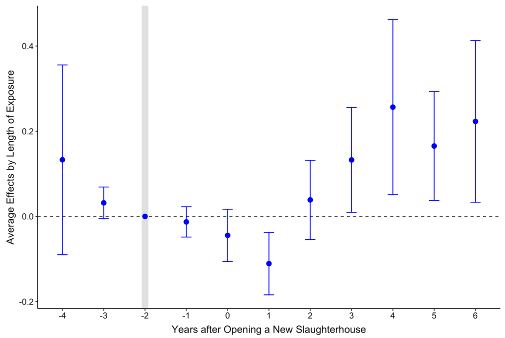
(c) Pasture Area (100km)



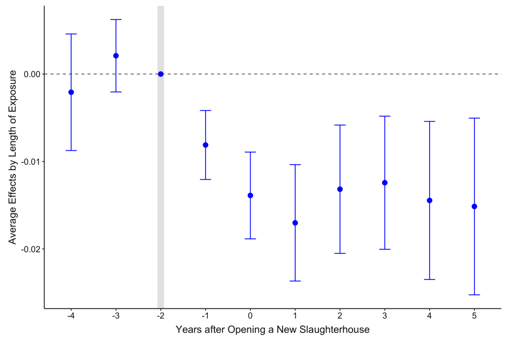
(d) Pasture Area (300km)



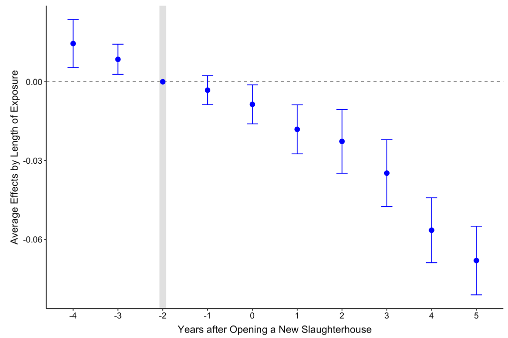
(e) Degraded Pastureland (100km)



(f) Degraded Pastureland (300km)



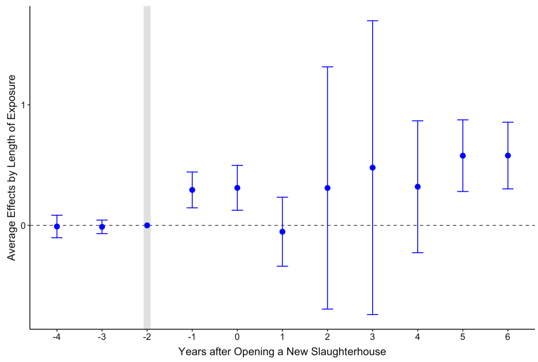
(g) Natural Forest Area (100km)



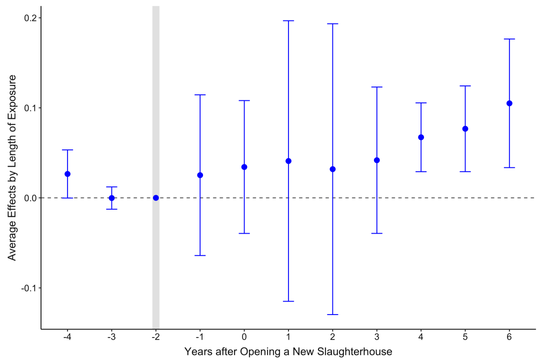
(h) Natural Forest Area (300km)

Notes: This figure presents the results of Equation (1) using the dynamic effects for different radiuses of treatment. Panels (a) and (b) display results for cattle heads for 100km and 300km, respectively. Panels (c) and (d) show results for pasture area for 100km and 300km, respectively. Panels (e) and (f) display results for degraded pastureland for 100km and 300km, respectively. Panels (g) and (h) show results for natural forest area area for 100km and 300km, respectively. Period -1 is the first treatment period due to anticipation.

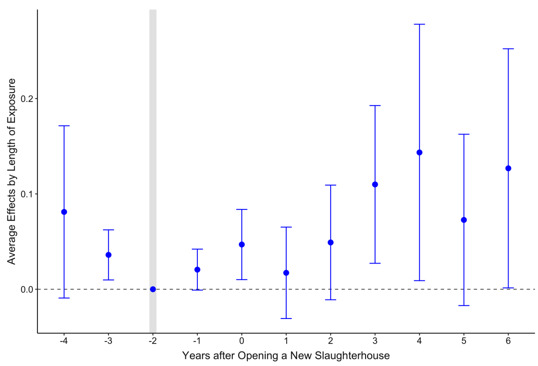
Figure A.3: Robustness Check: using “Never-Treated" Municipalities as Control Group to Estimate the Effects on Cattle Heads, Pasture Area, Degraded Pastureland, and Natural Forest Area



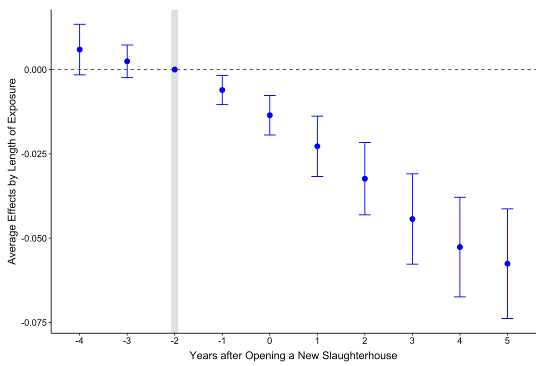
(a) Cattle Heads (100km)



(b) Pasture Area



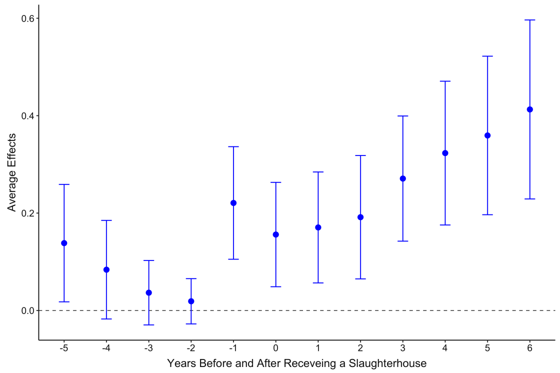
(e) Degraded Pastureland



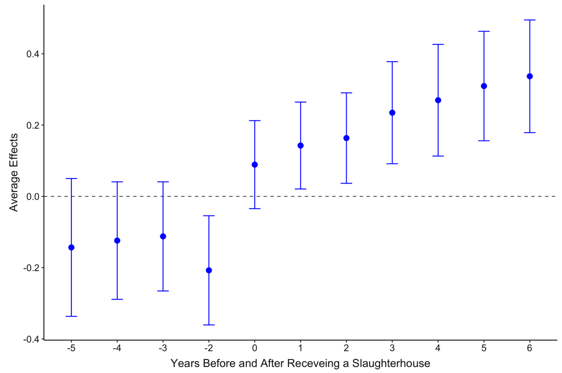
(f) Natural Forest Area

Notes: This figure presents the results of Equation (1) using the dynamic effects for a different control group: never-treated municipalities. Panels (a) and (b) display results for cattle heads and pasture areas, respectively. Panels (c) and (d) show results for degraded pasture areas and natural forest areas, respectively. Period -1 is the first treatment period due to anticipation.

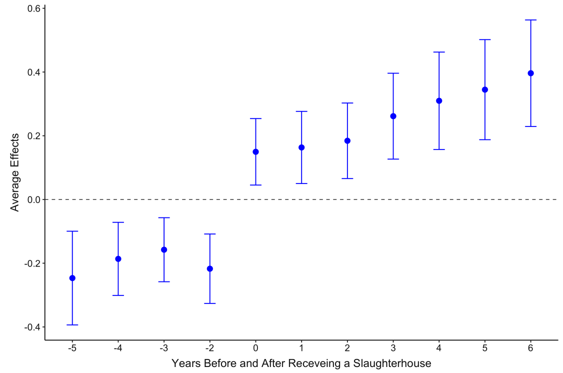
Figure A.4: Robustness Check: Alternative Estimators for Cattle Heads



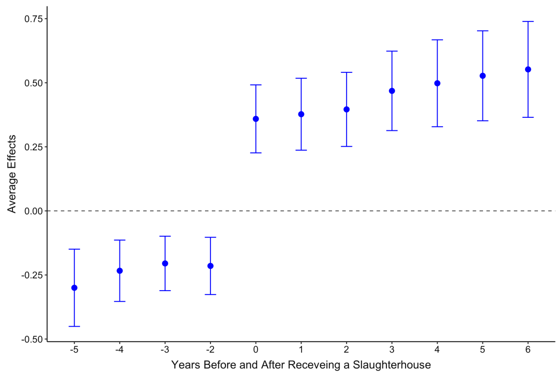
(a) Callaway and Sant'Anna (2021)



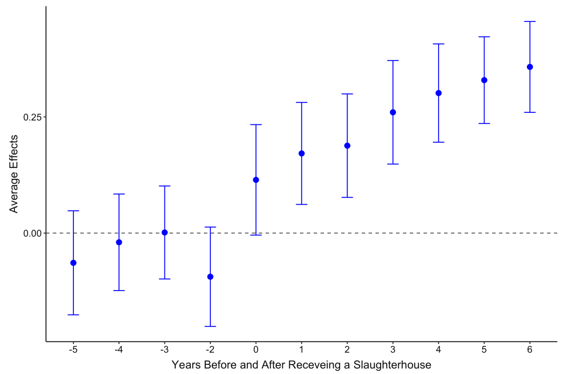
(b) Two-Way Fixed Effects



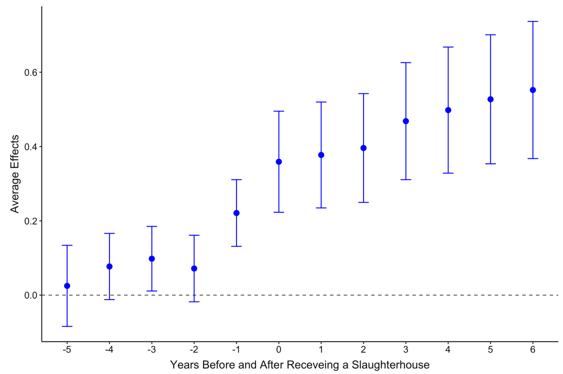
(c) Sun and Abraham (2021)



(d) Borusyak et al. (2021)



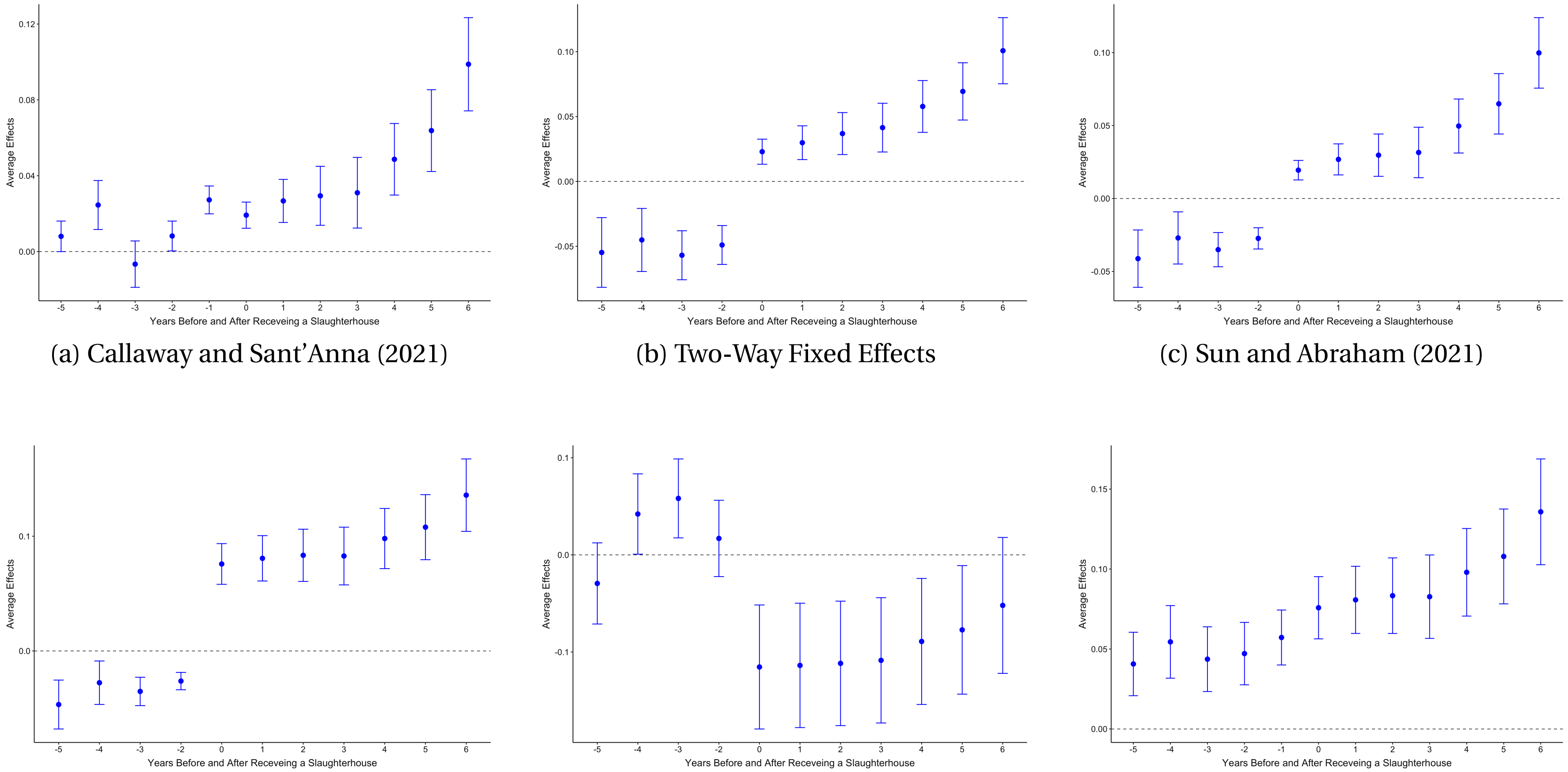
(e) Roth and Sant'Anna (2021)



(f) Gardner (2022)

Notes: This figure presents the results of the alternative estimators described in Section 5.5 for dependent variable “Cattle Heads". Panel (a) display the results of our baseline approach by Callaway and Sant'Anna (2021). Panel (b) shows the TWFE outcomes for comparison — though the estimates are biased due to heterogeneous treatment effects. Panel (c) presents the estimators by Sun and Abraham (2021), which use as control group the last-treated unit. Panel (d) displays the results for estimators using the methodology developed by Borusyak et al. (2021). Panel (e) shows the outcomes for the estimators by Roth and Sant'Anna (2021). Finally, panel (f) presents the estimators following Gardner (2022). Notice that we do not make use of a universal base period, and hence pre-treatment coefficients are not estimated in relation to a given year. Period -1 is the first treatment period due to anticipation and dependent variables are transformed using $log+1$.

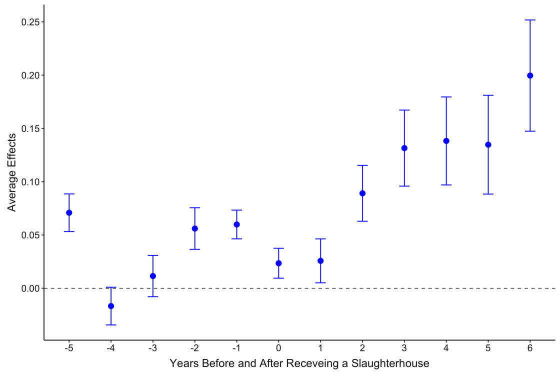
Figure A.5: Robustness Check: Alternative Estimators for Pasture Area



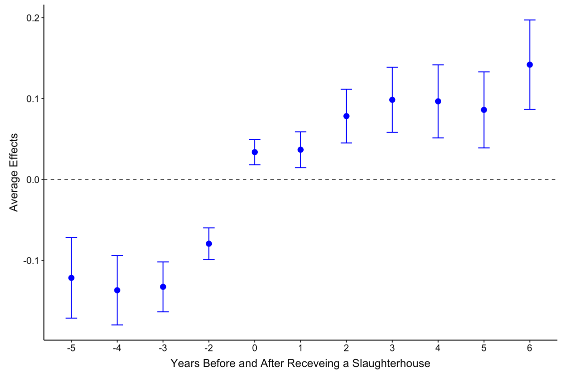
(a) Callaway and Sant'Anna (2021)
(b) Two-Way Fixed Effects
(c) Sun and Abraham (2021)
(d) Borusyak et al. (2021)
(e) Roth and Sant'Anna (2021)
(f) Gardner (2022)

Notes: This figure presents the results of the alternative estimators described in Section 5.5 for dependent variable "Pasture Area". Panel (a) display the results of our baseline approach by Callaway and Sant'Anna (2021). Panel (b) shows the TWFE outcomes for comparison — though the estimates are biased due to heterogeneous treatment effects. Panel (c) presents the estimators by Sun and Abraham (2021), which use as control group the last-treated unit. Panel (d) displays the results for estimators using the methodology developed by Borusyak et al. (2021). Panel (e) shows the outcomes for the estimators by Roth and Sant'Anna (2021). Finally, panel (f) presents the estimators following Gardner (2022). Notice that we do not make use of a universal base period, and hence pre-treatment coefficients are not estimated in relation to a given year. Period -1 is the first treatment period due to anticipation and dependent variables are transformed using $log+1$.

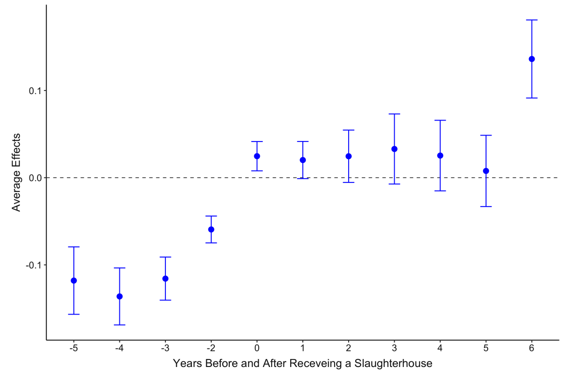
Figure A.6: Robustness Check: Alternative Estimators for Degraded Pastureland



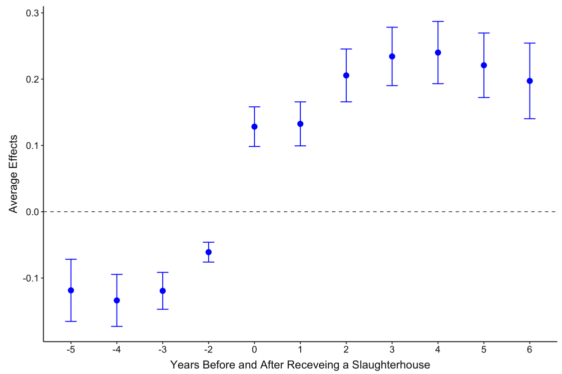
(a) Callaway and Sant'Anna (2021)



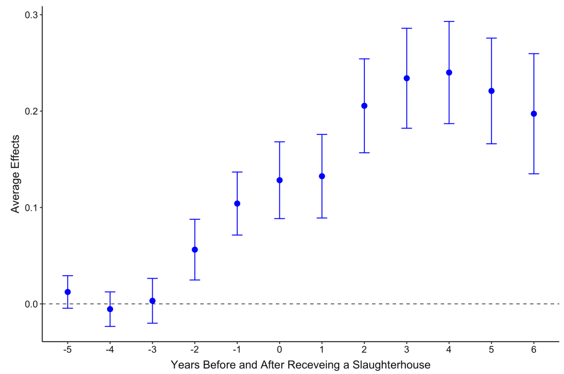
(b) Two-Way Fixed Effects



(c) Sun and Abraham (2021)



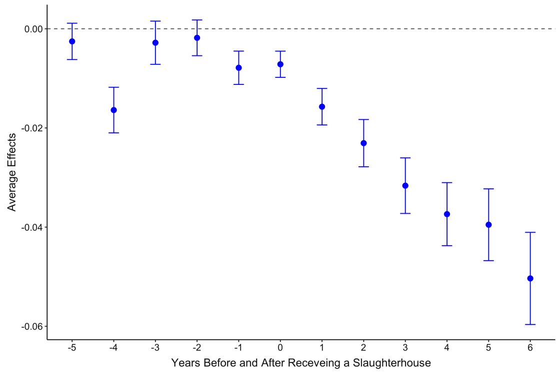
(d) Borusyak et al. (2021)



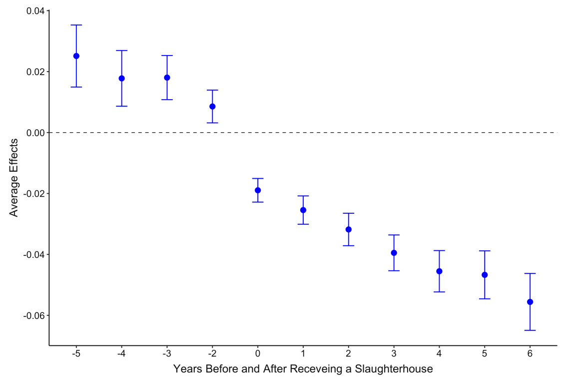
(e) Gardner (2022)

Notes: This figure presents the results of the alternative estimators described in Section 5.5 for dependent variable "Degraded Pastureland". Panel (a) display the results of our baseline approach by Callaway and Sant'Anna (2021). Panel (b) shows the TWFE outcomes for comparison — though the estimates are biased due to heterogeneous treatment effects. Panel (c) presents the estimators by Sun and Abraham (2021), which use as control group the last-treated unit. Panel (d) displays the results for estimators using the methodology developed by Borusyak et al. (2021). Finally, panel (e) presents the estimators following Gardner (2022). Estimators by Roth and Sant'Anna (2021) were not identified for this sample and hence are not shown. Notice that we do not make use of a universal base period, and hence pre-treatment coefficients are not estimated in relation to a given year. Period -1 is the first treatment period due to anticipation and dependent variables are transformed using $log + 1$.

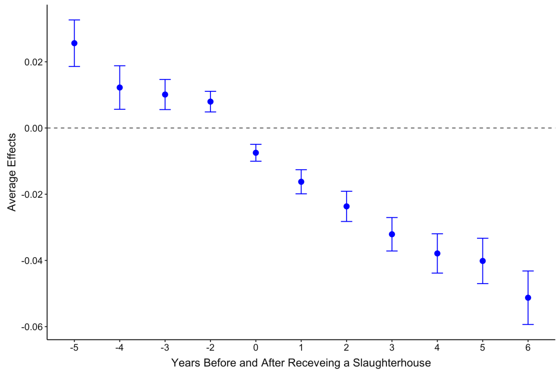
Figure A.7: Robustness Check: Alternative Estimators for Natural Forest Area



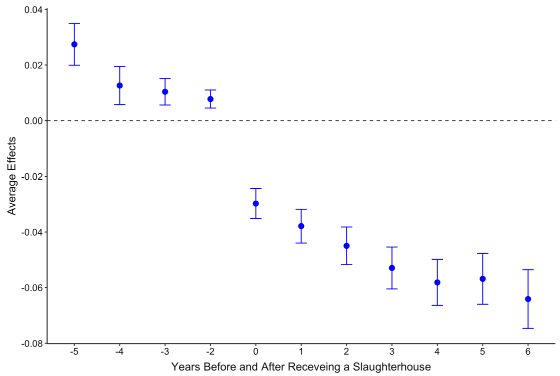
(a) Callaway and Sant'Anna (2021)



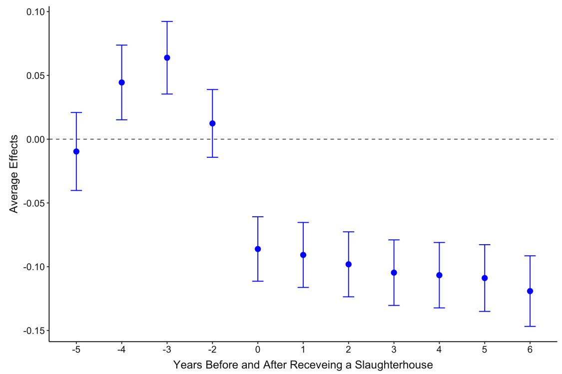
(b) Two-Way Fixed Effects



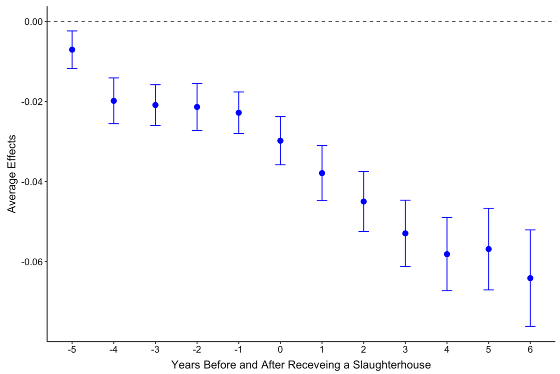
(c) Sun and Abraham (2021)



(d) Borusyak et al. (2021)



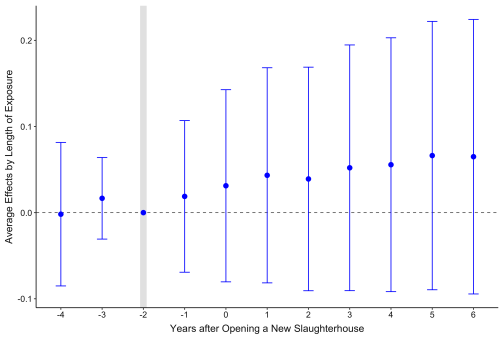
(e) Roth and Sant'Anna (2021)



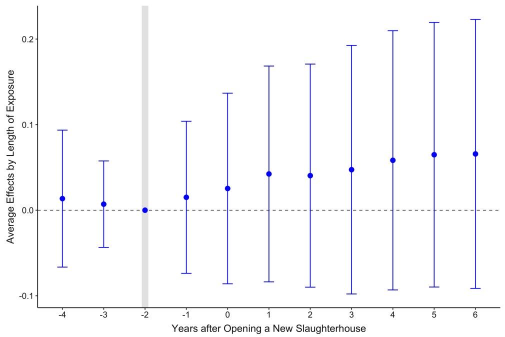
(f) Gardner (2022)

Notes: This figure presents the results of the alternative estimators described in Section 5.5 for dependent variable "Natural Forest Area". Panel (a) display the results of our baseline approach by Callaway and Sant'Anna (2021). Panel (b) shows the TWFE outcomes for comparison — though the estimates are biased due to heterogeneous treatment effects. Panel (c) presents the estimators by Sun and Abraham (2021), which use as control group the last-treated unit. Panel (d) displays the results for estimators using the methodology developed by Borusyak et al. (2021). Panel (e) shows the outcomes for the estimators by Roth and Sant'Anna (2021). Finally, panel (f) presents the estimators following Gardner (2022). Notice that we do not make use of a universal base period, and hence pre-treatment coefficients are not estimated in relation to a given year. Period -1 is the first treatment period due to anticipation and dependent variables are transformed using $log + 1$.

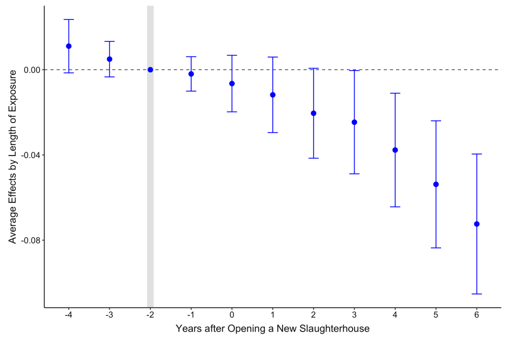
Figure A.8: Robustness Check: Event-Study Placebo With Time Randomization shuffling treatment-time 50 and 100 times



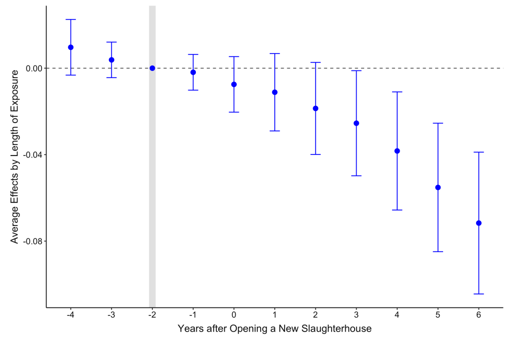
(a) Cattle Heads (50 reps)



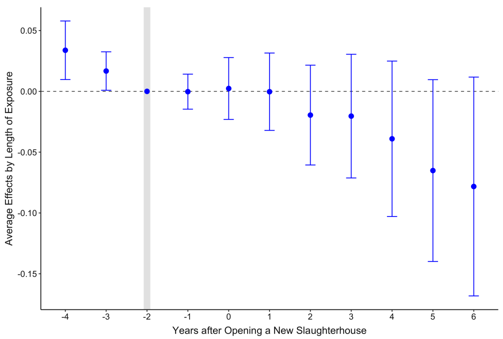
(b) Cattle Heads (100 reps)



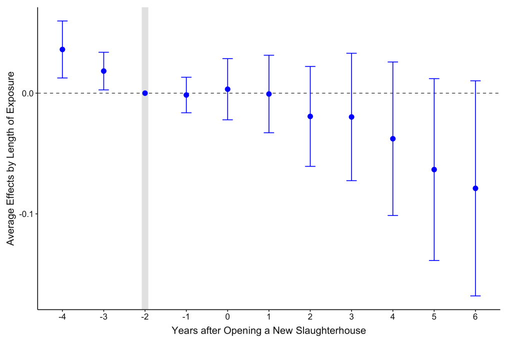
(c) Pasture Area (50 reps)



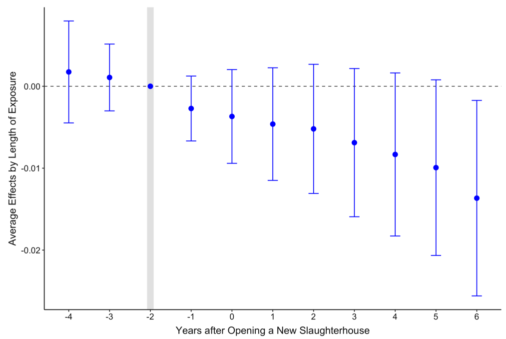
(d) Pasture Area (100 reps)



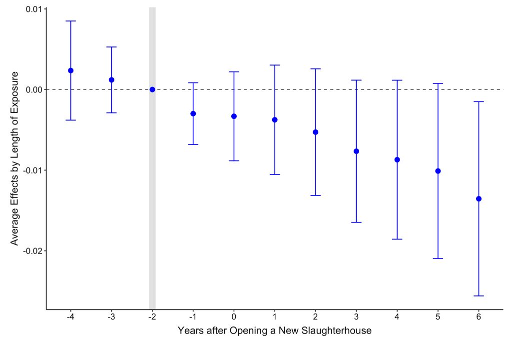
(e) Degraded Pastureland (50 reps)



(f) Degraded Pastureland (100 reps)



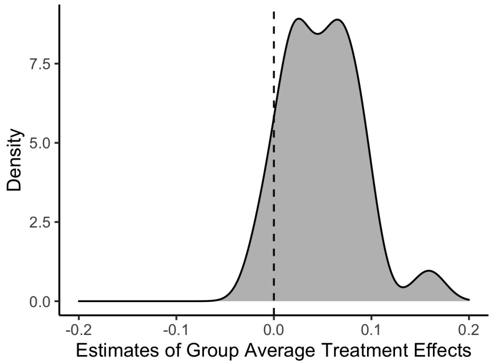
(g) Natural Forest Area (50 reps)



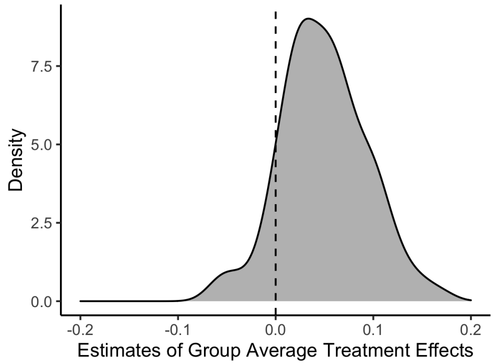
(h) Natural Forest Area (100 reps)

Notes: This figure presents the results of Equation (1) using dynamic effects with randomized treatment timing. We first shuffle the treatment timing 50 and 100 times and re-run the regressions by Callaway and Sant'Anna (2021) using the same approach as in our baseline design (event-study). Above we plot the median coefficients and standard errors. Panels (a) and (b) display results for cattle heads for 50 and 100 repetitions, respectively. Panels (c) and (d) show results for pasture area following the same pattern. Panels (e) and (f) display results for degraded pastureland. Panels (g) and (h) show results for natural forest area area. Period -1 is the first treatment period due to anticipation.

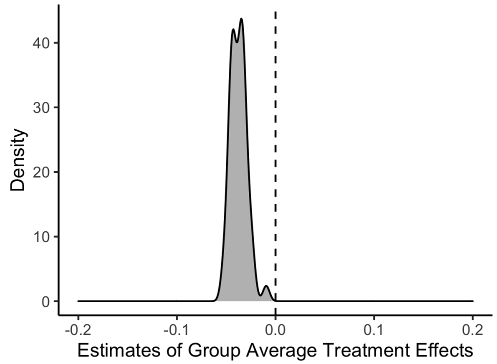
Figure A.9: Robustness Check: Group Average Treatment Effect Placebo With Time Randomization shuffling treatment-time 50 and 100 times



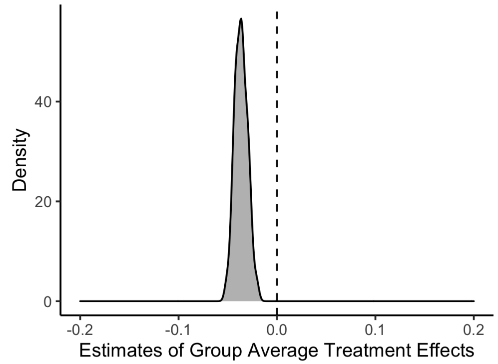
(a) Cattle Heads (Level)



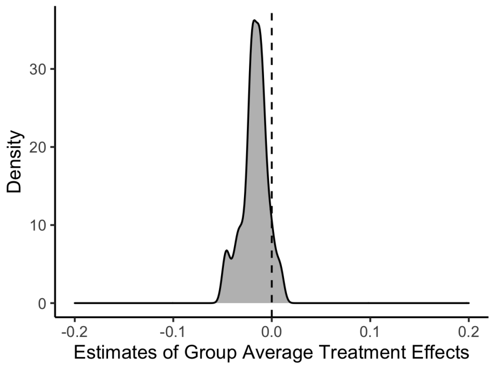
(b) Cattle Heads (Log)



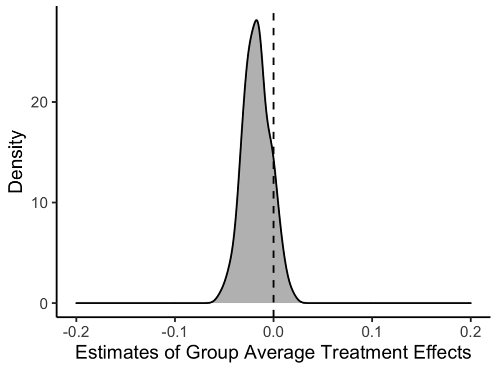
(c) Pasture Area (Level)



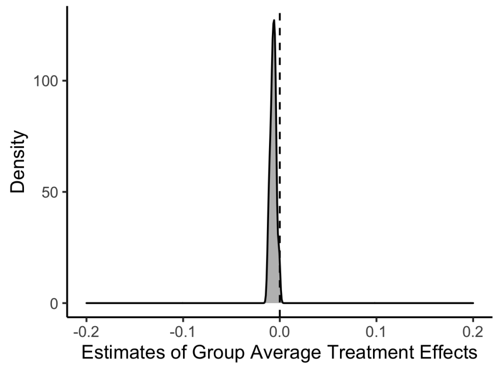
(d) Pasture Area (Log)



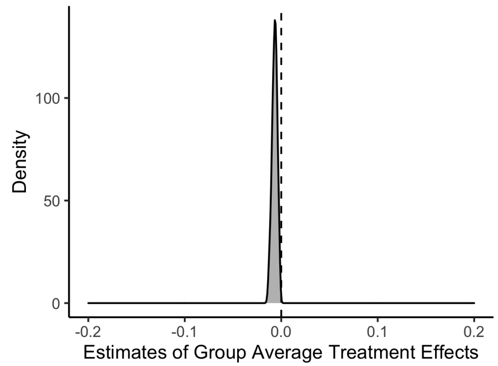
(e) Degraded Pastureland (Level)



(f) Degraded Pastureland (Log)



(g) Natural Forest Area (Level)



(h) Natural Forest Area (Log)

Notes: This figure presents the distribution of coefficients from Equation (1) using group average treatment effects with randomized treatment timing. We first shuffle the treatment timing 50 and 100 times and re-run the regressions by Callaway and Sant'Anna (2021) using the same approach as in our baseline design (group average treatment effects). Above we plot the density distribution of the estimated coefficients. Panels (a) and (b) display results for cattle heads for 50 and 100 repetitions, respectively. Panels (c) and (d) show results for pasture area following the same pattern. Panels (e) and (f) display results for degraded pastureland. Panels (g) and (h) show results for natural forest area area. Period -1 is the first treatment period due to anticipation.