Environmental Policies That Shape Productivity: Evidence from Cattle Ranching in the Amazon

Fanny Moffette, Marin Skidmore and Holly K. Gibbs*

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Abstract:
We examine potential economic benefits of environmental policies, increased agricultural investment and productivity. Two anti-deforestation policies in the Brazilian Amazon are analyzed: the Priority List, which increases the intensity of fines for deforestation, and the G4 Cattle Agreements, which is a market exclusion mechanism. We compare cattle ranchers' optimal behavior under each policy and predict their impacts to determine which agricultural actors are affected and what the expected combined policy effects might be. We combine a unique dataset of slaughterhouse locations with a spatial database on land-use in Brazil from 2004-2016; this allowed us to restrict our sample to the municipalities that had an exporting slaughterhouse nearby. Because most municipalities on the Priority List fell within reach of these slaughterhouses, the result is a comparable sample for analyzing the two policies. We use variations in time and exposure levels of the Priority List and the G4 Cattle Agreements, and find that both increased productivity, while the G4 also increased investment. This research reveals both indirect and unexpected benefits of environmental regulation.

Keywords: Environmental regulation, unexpected benefits, Amazon, productivity, land investment, induced intensification.

*Moffette: Nelson Institute for Environmental Studies and Department of Agricultural and Applied Economics, University of Wisconsin-Madison. Skidmore: Department of Agricultural and Applied Economics, University of Wisconsin-Madison. Gibbs: Department of Geography, Nelson Institute for Environmental Studies, Center for Sustainability and the Global Environment (SAGE), University of Wisconsin-Madison. We thank Jennifer Alix-Garcia, Kathy Baylis, Jill Caviglia-Harris, Jens Engelmann, Jeremy Foltz, Laura Schechter, Andrew Stevens, and participants at the MWIEDC 2019, AERE Summer Conference 2019, AERE@ASSA 2020, Development Workshop at the University of Wisconsin-Madison for helpful comments and suggestions. Jacob Munger assisted with the construction of the database and Ian Schelly prepared the maps. Funding provided by the Gordon and Betty Moore Foundation and Norwegian Agency for Development Cooperation's Department for Civil Society under the Norwegian Forest and Climate Initiative. Any errors or omissions are the sole responsibility of the authors.

1 Introduction

The literature on environmental regulations has traditionally focused on measuring their effect on emissions, but a growing body of research analyzes their indirect economic benefits. Through change in input usage or health, environmental regulation can increase productivity and alter labor supply, social capital, R&D, among others. Despite the potential impact on productivity and investment, little attention has been paid to indirect benefits of policies to protect forest. By making land artificially scarce and unavailable for conversion to agriculture, environmental policies can have positive spillovers onto productivity (Koch et al., 2019). When land is relatively inexpensive and widely available compared to capital, agricultural producers should expand their production rather than intensify it; producers typically do not adopt semi-intensive methods until land clearing is no longer an option (Angelsen, 2010; Kaimowitz and Angelsen, 2008; Phalan et al., 2016). By using the case of skyrocketing cattle production in the Brazilian Amazon, we theoretically and empirically examine the impacts of two environmental policies on productivity and investment in inputs and capital. Specifically, we study the Priority List (*Municípios Prioritários*), which began in 2008 and sought to increase the expense of deforestation fines in targeted municipalities, and the G4 Cattle Agreement (G4), which began in 2010 and is a zero-deforestation agreement that excludes suppliers with post-2010 deforestation.

The cattle herd in the Brazilian Amazon has grown by 270% from 23 million head in 1988 to 85 million head in 2016 (IBGE, 2017), making Brazil the world's leading producer and exporter of beef (USDA Foreign Agricultural Service, 2019). Despite this increase, production in the region is characterized by low-density ranching that produces only a third of the animals that could be supported on the same pasture area under methods of sustainable intensification (Ermgassen et al., 2018; Gil et al., 2018). Whether improvements in agricultural productivity would reduce deforestation has been widely debated in the economic and environmental literature and remains a fundamentally empirical question.[1] In Brazil, studies suggest that productivity increases can lead to decreased deforestation (Assunção et al., 2015, 2017b; Cohn et al., 2014). This is key for the Amazon because extensive cattle production has been widely associated with high deforestation rates (Nepstad et al., 2014). Although a combination of different policies has been shown to successfully reduce deforestation since 2004 (e.g. Burgess et al. 2018; Assunção et al. 2019), analysis of their effects on productivity and investment is sparse. The most

[1]On the one hand, Borlaug's hypothesis (following Borlaug 2007) states that increased productivity allows producers to increase production without additional land, and thereby reduces clearing. On the other hand, Jevon's paradox states that productivity increases clearing by increasing the profitability of land. If Jevon's paradox is true, increases in productivity caused by a response to environmental policies could lead to no aggregate impact on deforestation. See Villoria et al. (2014) for a review.

related study to ours, Koch et al. (2019), studied the impact of the Priority List on the productivity of several agricultural products and found the policy increased cattle productivity. Here we further explore whether the G4 had also an effect on productivity, whether these policies function as complements or substitutes, and how those two policies impacted investment in inputs and capital.

Pasture degradation, which results from a lack of investment in the land, plays a critical role since it eventually renders the land unproductive and leads to deforestation. Based on this mechanism, our micro-model predicts ranchers' input usage, clearing and productivity decisions under a fines-for-deforestation policy (i.e. the Priority List), a supply chain exclusion policy (i.e. the G4), and a combination of the two. The Priority List, which increases the expected penalty for larger areas of deforestation, should have greater effects on large ranches with substantial remaining forest. The G4, which penalizes any deforestation, should separate ranchers into those who intensify and those who continues to deforest. In this case, ranchers with little remaining forest should respond to the policy and intensify. Thus each policy is potentially more effective in some contexts than in others and our work seeks to predict the expected combined effects of the two.

A unique spatial dataset that identifies slaughterhouse location enables us to analyze only those municipalities that ever had a slaughterhouse owned by the G4 signatories (i.e. the four largest meatpacking companies in Brazil) either in the municipality or within a 100-km buffer, and the *Municípios Prioritários* (MPs) that are adjacent to this sample. This choice provides the advantage of using slaughterhouse locations, which are based both on observables and unobservables, to ensure sample comparability (Alix-Garcia and Gibbs, 2017). Since 86% of the MPs in our sample falls naturally within the reach of G4-owned slaughterhouses, there are plausible overlaps between the underlying mechanisms leading municipalities to be added to the Priority List and characteristics that attract G4-owned slaughterhouses. Further, because the Brazilian government adhered closely to a threshold rule based on deforestation levels for assignment to the list, and not on deforestation trends, it is possible to not reject the common trend assumption (Assunção et al., 2019).

Using a difference-in-differences strategy, we test the effect of the G4, the Priority List, and their interaction on our main outcomes, productivity and investment. Our analysis integrates an annual spatial dataset that identifies changes in pasture; this is used to normalize productivity (measured as cattle/ha of pasture) and investment (measured as credit for livestock/ha of pasture). Our main proxy for productivity, the stocking rate, is established in the literature (e.g. Koch et al. (2019); Merry and Soares-Filho (2017)). Our second productivity outcome is a measure relative to the land potential and allows for comparison of municipalities across regions and biomes. Our proxy for investment offers the advantage of creating a panel of credit used specifically for cattle operation and investment. While our proxy does not include investment achieved without financing, the lines of credit included in our data are widely used by producers of all sizes and cover all subsidized credit through public and private financial institutions. Two outcomes are constructed from these data: the credit for livestock/ha of pasture as well as the total number of contracts in the municipality.

Our results suggest that both policies increased productivity and that investment increased after exposure to the G4, although results were heterogeneous across municipalities. Those that were exposed only to the G4 increased their productivity by 6.08% compared to their baseline level, while municipalities that were exposed only to the Priority List saw an increase of 11.57%. In accordance with the conclusions of our micromodel, municipalities that were exposed to both policies saw the largest effect, with an increase of 16.39%, which is not significantly different from the sum of the two individual effects. We also show that the G4 increased investment in inputs and capital specific to livestock by at least 5.15 billion reais in combination with an additional 63,569 credit contracts. Productivity increased more in municipalities with less remaining forest (as ranchers had less to gain from breaking the zero-deforestation policy) and in municipalities closer to G4 slaughterhouses (as ranchers faced the strongest potential loss if they were excluded from the supply chain following deforestation). The Priority List largely had an effect in municipalities with high proportions of large ranches, since these ranches faced higher risk of being fined should they deforest.

To complement our analyses and to address endogeneity concerns, we carry out several robustness and falsification tests. First, since the causality of our estimates depends on the parallel trend assumption, we use an alternative specification that tests and finds supportive pre-trends. Next, we support with falsification tests the premise that the results were driven by the G4 Cattle Agreements rather than by the presence of a major slaughterhouse by using an alternative sample that includes all municipalities within the reach of a G4-owned slaughterhouse, but that are outside the Amazon. Third, we extend the definition of our sample and include a broader set of municipalities with slaughterhouses (i.e. municipalities with non-G4 slaughterhouses); we find suggestive evidence that our results could represent lower bound estimates as expanding the definition of the control group leads to greater effects on both productivity and investment. Fourth, to avoid bias that could enter our estimates from changes in slaughterhouse and supplier locations, we test the robustness of our results by limiting our analysis to 2004 - 12. Fifth, to ensure that we did not introduce sample bias by adding the MPs not treated by the G4, we show that our results are robust when we exclude them. Finally, our empirical strategy supports previous evidence of reduced deforestation by the Priority List and no evidence of reduced deforestation induced by the

G4.[2]

This paper is related to the broader discussion of indirect benefits generated by environmental policies. Agricultural productivity can be improved by mining regulations (Aragón and Rud, 2016) and anti-deforestation policies (Koch et al., 2019); labor productivity (Archsmith et al., 2018; Hanna and Oliva, 2015) and firm productivity (Berman and Bui, 2001; Yang et al., 2012) can increase through changes in air quality. Payments for environmental services programs support social capital (Alix-Garcia et al., 2018) and stringent air quality regulation increases R&D (Yang et al., 2012). Here, we show that ranchers substitute investment in inputs and capital, instead of deforesting, when they are subject to policies that penalize deforestation. We estimate for the first time whether the G4 generated indirect benefits in terms of productivity and investment, and provide the second study of unexpected benefits from the Priority List. Our study differs from Koch et al. (2019), who also finds that the Priority List increased cattle productivity, in four main aspects. First, we study the impact of the Priority List on investment in inputs and capital, an important method to increase productivity that these authors do not consider. Second, while Koch et al. (2019) studied three years to measure the change in cattle productivity (with a single time-period after the policy began), we estimated a full panel from 2004 - 16. Third, our micromodel considers pasture degradation (rather than credit constraints) as a mechanism through which the policies can affect productivity. Fourth, we analyze the interactions between the Priority List and the G4, both theoretically and empirically.

This paper adds to the literature that investigates the impacts of public and private anti-deforestation policies. To the best of our knowledge, we provide the second theoretical model of producer decisions under a market-exclusion policy. Compared to Jung and Polasky (2018), which is the first to consider whether a market exclusion policy could lead to avoided deforestation, we develop our model to allow for a broader set of propositions that considers the circumstances under which these policies are effective.[3] The number of commitments to reduce deforestation in supply chains has greatly increased in recent years (e.g. Lambin et al. 2018; Garrett et al. 2019) and covers a wide range of commodities such as cattle, soy, cotton, cocoa, and palm oil. Some of these agreements reduced deforestation (e.g. Carlson et al. 2017), but theoretical and empirical analysis remain limited. Given the remarkable expansion of these commitments, the expected consequences and conclusions derived in our micromodel favor a

[2]See Arima et al. (2014); Assunção and Rocha (2014); Assunção et al. (2019); Cisneros et al. (2015); Koch et al. (2019) who have shown reduction in deforestation following the Priority List, and Alix-Garcia and Gibbs (2017) for an analysis of the G4 impact on deforestation.

[3]Other authors such as Azevedo et al. (2017); Heilmayr and Lambin (2016); Heilmayr et al. (2019); Lambin et al. (2014); le Polain de Waroux et al. (2019); Nepstad et al. (2014) study private- and public-led environmental policies but did not develop a theoretical analysis for a market exclusion policy.

greater understanding and can apply to a variety of settings

Policies are rarely implemented in a vacuum. Governmental and market institutions often create policies that interact and can either substitute or complement each other. Understanding these interactions, which have clear consequences in terms of policy efficiency, is critical for improved design of environmental policies. Examples of the literature that studies policy interactions can be found in environmental economics (Sims and Alix-Garcia, 2017; Jaime et al., 2016) but also in other fields such as labor and health economics where these policy interactions are also frequent (Deserranno et al., 2020; Pless, 2019; Autor and Duggan, 2003; Inderbitzin et al., 2016; Ashraf et al., 2013). Our research provides a first attempt to examine how, in theory, private- and public-led environmental policies will interact to reduce deforestation and increase productivity. Empirically, we do not find evidence that the two policies are complements in increasing productivity, but we also do not find evidence that they are substitutes. In the context we study, policymakers should therefore not view private-led policy as a replacement for public policy, and vice versa.

2 Background

2.1 Cattle production in Brazil

Brazil's beef productivity is currently at one third of its sustainable potential. This extensive production of cattle in the Amazon is characterized by low investment in pasture, which over time has led to 40% of pasture being moderately or severely degraded (Ermgassen et al., 2018; Cohn et al., 2014; Strassburg et al., 2014). The degradation of pasture is partly explained by the investment costs to restore or increase its productivity, although credit for livestock is available to cover operating and investment costs (see section 4.2 for more details). Through mixed legume pastures, pasture rotation, correction of soil imbalance, pasture fertilization, silvo-pastoral systems, or confinement operations, high productivity ranching requires $410 - 1,280 per ha in startup costs, and can take 2.5 - 8.5 years to repay its investment. Specific initiatives to introduce these techniques have shown an increase in productivity from less than one animal unit per hectare to one and a half to three animal units per hectare (Ermgassen et al., 2018).

The typical production cycle of the cattle supply chain is complex. In the Amazon, ranches may specialize in raising calves, in intermediate fattening, or in the final fattening immediately preceding slaughter. Thus, animals may be transported among several properties before slaughter, which hampers the ability of slaughter and meatpacking companies to monitor their movement.

2.2 G4 Cattle Agreements

Following a Greenpeace-led campaign that linked deforestation to the cattle sector in Brazil, the four largest slaughter and meatpacking companies (JBS, Marfrig, Minerva and Bertin[4]) signed the G4 in October 2009. By threatening the reputation of brands that were buying meat from the Amazon, the NGO provided incentives for the slaughterhouses to sign these agreements, lest they lose exports and a portion of their domestic markets. For this reason, the companies agreed to exclude suppliers who deforested after 2009, who were accused of slave labor violations, who lacked environmental property boundary registration, who were located within protected areas, or who had been embargoed (a tool by which the Brazilian Forest Code was applied and fines for illegal deforestation were imposed) (Greenpeace, 2009). Current rules of the policy imply that once a property has been deforested after 2009, it is and will remain non-compliant.

Since 2010, the G4 companies have been using the services of an agribusiness intelligence firm to determine the compliance status of their direct suppliers.[5] To evaluate compliance, the monitoring company first determines the suppliers' property boundaries. The property area is compared to geospatial data, and each supplier's tax identification number is compared to embargo and forced-labor lists. When a supplier is verified as compliant, the slaughterhouse proceeds with the sale. Thus, rather than tracking movements among properties throughout an animal's life, the slaughterhouses monitor only their direct suppliers. It is therefore possible for non-compliant cattle to enter the supply chains indirectly through intermediary suppliers. Such suppliers use this logistical loophole to launder cattle, or to move them strategically among properties for monetary gains (Walker et al., 2013; Gibbs et al., 2020).[6]

Research has shown that JBS, the world's largest meatpacking company, blocked non-compliant suppliers in some regions although in other regions enforcement was weaker, especially where competition from non-monitoring slaughterhouses threatened the company's quotas (Gibbs et al., 2016, 2020). As a consequence of incomplete enforcement and the laundering behavior of suppliers, the G4 had heterogeneous effects on deforestation characterized by its decrease on certain properties and leakage of avoided deforestation on others (Alix-Garcia and Gibbs, 2017). This evidence suggests that the policy generated some effects, but their impacts were mitigated by avoidance behavior.

[4] Bertin was later acquired by JBS.

[5] Legally binding "Terms of Adjustment of Conduct" (TAC) contracts occurred on a similar timeline and obliged signatories to exclude suppliers linked to areas with illegal deforestation or violations of other government sanctions. While the major G4 companies monitored their suppliers since the beginning and signed both the G4 and the TAC, the slaughterhouses that only signed TAC did not monitor geospatial characteristics of suppliers (e.g. deforestation) until after the timeframe of this study (Gibbs et al., 2020; Moffette and Gibbs, 2020).

[6] Recent negotiation to monitor the G4 proposed tracking of animals through the Guide to Animal Transport (GTA), documents issued by state-level sanitation control agencies for all transport of cattle. The GTA include the origin and destination of the cattle being moved, but no formal agreement has yet been reached.

2.3 Priority List

In 2007, the President of Brazil signed a decree that permitted targeting and differential enforcement of environmental policies in municipalities with the highest incidence of deforestation. The Priority List was part of the action plan to curb deforestation (Portuguese acronym, PPCDAm). The first list was published in 2008 and included 36 priority municipalities (MPs) that were responsible for 45% of deforestation in 2007 (Assunção et al., 2013). While municipalities were then added and removed from the list in different years, most of the variation comes from the first list. No municipality ever returned to the list after being removed.

Officially, municipalities were chosen based on their total deforested area, recently deforested area, and recent rate of change in deforestation. However, Assunção et al. (2019) show that while the level of previous deforestation was a strict requirement, the recent rate of change of deforestation did not influence placement on the list.[7] The authors show that assignment to the list was determined by official criteria and was not influenced by political factors. Indeed, Assunção et al. (2019) were able to replicate 97% of the 2008 list using inferred thresholds for the total deforested and recently deforested areas. They find common trends in deforestation among the municipalities on either side of this threshold, which lends support to the statement that assignment was not based on political influence. Pailler (2018) finds further evidence that local politicians have had little influence over environmental enforcement and fines.

The creation of the Priority List gave the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) the power to dedicate a larger share of their resources to MPs (Assunção et al., 2013). IBAMA is responsible for monitoring changes in land cover in the Amazon using the Real-Time Detection of Deforestation System (DETER). After receiving alerts, IBAMA issues fines and embargoes properties. The Priority List authorized IBAMA to prioritize alerts in MPs, and thus properties in MPs were at higher risk for environmental fines or embargoes. Other Amazon-wide environmental policies were to be strictly enforced in MPs, including Resolution 3.545, which requires that banks deny credit to properties that are not in compliance with environmental law (Presidência da República, 2009). This portion of the policy has been shown to have been less effective than the command and control enforcement implemented by IBAMA (Assunção et al., 2013; Cisneros et al., 2015). Early analysis by Assunção and Rocha (2014) found that deforestation would have been 54% higher without the policy. Cisneros et al. (2015) demonstrate that the policy had a stronger effect during its second year, and the

[7]Specifically, the level of previous deforestation criteria looked at i) the amount of deforestation cleared in the municipality from its creation up to the year before being added to the list as well as the amount of deforestation in the municipality in the three-year period ending before the addition to the list. The criteria for the rate of change of deforestation was whether the municipality observed increased deforestation at least three times in the five-year before the addition to the list.

reduction in deforestation was strongest in the third year after addition to the list. A novel analysis by Assunção et al. (2019) confirmed that the policy's reduced deforestation between 2008 - 19 and further identified a set of targeted ex-post optimal municipalities for the list; this list would result in 7.4% lower carbon emissions than the actual list of municipalities, and 25% lower carbon emissions than a list of randomly chosen municipalities.

3 A model of cattle ranching

We develop a basic model for a cattle rancher's choice of pasture area and inputs and then we introduce two policies: one uses fines-for-deforestation and the other consists of market exclusion following clearing. We compare the optimal levels of key factors under each policy to the basic model. To gain further insights, we consider the case where both policies are enforced. To conclude, we discuss limitations and extensions of the model.

3.1 Theoretical model setup

We model a rancher producing cattle using a set of inputs, M, already cleared pasture, L, and newly cleared pasture, L^n. Inputs M are used to increase the carrying capacity of land and can take two distinct forms: consumable inputs (e.g., non-pasture feed, nutritional supplements, fertilizer) and capital (e.g. tractors, machinery to reform pasture, or infrastructure for confinement and semi-confinement operations). The per unit cost of these inputs is r, which can be regarded as the cost of consumable inputs plus machinery rental or payments on loans for machinery or infrastructure. Clearing pasture incurs a per unit cost c. Since we assume that land rental is not a viable option,[8] ranchers are constrained such that $L + L^n$ cannot exceed their total area, A.

Cattle are produced according to production function $f(M, (1-\alpha)L + L^n)$. We assume that f is twice differentiable, concave, and the cross-derivatives of land and inputs are positive. Pasture degrades such that already cleared land enters the production function as $(1-\alpha)L$, where $0 < \alpha < 1$. While cleared land may gain speculative value over time (Vale, 2015), it loses productive capacity as pasture becomes degraded, typically within a decade for Amazonian soils (Fearnside and Barbosa, 1998). Similarly, in the Brazilian state of Rondônia, twelve-year-old pasture was found to be half as productive as three-year-old pasture (Fearnside, 1989). We assume that within the period the size of the cattle herd is fixed at $\overline{Q}$.

[8]This assumption is largely representative of the land market in the Brazilian Amazon. In 2006, only 3.3% of Brazilian agricultural land was leased. By 2016, the proportion had increased to 8% nationally, but remained at 2% for the Northern region that encompasses the Amazon biome (IBGE, 2007, 2019)

We normalize the price of cattle to one. The rancher's optimization problem is

$$
\begin{aligned}
Max_{\{M,L^n\}} \quad & f(M,(1-\alpha)L+L^n) - rM - cL^n \\
& + \lambda(L+L^n-A) \\
& + \mu(f(M,(1-\alpha)L+L^n) - \overline{Q})
\end{aligned}
\tag{1}
$$

The first order conditions are $(1+\mu)f_M(M,(1-\alpha)L+L^n) - r = 0$ and $(1+\mu)f_{L^n}(M,(1-\alpha)L+L^n) - c + \lambda = 0$. If the rancher chose L in the past because it satisfied $(1+\mu)f_L(M,L) - c = 0$, the pasture degradation implies that the rancher no longer can satisfy the first order condition (FOC) without clearing additional pasture. This highlights the role of pasture degradation in motivating the ongoing deforestation in the Amazon. If input prices do not change, the rancher will simply replace the degraded land and clear $L^{n*} = \alpha L$, conditional on the land constraint.

Ranchers choose to produce such that the ratio of the marginal benefits is equal to the ratio of the marginal costs, or

$$
\frac{f_M}{f_{L^n}} = \frac{r}{c-\lambda}. \tag{2}
$$

Ranchers that are not land constrained ($\lambda = 0$) produce such that the ratio of the marginal products is $\frac{r}{c}$. Ranchers that are land constrained clear $L^n = A - L$, and λ takes a positive value that leads the rancher to purchase inputs to satisfy the production constraint.

3.2 Policy 1: Fines for deforestation

The Priority List increased enforcement of fines for deforestation that was in violation of the Forest Code. Although ranchers may evade payment of fines (Rausch and Gibbs, 2016), this evasive behavior incurs a cost such as bribery or legal fees. We model these fines as an additional cost of clearing L^n. For simplicity, we assume that all new clearing (L^n) is not compliant with the policy and subject to fines. All clearing that occurs after the onset of the policy remains non-compliant for the life of the policy.[9]

Because enforcement is imperfect, even with the increased scrutiny of the Priority List, we represent this cost as $P(L^n)$, which is increasing and convex. The function is increasing following the Federal Decree (6,686/2008) that defines the fines for deforestation as a linear function of the number of hectares cleared. The convexity of $P(L^n)$ is drawn from the probability of being fined increasing in L^n. Indeed, enforcement is higher on large patches of clearing to maximize the limited resources for enforcement and

[9] The majority of properties in the Amazon biome are not in compliance with the Forest Code which allows clearing of only 20% of the property area (Godar et al., 2015). For example, 98% of the 26,510 direct suppliers of JBS in the Amazon are non-compliant (Gibbs et al., 2020). Thus, while deforestation can be legal, most deforestation is not.

due to limitations to detection technology (Koch et al., 2019; Godar et al., 2014; Assunção et al., 2017a). Thus, the ratio of the FOC becomes $\frac{f_M}{f_{L^n}} = \frac{r}{c+P'(L^n)-\lambda}$.

Proposition 1: *A policy that imposes fines for deforestation results in: (a) a reduction in newly cleared land L^n, (b) an increase in the use of inputs M, (c) an increase in the heads of cattle per hectare, $\frac{\overline{Q}}{L+L^n}$, and (d) an increase in the inputs per hectare, $\frac{M}{L+L^n}$.*

The addition of $P'(L^n)$ decreases the left-hand side of equation 2. As a result, the marginal product of M will be lower and the marginal product of L^n will be higher at the optimal allocation under the priority list. Thus, the rancher will use more inputs and less land. Since herd size is fixed, it follows that there will be more heads per hectare and more inputs per hectare.

Proposition 2: *(a) The response to a policy that imposes fines for deforestation is increasing in the size of initial pasture, L. (b) Among properties for whom the land constraint binds, the response is increasing in the area of remaining forest, $A - L$. Together, these imply that the policy response is increasing in property size.*

The convexity of $P(L^n)$ leads to a greater effect on the FOC at higher levels of L^n, or for properties that would clear a larger area, L^{n*} prior to the policy. This follows from having a larger area L that is degraded and needs to be replaced as well as having a larger remaining forested area, $A - L$.

3.3 Policy 2: Market exclusion following deforestation

We now model a policy where a group of slaughterhouses refuse to buy cattle from properties with deforestation; we refer to these slaughterhouses as the G4 slaughterhouses. G4 slaughterhouses consider all clearing $L^n > 0$ that takes place after the start of the policy to be non-compliant, and clearing remains non-compliant for the life of the policy. If $L^n > 0$, the ranchers incurs a penalty of $\beta\%$ on the ranch's production income, where $0 < \beta < 1$. This penalty can take several forms, which include: (1) increased transportation cost to non-G4 slaughterhouses (which implicitly affects income, although we do not model explicitly transportation cost for the sake of simplicity); (2) lower expected prices from non-G4 slaughterhouses (which directly affects income); and (3) the cost of laundering cattle through compliant properties. If every slaughterhouse enforces the policy, then (1) and (2) are no longer an option, and ranchers with non-compliant deforestation can sell cattle only through compliant properties (which pay less than the slaughterhouse price and keep β as profit margin). If market power concentrates on a few compliant properties, β should increase but remain lower than 1, since non-compliant properties would exit the market if the compliant properties extracted all the revenue. If no slaughterhouse enforces the policy, $\beta = 0$.

Proposition 3: *A policy that imposes a penalty on production that takes place on land with deforestation will divide properties into two groups. The first chooses $L^n = 0$ and replaces newly cleared land with additional inputs. For this group, there is (a) a reduction in newly cleared land L^n, (b) an increase in the use of inputs M, (c) an increase in the heads of cattle per hectare, $\frac{\overline{Q}}{L+L^n}$, and (d) an increase in inputs per hectare, $\frac{M}{L+L^n}$. A second group continues producing as they would in the absence of the policy; (a) L^n, (b) M, (c) the heads per hectare, and (d) inputs per hectare are all unchanged.*

Given the discontinuous nature of the penalty, the rancher now chooses between the optimal allocation with no clearing and with clearing. If the ranchers chooses no new clearing ($L^n = 0$), they increase inputs to M^1 to satisfy the production constraint. If the rancher continues to clear, the ratio of the FOC is unchanged from equation 2, and the rancher chooses the same allocation of land and inputs as they would without the policy, denoted (M^2, L^{n2}).

Proposition 4: *Ranchers will choose $L^n = 0$ if they were going to clear a small area relative to their production in the absence of the policy. Thus, properties are more likely to choose $L^n = 0$ if they are land constrained, and they are increasingly likely as the degree of land constraint increases (i.e. the likelihood of choosing $L^n = 0$ is increasing in λ).*

The rancher's choice between $(M^1, 0)$ and (M^2, L^{n2}) is determined by the profit of the two cases. The rancher will choose not to clear if $\overline{Q} - rM^1 > (1-\beta)\overline{Q} - rM^2 - cL^{n2}$, or $cL^{n2} > rM^1 - rM^2 - \beta\overline{Q}$. Because of the concavity of f, the units of M required to replace a unit of L^n are increasing in L^n. Thus, it is more profitable to produce at $L^n = 0$ if the rancher would choose a small amount of clearing L^{n*} in the absence of the policy. However, it is more profitable to continue clearing if the rancher would clear a large area in the absence of the policy. Whether L^{n*} is large enough to continue clearing is relative to $\overline{Q}$; a large difference in input costs will be counterbalanced by a large loss in revenue based on the size of the herd. Ranchers that are land constrained have the smallest optimal value of L^{n*} relative to their production, and are therefore most affected by the policy.

3.4 Interaction of the policies

Combining these policies yields the greatest reduction in deforestation and increase in intensification.

Proposition 5: *Combining policies reduces deforestation and increases intensification through three channels: (1) more ranchers choose not to deforest at all; (2) those that continue deforesting still clear less and intensify more than they would under the market-exclusion policy alone; and (3) some large ranchers that would have cleared large amounts under the market exclusion policy alone may choose not to deforest due to the high fines they would incur.*

The discontinuous nature of the optimal solution to the market exclusion again divides ranchers into two groups. Now, ranchers choose not to clear if the combined cost of clearing and fines is higher than the decrease in profit from clearing, or $cL^{n2} + P(L^{n2}) > rM^1 - rM^2 - \beta\overline{Q}$. The addition of fines leads more ranchers to not deforest and instead intensify, as the fines reduce the profitability of continuing to clear.

Ranchers that choose to clear will clear less than they would under market exclusion alone, due to the addition of fines. As before, ranchers with high levels of deforestation will be most responsive to the fines-for-deforestation policy. In the market exclusion policy, ranchers with high levels of optimal clearing relative to production continue clearing. Now, however, ranchers with high absolute levels of optimal clearing face a high additional cost for deforestation. Depending on the value of fines, some ranchers that would have cleared large areas could instead choose not to clear. We will test empirically whether the increase in intensification under both policies is larger or smaller than the combined effect of each policy individually.

3.5 Discussion of assumptions

While we model the same decision choice as Koch et al. (2019), we depart from their model in several meaningful ways. First, we model two policies and their mechanisms occur through i) an increase in fines for deforestation and ii) a decrease in the value of production. Second, by incorporating pasture degradation, our model depicts a reality faced by ranchers who are choosing between land and investment in inputs and capital for production. Third, we do not impose a credit constraint. Indeed, the inclusion of an exogenous credit constraint could be inappropriate given the Priority List's potential direct impact on credit availability. While many ranchers in the Amazon indeed experience credit constraint (Assunção et al., 2013), this assumption is least applicable for large unconstrained landholders who make critical decisions about productivity and clearing.

One caveat of our model compared to Koch et al. however, is that we model the rancher's allocation of land and inputs at a fixed level of production, while the form in which they model the policy leads to an increase in both productivity and cattle herd. The policy they model reduces the benefit to clearing that is unrelated to agricultural production; reducing this benefit reduces the overallocation of the budget to land beyond optimal levels for production. However, if the policy in the model of Koch et al. was to decrease the budget, this would lead to ambiguous effects on the total production. The authors also show that relaxing the assumption of the credit constraint leads to a reduction in total production and thereby an ambiguous effect on heads per hectare. Instead, we model policies that directly affect production costs and revenues, as this better reflects the policies in the Amazon.

While our assumption of fixed production is not realistic in the long term, this one-period model clearly demonstrates the tradeoffs between clearing pasture and using inputs. The assumption allows us to present clear testable hypotheses on the head of cattle per hectare (which we do not obtain without such a constraint) and is similar to a model of cost minimization at a fixed level of production. Some degree of disconnect between the assumptions of a one-period model and the long term reality is unavoidable; indeed, Koch et al.'s results are based on speculative land clearing, but their one-period model imposes that ranchers cannot buy, sell, or rent land.

We consider the implications of relaxing this constraint, which we detail in section Appendix A. Without a production constraint, both policies would reduce the production of cattle. In both cases, the rancher would decrease clearing and increase the use of inputs. The increase in inputs would offset the decrease in clearing sufficiently to still predict an increase in productivity in terms of heads per hectare and inputs per hectare. However, under the assumptions of our model, the inputs would not be sufficient to maintain or increase production levels.

The data show that total production increased at the same time that policies happened (table B8). This discrepancy from our model, or its unconstrained equivalent, can be explained by three ways that our model simplifies reality. First, we model inputs as continuous. In reality, many inputs are lumpy, such as tractors and confinement operations. Moreover, we do not model the long-term benefits to some types of inputs. These factors may lead the rancher to choose a discrete increase in inputs that is larger than the increase we model here. Finally, we do not consider how inputs affect the shape of the production function. Some inputs do not merely enter the production function as an input, but also affect its form, as a type of technology. Thus, a dynamic model that accounts for these two phenomena would show that the investment in inputs that we represent in our one-period model could lead to long-term increases in production.

4 Data

This section presents our sample, data sources, and descriptions of treatment, outcomes and control variables. It concludes with summary statistics.

4.1 Sample

We analyze a sample of municipalities in Brazil from 2004 - 16. We updated and extended a geocoded map of federally inspected slaughterhouses (SIFs) (Alix-Garcia and Gibbs, 2017) to select municipalities in the supply zones of the G4 slaughterhouses owned by the leaders of the Brazilian cattle industry: JBS, Marfrig, Bertin and Minerva.[10] Our sample is composed of all municipalities in the Amazon biome that have ever had a G4-owned slaughterhouse either in the municipality or within a 100-km buffer. As robustness, we also test how the policy's effect varies with distance to the nearest slaughterhouse by comparing municipalities with a G4-owned slaughterhouse in their 60, 100, or 140 km buffer – 100 km is the mean distance travelled by a supplier and 40 kilometers is half a standard deviation of the distance from the supplier to slaughterhouses.[11] We include the MPs adjacent to our sample in order to gain power on the identification of the effects of the Priority List without losing the geographical similarities provided by our sample definition. This step includes eight more municipalities.[12] To address selection bias concerns, we compare the observable characteristics of those municipalities to the rest of the sample in table 2, and we provide a robustness check without those municipalities in section 7.4.

We create a falsification sample of all municipalities outside of the Amazon that are within the 100-km buffer of a G4-owned slaughterhouse. Figure 1 shows the geographical variation of our main sample (restricted to the Amazon biome) as well as the falsification sample (located outside of the Amazon biome). This figure also illustrates the municipalities that were treated by one or both of the policies at any time, as well as the spatial distribution of all the G4-owned slaughterhouses and the non-G4 SIFs of the country. Our main sample has N=242 and the falsification sample has N=1,292 municipalities.

4.2 Data sources and description

Municipalities are exposed to the Priority List from the year they were added to the list until the end of the study period, unless they were removed from the list before 2016, in which case they are treated through their final year on the list. Exposure to the G4 Cattle Agreements is calculated for each municipality as the number of slaughterhouses that signed the G4 divided by the total number of SIFs within the municipality buffer (figure 2).[13] This definition of exposure accounts for the influence of

[10] Within the Amazon, these companies controlled 23 of the 55 federally inspected slaughterhouses in 2016.

[11] These numbers were extracted from the public traceability data of the world largest exporter of meat – JBS – and used over 25,000 mapped properties that supplied the company at any time between 2008 - 15 (see Gibbs et al. 2020).

[12] Two MPs remain excluded from the sample: Mucajaí, Roraima (added to the list in 2009 and not yet removed as of 2019) was excluded because it is far north of our sample. Grajaú, Maranhão (added to the list in 2011 and not yet removed as of 2019) was excluded because the majority of its area is located within the Cerrado biome.

[13] Alix-Garcia and Gibbs (2017) used a similar definition of the treatment variable, with the difference that their sample was composed of points within two states of the Amazon.

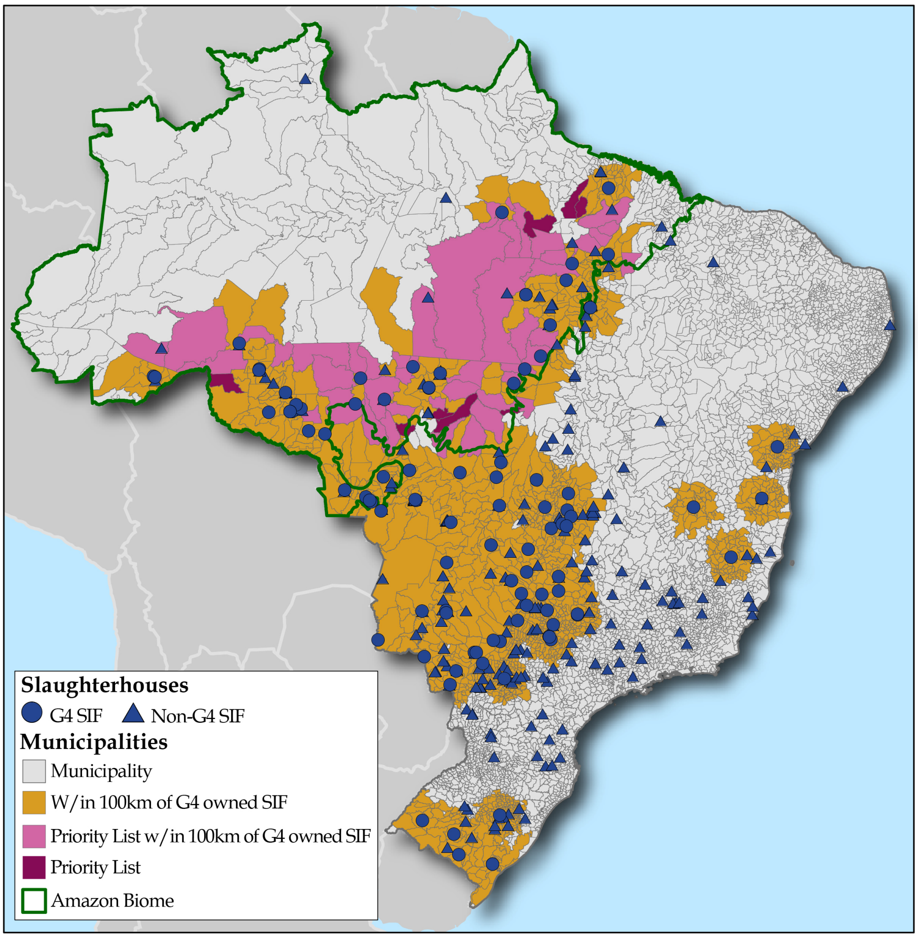


Figure 1: Locations of G4 and non-G4 slaughterhouses and spatial variation of municipalities that have been treated by the G4, the Priority List, or both policies. The main sample is composed of all coloured municipalities within the Amazon biome, and the falsification sample is composed of the colored municipalities outside of the Amazon biome.

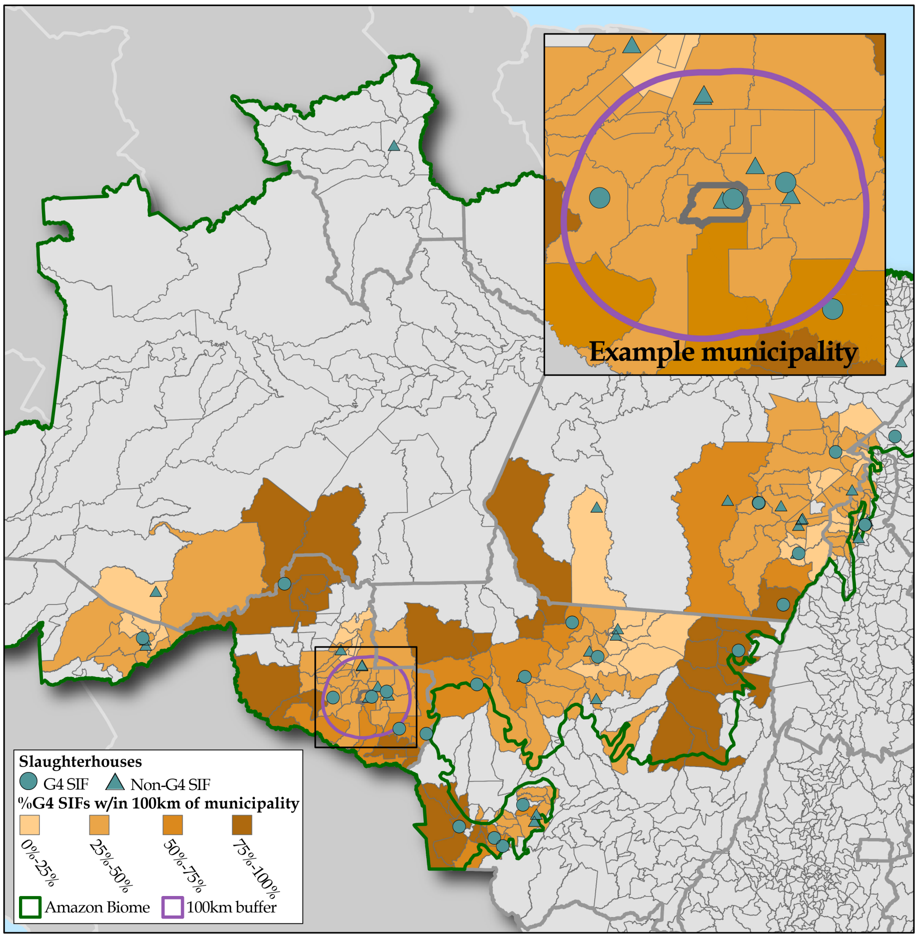


Figure 2: Locations of G4 and non-G4 slaughterhouses in the Brazilian Amazon and spatial variation in average exposure to the G4, which varies due to slaughterhouses openings and closings.

nearby G4 plants that are outside the municipal boundaries yet are within the common travel distance of a rancher. The measure varies across both time and space because the G4 did not exist prior to 2009 and SIFs opened and closed throughout the post-G4 period. Table 1 shows how many municipalities were treated by the two policies over time.

Our first outcome is productivity, which we define in two ways. First, we estimate the stocking density of cattle (head per hectare of pasture), as in Koch et al. (2019). Next, we divide this density by the sustainable cattle units per hectare to estimate the density as a percentage of its sustainable capacity (which allows us to capture increases in productivity in areas with low sustainable capacity that appear modest in absolute terms). Head of cattle per municipality are reported by the Brazilian Institute of Statistics and Geography IBGE (2017), and pasture area is calculated according to MapBiomas (Col-

Table 1: Number of treated municipalities over time

	G4 Cattle Agreements	Priority List	G4 and Priority List
2008	0	36	0
2009	0	42	0
2010	183	42	27
2011	196	47	32
2012	200	48	40
2013	199	44	33
2014	192	39	28
2015	192	39	28
2016	181	39	26

Note. The total number of treated municipalities in a year includes those that were removed from the Priority List during the year. Six municipalities entered the list in 2009 and in 2011, and two municipalities were added in 2012. One municipality left the list in 2010, followed by another one in 2011, four in 2012, and five in 2013.

lection 3).[14] MapBiomas is a yearly land-use dataset that covers all territory of Brazil and is based on Landsat images (30 m resolution). The sustainable cattle units per hectare is based on MODIS satellite imagery and estimated by LAPIG; it corresponds to the production and demand of food for an animal unit (which corresponds to a cow with an approximate weight of 450 kg and requires around 13.5 kg of food per day). Our two measures of productivity provide an unscaled measure of density as well as a measure relative to the land potential, which allow comparison of municipalities across regions and biomes.

Next, we consider investment in inputs using data on rural credit provided by the Central Bank of Brazil as a proxy. This credit is paid to producers or cooperatives through the National System of Rural Credit (SNCR). We use two definitions of the credit outcome: first, the municipal rural credit (transformed into 2016 Brazilian reais, using World Bank deflators) divided by the pasture area, and next, the number of contracts for rural credit in the municipality. We include two categories of credit for livestock production: credit for operations and credit for investment.[15] Credit for operations covers the standard cycle of production, including the purchase of fertilizer, animal feed or nutritional supplements, and animals for fattening (only when purchased by an independent rural producer). Credit for investment covers the construction or renovation of permanent installations (such as rotational grazing or a confinement), purchase of equipment that will last for more than five years (e.g., tractors and machinery), irrigation or drainage work, pasture investment (e.g., recuperation, soil protection, or correction), or animals for

[14] We consider pasture to be the sum of pasture areas and the pasture or agriculture areas provided by MapBiomas. The pasture or agriculture category is known to be primarily comprised of pasture area but can contain patches of agriculture.

[15] Disaggregated results for those two categories are presented in table B1.

reproduction.[16] All of these investment projects require high up-front costs, and many increase long-run productivity. We exclude credit for commercialization because it is not related to potential increases in productivity.

According to the Brazilian Central Bank, SNCR was founded in 1965 by law 4.829 with the objective of increasing agricultural productivity. Today, producers are eligible to receive the subsidized credit through public and private financial institutions. In 2017, more than half of agricultural properties that received credit were the recipients of a line of government-subsidized credit. These included the National Program of Strengthening Family Agriculture and the National Program of Support for Medium-sized Producers, two hallmark examples of the Brazilian government's efforts to offer credit to small and medium-sized rural producers (IBGE, 2019). Although they are subsidized, not all lines of credit offered under SNCR are limited to small and medium-sized producers (Banco do Brasil, 2019). The use of credit as a proxy for investment follows de Castro and Teixeira (2012), who use rural credit as proxy for input expenditure and find it to be highly correlated with demand for inputs. Although credit is an imperfect measure of investment in inputs, it offers the clear advantage of creating a panel otherwise not available for agricultural investment in Brazil (Agricultural Census data are only available once every decade).

For comparison with the existing literature on avoided deforestation from the two policies, we also provide complementary results on clearing (table B6). We consider clearing of natural vegetation when the land is subsequently used for pasture (extracted from MapBiomas). Two measures are used: first, clearing in hectares and second, clearing as a percent of the total hectares in the municipality. Reforestation is not considered in this analysis because it is not incentivized by the policies we study.

Additional variables come from other sources. For heterogeneity analyses, we use data from the 2006 Agricultural Census to estimate the percentage of properties in a municipality that are over 500 hectares. We use the baseline natural vegetation area (MapBiomas) to estimate the percentage of the municipal area in natural vegetation (used for heterogeneous analysis and as control). Finally, we create a single category that combine various protected areas: indigenous territory (from the National Indian Foundation), and strict protection and sustainable use areas (from the Brazilian Ministry of the Environment).

Summary statistics are presented in table 2 for our treatments, outcomes, and the additional co-

[16] Although both the operation and the investment credit fund the purchase of animals, credit for investment only funds the purchase of animals for reproduction, which is unlikely to cause an immediate increase in the region's productivity. Rather, it could lead to a larger increase in productivity in subsequent years. Unfortunately, we are unable to distinguish between credit used for the acquisition of animals and that used for the purchase of inputs or machinery. However, we test the policy's effect on total herd size to provide additional understanding of changes that occurred during our study-period (table B8).

variates presented in this section.[17] In the table, we show the mean and standard deviations for five mutually exclusive group of municipalities located in the Amazon biome: those municipalities that were exposed only to the G4 (G4-only), MPs that were never exposed to the G4 (MP-only), municipalities that were exposed to both the G4 and the Priority List (G4-MP), the municipalities exposed to only a non-G4-owned federal slaughterhouse (non-G4 only) and all other municipalities never exposed to a federal slaughterhouse nor the Priority List. We exclude municipalities that have more than 10 head per hectare of pasture on average during our study-period since these higher values are explained by the small areas of pasture which, due to cloud cover (Koch et al., 2019), leads to higher measurement error. This corresponds to 5 non-G4 only municipalities and 23 in all others. As presented in section 4.1, our sample is composed of 192 G4-only municipalities, 8 MP-only municipalities, and 42 G4-MP municipalities. The municipalities that are not included in our main sample are 93 non-G4 only municipalities (which we use for a robustness check in section 7.2) and 136 other municipalities located in the Amazon biome.

We first note that most MPs have also been exposed to the G4, which suggests some natural overlap between underlying factors that lead a municipality to be added to the Priority List and factors that lead G4 companies to open a slaughterhouse in a given municipality. Columns 1 and 3 show similar average exposure to the G4, independently of whether the municipality was on the Priority List. Column 2 shows that most of the MP-only were not part of the first list (which matters for comparing our results to the literature since Koch et al. 2019 used exclusively the first list).[18] Outcomes are relatively similar for G4-only, MP-only, and G4-MP. They are, however, higher for the non-G4 only and all others. This is most likely explained by the fact that those regions have smaller farms with fewer cattle head and thus, the small patches of pasture are less detectable by satellite imagery. Average clearing for pasture for the pre-policy years was similar for the municipalities in our sample (G4-only, MP-only, and G4-MP), but was smaller for the other municipalities. Similarly, our sample contained more large properties. Municipalities out of our sample (non-G4 only and all others) were more covered by protected areas; this is unsurprising as protected areas are generally located in more remote regions that have less economic activity. G4-MP municipalities are generally larger in total municipal area.

[17] We also include an estimate of the average value of credit per financed hectare (2004 - 2007), which we do not use in any regression specification. Our definition of credit per hectare measures the average value of credit per hectare if credit were evenly distributed across all pasture in the municipality. As our model estimates the average effect of the policy at the municipal level, we prefer this definition. However, we present an estimate of the value per financed hectare for context and comparison of the baseline credit allocation to the cost of pasture-improving technology. We proxy this using the average pasture area per property in based on the 2006 Agricultural Census and the number of contracts.

[18] Next, we consider medium-run treatment effects by analyzing municipalities from all lists published before 2016 and observing effects up to eight years after a municipality was added to the list.

Table 2: Summary statistics (means and standard deviations)

	G4-only	MP-only	G4-MP	Non-G4 only	All others
Treatments					
Exposure to the G4 (2010)	0.35	0.00	0.34	0.00	0.00
	(0.25)	(0.00)	(0.29)	(0.00)	(0.00)
Blacklist (2008)	0.00	0.13	0.83	0.00	0.00
	(0.00)	(0.35)	(0.38)	(0.00)	(0.00)
Outcomes					
Productivity (2004-2007)	1.44	0.98	1.09	1.76	2.57
	(0.62)	(0.61)	(0.54)	(1.70)	(2.44)
Prod. relative to capacity (%) (2004-2007)	41.33	30.26	30.66	62.42	78.85
	(20.91)	(22.55)	(20.27)	(61.91)	(86.09)
Credit/ha of pasture (R$) (2004-2007)	77.98	55.80	52.26	178.57	258.68
	(70.01)	(43.29)	(23.36)	(292.40)	(378.67)
Nbr of contracts (2004-2007)	251.35	149.56	612.21	374.23	137.56
	(290.67)	(195.57)	(853.26)	(529.90)	(224.87)
Appendix outcomes					
Credit for operation/ha of pasture (R$) (2004-2007)	30.46	22.42	17.42	174.97	34.17
	(27.06)	(14.66)	(10.53)	(1147.63)	(73.89)
Credit for investment/ha of pasture (R$) (2004-2007)	47.53	33.38	34.84	291.98	307.55
	(58.27)	(29.52)	(21.42)	(1073.71)	(616.50)
Nbr of contracts for operations (2004-2007)	77.66	70.09	98.11	25.98	5.93
	(110.45)	(136.11)	(89.34)	(66.89)	(13.72)
Nbr of contracts for investment (2004-2007)	173.69	79.47	514.10	335.88	130.99
	(261.27)	(82.74)	(845.92)	(511.99)	(219.34)
Other variables					
Clearing for pasture (%) (2004-2007)	0.015	0.015	0.014	0.009	0.007
	(0.012)	(0.004)	(0.007)	(0.009)	(0.017)
Properties $\geq$ 500 ha (%) (2006)	0.07	0.18	0.12	0.03	0.02
	(0.08)	(0.17)	(0.11)	(0.06)	(0.03)
SIFs w/in 100 km buffer (2004-2007)	3.58	1.00	2.86	1.42	0.00
	(2.37)	(1.07)	(2.07)	(0.61)	(0.00)
Natural vegetation (%)	0.50	0.75	0.73	0.69	0.88
	(0.26)	(0.18)	(0.16)	(0.24)	(0.13)
Pasture (%) (2004-2007)	0.49	0.19	0.26	0.22	0.05
	(0.27)	(0.15)	(0.17)	(0.26)	(0.09)
Protected area (%) (2004-2007)	0.12	0.19	0.22	0.33	0.41
	(0.22)	(0.26)	(0.22)	(0.35)	(0.36)
Sustainable capacity (head per ha)	3.59	3.47	3.77	2.88	3.56
	(0.51)	(0.55)	(0.62)	(0.49)	(0.73)
Credit / financed ha (R$) (2004 - 2007)	662.03	1015.69	590.82	594.83	1290.92
	(1087.04)	(922.91)	(913.15)	(1092.77)	(2354.05)
Head of cattle ('000) (2004-2007)	160.95	116.46	344.91	44.07	18.23
	(131.59)	(111.34)	(279.97)	(55.74)	(27.73)
Pasture area (kha) (2004-2007)	121.45	104.41	332.85	39.32	12.61
	(93.82)	(44.50)	(224.57)	(52.98)	(24.16)
Municipality area (kha)	396.47	718.68	2031.80	544.12	1389.76
	(609.00)	(381.97)	(2700.73)	(1065.21)	(2280.54)
Observations	192	8	42	93	136

Note. Unit of observation is the municipality. Means and standard deviations are presented for municipalities that were exposed only to the G4 in column 1, for MPs that were never exposed to the G4 in column 2, for municipalities that were exposed to both the G4 and the Priority List in column 3, for the municipalities exposed to only non-G4-owned federal slaughterhouse in column 4, and for all others in column 5.

5 Estimation Strategy

We identify the effect of the G4 and the Priority List using variation in the exposure of a municipality to each policy over time. We estimate panel regressions with municipality and time fixed effects using the following specification:

$$Y_{mt} = \gamma_m + \theta_t + \beta_1 G4_{mt} + \beta_2 MP_{mt} + \beta_3 G4_{mt} * MP_{mt} + \delta' \mathbf{X}_{mt} + \epsilon_{rt}, \tag{3}$$

where Y_{mt} is cattle productivity, rural credit or clearing of natural vegetation. $G4_{mt}$ is a continuous measure of the level of exposure to the G4 and MP_{mt} represents the binary exposure to the Priority List. The interaction term $G4_{mt} * MP_{mt}$ tests how the effect of enforcement of both policies differs from the sum of the individual effects. The matrix $\mathbf{X}_{mt}$ is composed of the total number of SIFs in the municipality or its buffer to control for openings and closings of slaughterhouses over time as well as protected areas per municipal ha which change over time and restrict the available land. Municipality fixed effects (γ_m) control for unobservable fixed characteristics of the municipality, including land quality, and time fixed effects (θ_t) control for potential shocks affecting all municipalities during the same year. We follow Bustos et al. (2016) and cluster our robust standard errors (ϵ_{mt}) at the microregion level.[19]

When G4-owned companies choose to open a slaughterhouse, they are likely to prefer municipalities with a higher productivity or skill level. To include municipalities that never had a G4-owned slaughterhouses nearby could bias our estimate upward, since the largest companies likely decide to operate in the regions where productivity is increasing faster, a potential sign that ranchers in those regions are more inclined to adopt new technologies or more responsive to incentives. We test and find support for this assumption in section 7.2. Thus, we restrict our sample to those municipalities that have ever had a G4-owned slaughterhouse or the adjacent MPs.[20] To address endogeneity concerns for the eleven municipalities that move out of the Priority List before the end of our study period, we perform a robustness check with a treatment that stays equal to one once it is added to the list and never turns back to zero.[21]

We prefer our empirical strategy to selection-on-observables techniques (matching or propensity scores) for three reasons. First, slaughterhouse site selection reveals preferences associated with both observable characteristics of the location (e.g. productivity) and unobservable ones (e.g., skill level) and selection-on-observables would consider only observable characteristics. Second, based on the two main

[19] Microregions are created by IBGE to facilitate the collection of data. There are 558 microregions in Brazil, 75 of which are in the Amazon biome and 47 are in our main sample.

[20] A robustness test without the MPs adjacent to our sample is presented in section 7.4.

[21] Results are consistent and are available from the authors upon request.

criteria of the Priority List, there is very little overlap among the MPs and municipalities that were not added to the List (Assunção et al., 2019). Third, our sample of municipalities is connected to the global beef market due to being close to a G4-owned slaughterhouse. Because these slaughterhouses are exporters, their prices are based on global prices rather than solely on local supply. Thus, potential concerns over general equilibrium effects from the policies are less salient.

Most of the MPs naturally fall within the reach of G4 companies (as shown in figure 1 and table 1). With the exception of three MPs, all municipalities that have ever been on the Priority List have also been within 140 km of a G4-owned slaughterhouse. This indicates that MPs shared observable and unobservable characteristics with municipalities where G4 companies chose to open slaughterhouses. Because of the preferences revealed by slaughterhouse site locations, it is possible that productivity and investment increase more in the municipalities that are closest to the G4. If this is the case, our choice of G4 municipalities as a counterfactual for MPs offers a lower bound estimate of the effect of the Priority List.

6 Results

In this section, we present results of the impact of the G4 and the Priority List on productivity and investment in inputs, followed by heterogeneous results and alternative specifications that test for pre-policy effects. To explain the interaction of the policies, we discuss the effects on three mutually exclusive groups: municipalities that were only exposed to the G4 (hereafter G4-only), those that were only exposed to the MP (hereafter MP-only), and those that were exposed to both the G4 and the Priority List (hereafter G4-MP). To estimate the effect on the G4-MP, we estimate the linear combination of the treatments for G4 and MP as well as the interaction term and test it for statistical significance. We discuss the effect of the G4 based on the average level of exposure in that group.[22]

6.1 Effects of the G4 and the MPs on productivity and investment in inputs

We find that exposure to both the G4 and the Priority List had a positive effect on productivity (table 3). In our preferred specification with the full set of controls, the average G4-only municipalities increased productivity by 0.08 head/ha of pasture compared to a municipality with no exposure. The effect we detect is a 6% increase relative to the G4-only baseline productivity of 1.44 head/ha. These municipalities were 2.52 percentage points closer to producing at their sustainable capacity. For MP-

[22]This average level of exposure corresponds to 0.55 for G4-only and 0.66 for G4-MP.

only municipalities, being added to the Priority List increased productivity by 0.10 head/ha of pasture, although this is not statistically significant after we include controls. These municipalities were 2.50 percentage points closer to producing at their sustainable capacity, although these results are not precisely estimated. As our micromodel predicts, G4-MP municipalities had the biggest increase in productivity; they saw an increase of 0.17 head/ha of pasture on average, or a 16% increase relative to their baseline productivity, and they were 4.76 percentage point closer to producing at their sustainable capacity. The interaction terms between the two policies was not significantly different zero, indicating that these policies are neither complements nor substitutes in regards to productivity.

Exposure to the G4 increased the use of credit by R$32.67/ha of pasture in G4-only municipalities, which is a 42% increase from their baseline value. These municipalities also had 56.31 more contracts on average than municipalities with no exposure. This corresponds to an additional 5.15 billion reais in the use of credit and 63,569 credit contracts.[23] We find no evidence of an effect of the Priority List on credit, although the interaction between the two policies is negative and statistically significant, indicating that credit increased less in G4 municipalities if that municipality was also on the Priority List. These results incorporate both the demand for credit by ranchers and the availability of credit from banks. As such, the estimated increase in credit following the G4 could have been caused by an increase in demand or an increase in supply by banks in response to the policy (if unmet demand existed prior to the policy). We provide additional insights in this regard in the falsification test presented in section 7.1. Similarly, the Priority List intended that banks apply environmental laws regarding credit more thoroughly in MPs. This means that properties with illegal deforestation could have suffered additional restrictions that counteract any increase in demand by intensifying properties and thereby result in a null aggregate effect on credit in MP-only and a negative aggregate effect in G4-MP.

In table B1, we test the two types of credit separately (i.e. operation and investment), and see that the G4 had a larger effect on credit for investment, which includes purchase of tractors, infrastructure for production, animals for reproduction, and irrigation. Indeed, there were 47.13 more contracts for investment for G4-only municipalities compared to 22.57 more contracts for operations. This suggests that many ranchers took on large-scale projects in response to the G4. Some increased their use of inputs such as fertilizer or feed or their purchase of animals for fattening, which are covered by operations, but this was a small effect compared to investment in projects for long-run productivity. While credit may be

[23] We estimate the policy's effect on contracts in municipality m in year t by multiplying the coefficient by the municipality's exposure to the policy in that year. To estimate the policy's effect on credit per hectare, we multiply the coefficient by the municipality's exposure to the policy in year t and the municipality's pasture area. In both cases, the total effect of the policy is the sum of the effects over all municipalities and all years.

used to purchase animals in both categories, our results support the propositions 1 and 3 of the theoretical model, which predicts that ranchers invest in non-animal inputs. First, breeding cows account for a small proportion of the herd, so an increase in cattle density is unlikely to be driven only by acquisition of breeding cows, which are the only animal eligible for investment financing. Second, the G4 led to a 40% increase in the value of credit per hectare in G4-only municipalities, but it only led to a 4% increase in the heads per hectare. Thus, the increase in credit far outpaced the increase in heads, leading us to believe a significant amount of the funds went toward non-animal inputs.

Table 3: Estimated effect of the G4 and the Priority List on cattle productivity and credit

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.155**	0.154**	4.622**	4.596**	59.206***	59.417***	102.729***	102.388***
	(0.061)	(0.061)	(1.902)	(1.907)	(21.991)	(21.954)	(30.513)	(30.483)
MP	0.117*	0.104	2.870	2.492	21.587	24.594	15.400	10.536
	(0.065)	(0.065)	(1.868)	(1.903)	(18.317)	(18.348)	(49.064)	(50.086)
G4 × MP	-0.054	-0.051	-1.238	-1.158	-69.889***	-70.536***	-271.420*	-270.372*
	(0.062)	(0.063)	(2.142)	(2.164)	(22.277)	(22.205)	(144.096)	(143.991)
Lincom								
G4 + MP	0.218**	0.207**	6.253**	5.930**	10.905	13.474	-153.291	-157.448
+ G4 × MP	(0.083)	(0.083)	(2.558)	(2.571)	(19.984)	(19.558)	(126.497)	(128.030)
Observations	3,144	3,144	3,144	3,144	3,093	3,093	3,093	3,093
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Time & munic FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and their interaction. * p< 0.10, ** p<0.05, *** p<0.01.

6.2 Heterogeneous effects

6.2.1 Effects by property size

The theoretical micromodel suggests that the Priority List has heterogeneous impact relative to property size (proposition 2), which in aggregate leads to the hypothesis that the policy will be more effective in municipalities with larger properties. To test this hypothesis, we interact the baseline percentage of properties in a municipality that are more than 500 hectares with the exposure to the G4 and the Priority List. Results are reported in table 4.

The interaction between the percentage of large properties and exposure to the Priority List is positive and significant for our measures of productivity. The average MP had 12.76% of properties larger than 500 hectares with a standard deviation of 0.13. We find a net increase of 0.10 head/ha of pasture in the average MP after addition to the Priority List, which matches our result from table 3. The interaction term between that a one standard deviation increase in the proportion of large properties expanded the effect by an additional 0.13 head/ha of pasture, more than doubling the effect for the average municipality.[24] Moreover, the average MP was 2.40 percentage points closer to its sustainable capacity after addition to the list, but a one standard deviation increase in large properties corresponded to an additional percentage point increase of 3.82.[25] As in the main results, the policy had a modest effect on average, but this analysis demonstrates that the results in table 3 mask increases in productivity in municipalities with large ranches.

Credit per hectare of pasture also increased with the proportion of large ranches in MPs. Following the same interpretation, we find the average MP saw an increase in credit of R$23.27/ha of pasture, but a one standard deviation increase in large properties resulted in an additional increase of R$52.45/ha of pasture. While the interaction term in the model that estimated the effect on the number of contracts is also positive, it is not statistically significant. These results show that large ranches increased credit, suggesting they were the same ones that intensified, leading to an increase in the total value of credit/ha of pasture, but not increasing the number of contracts.

[24] We multiple the interaction effect, 1.084, by the standard deviation of percent large properties, 0.13.

[25] This interpretation is for both MP-only and G4-MP since the linear combination of all terms, including interaction terms, is statistically insignificant.

Table 4: Heterogeneous effects of the G4 and the Priority List on productivity and credit by property size

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.147**	0.148**	4.307**	4.337**	59.284**	59.059**	110.497***	110.902***
	(0.065)	(0.065)	(1.955)	(1.975)	(26.097)	(25.960)	(35.854)	(36.111)
MP	-0.021	-0.038	-1.147	-1.617	-35.012	-31.686	3.109	-2.881
	(0.100)	(0.097)	(2.968)	(2.933)	(24.970)	(24.699)	(82.944)	(84.685)
G4 × MP	0.017	0.020	0.888	0.964	-27.693	-28.227	-321.017	-320.056
	(0.102)	(0.103)	(3.576)	(3.615)	(30.831)	(30.640)	(198.038)	(198.055)
Lg properties × G4	0.052	0.027	2.688	1.986	-16.146	-11.098	-91.976	-101.066
	(0.257)	(0.266)	(7.448)	(7.676)	(142.932)	(137.698)	(233.736)	(238.066)
Lg properties × MP	1.063**	1.084**	30.814**	31.399**	434.901*	430.732*	90.106	97.615
	(0.516)	(0.515)	(15.113)	(15.126)	(230.724)	(227.976)	(282.368)	(284.202)
Lg properties × G4 × MP	-0.534	-0.523	-16.496	-16.180	-321.774	-324.117	459.518	463.738
	(0.525)	(0.541)	(16.443)	(16.869)	(263.253)	(260.385)	(601.268)	(599.150)
Lincom								
G4 + Lg properties × G4	0.200	0.176	6.995	6.324	43.138	47.961	18.521	9.836
	(0.244)	(0.251)	(7.210)	(7.377)	(130.606)	(125.651)	(217.550)	(221.310)
MP + Lg properties × MP	1.042**	1.046**	29.667**	29.782**	399.889*	399.045*	93.215	94.734
	(0.433)	(0.436)	(12.609)	(12.666)	(208.548)	(206.037)	(204.449)	(204.107)
G4 + MP + G4 × MP	0.707	0.718	20.165	20.891	121.254	94.662	571.253	248.253
+ For × G4 + For × MP	(0.508)	(0.441)	(17.759)	(15.104)	(98.573)	(88.847)	(626.770)	(495.598)
+ For × G4 × MP								
Observations	3,144	3,144	3,144	3,144	3,093	3,093	3,093	3,093
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on main effects and interaction effects for G4 and large properties, MP and large properties, and all three. * p< 0.10, ** p<0.05, *** p<0.01.

6.2.2 Effects of land constraint

According to our theoretical model, the Priority List should have a stronger effect on large properties that have large amounts of remaining forest in absolute terms, while the G4 should incentivize intensification on properties that are land constrained (i.e. properties that have little remaining forest relative). In aggregate, the G4 should have the largest effect in municipalities with many land-constrained properties, and properties where the land constraint is very binding. We test this using municipal-level forest and natural vegetation in 2006 as a percent of total municipal area. While this proxy does not measure the land constraint for each property owner, it represents the general availability of land for pasture expansion within the municipality. Results are presented in table 5.

The interaction between the percentage of forest and exposure to the G4 is negative and significant for the productivity measures and the value of credit/ha of pasture. This indicates that the G4 had the smallest impacts on productivity and credit in municipalities with a high percentage of forest cover and conversely, the largest impacts in municipalities with a low percentage of forest cover. The average G4-only municipality had 48% of remaining forest, with a standard deviation of 0.27. Numerically, this corresponds to an increased productivity of 0.10 head/ha of pasture in the average G4-only municipality (or a 3.11 percentage point increase relative to sustainable carrying capacity), while for those municipalities with less forest cover, estimated as a one standard deviation decrease in baseline forest, this leads to a further 0.07 increase in head/ha of pasture (or a 2.40 percentage point increase relative to sustainable capacity).[26] Similarly, the average G4-only municipality saw an average increase in credit of $R37.06/ha of pasture, while for those municipalities with less forest cover, the increase was a further $R17.87/ha of pasture. We also note that there is no heterogeneous impact for the number of contracts. This is consistent with our theory, since municipalities with a high percentage of forest cover could also have a proportionally smaller number of owners; new frontiers are characterized both by high deforestation and low population density, compared to established frontiers (Rodrigues et al., 2009). Our estimation supports the hypothesis that property owners in municipalities with high areas of remaining forest stand to gain by continuing to clear large areas, while those in municipalities with less remaining forest are more likely to comply with the zero-deforestation policy.

We do not find a significant interaction between the Priority List and forest cover; proposition 2 states that the response to the Priority list depends on the absolute rather than relative amount of remaining forest per property, which is likely better proxied by property size. We find that the Priority List offset

[26] In our preferred specification with all controls, we multiply the interaction term between the G4 and percent forest, -0.496, by the average G4 exposure, 0.55, and the average percent forest for G4-only municipalities, 0.48. We then add the main effect of the G4, 0.423.

the low productivity and credit response to the G4 in highly forested municipalities. While the interaction term between G4 and MP is negative and statistically significant in this model, the interaction between the two policies and forest cover is positive, statistically significant, and larger in magnitude. Thus, the net interaction between the two policies is effectively zero for most municipalities, but for municipalities with high remaining forest cover, the net interaction is positive. In these municipalities, the policies may function as complements. Despite having more remaining forest than G4-only municipalities, the average G4-MP increased productivity by 0.13 head/ha of pasture, or an increase of 3.49 percentage points relative to sustainable capacity.[27]

Table 5: Heterogeneous effects of the G4 and the Priority List on productivity and credit by percent forest cover

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.405***	0.423***	13.013***	13.531***	127.483***	126.094***	20.857	24.070
	(0.144)	(0.147)	(4.517)	(4.644)	(41.396)	(41.565)	(77.012)	(78.444)
MP	0.368	0.460	12.571	15.361	147.921	140.696	-160.152	-143.437
	(0.336)	(0.347)	(9.721)	(10.214)	(100.615)	(101.889)	(243.366)	(245.971)
G4 × MP	-0.332**	-0.360**	-9.995**	-10.827**	-186.943**	-184.759**	24.899	19.847
	(0.162)	(0.162)	(4.452)	(4.424)	(90.804)	(91.312)	(569.509)	(568.949)
Percent forest × G4	-0.462**	-0.496**	-15.443**	-16.470**	-125.412**	-122.677**	151.247	144.920
	(0.190)	(0.197)	(5.966)	(6.206)	(46.984)	(47.262)	(125.911)	(128.321)
Percent forest × MP	-0.343	-0.498	-13.305	-17.979	-174.546	-162.451	243.858	215.876
	(0.471)	(0.482)	(13.709)	(14.328)	(120.768)	(123.085)	(295.278)	(301.530)
Pct for × G4 × MP	0.510**	0.558**	16.125**	17.579**	195.610*	191.790*	-464.022	-455.186
	(0.248)	(0.247)	(7.359)	(7.288)	(110.668)	(111.646)	(858.333)	(855.698)
Lincom								
G4 + Pct for × G4	-0.056	-0.073	-2.430	-2.939	2.071	3.417	172.103**	168.990**
	(0.077)	(0.080)	(2.387)	(2.467)	(21.066)	(21.031)	(64.545)	(65.159)
MP + Pct fore × MP	0.025	-0.038	-0.734	-2.617	-26.624	-21.754	83.707	72.440
	(0.153)	(0.153)	(4.496)	(4.621)	(24.454)	(25.223)	(65.666)	(70.391)
G4 + MP + G4× MP	0.478*	0.087	12.961	1.196	171.056*	-11.306	-208.212	-193.909
+ For× G4 + For× MP	(0.273)	(0.203)	(8.601)	(6.658)	(91.129)	(25.969)	(827.684)	(328.336)
+ For× G4 × MP								
Observations	3,144	3,144	3,144	3,144	3,093	3,093	3,093	3,093
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on main effects and interaction effects for G4 and percent remaining forest, MP and percent remaining forest, and all three. * p< 0.10, ** p<0.05, *** p<0.01.

[27] The average G4-MP had an average of 70% remaining forest with a standard deviation of 0.17.

6.3 Alternative specifications that test for pre-policy effects

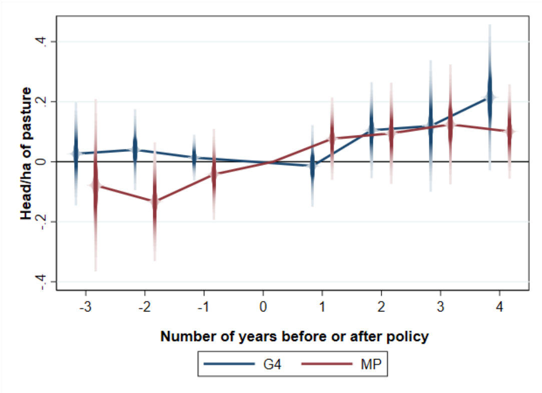
The validity of our estimates depends on the assumption that in the absence of the G4 and the Priority List, and while controlling for municipality and time fixed effects as well as our set of controls, municipalities would have followed parallel trends. This assumption, which cannot be tested directly, may be verified by comparing the pre-trends for the municipalities before the programs with a model adapted from the event study literature:

$$Y_{it} = \tilde{\alpha_i} + \tilde{\beta_t} + \sum_{k=-3}^{4} \tilde{\lambda_k} \mathbb{1}\{K_{mt} = k\} \hat{G}4_{mt} + \sum_{j=-3}^{4} \tilde{\gamma_j} \mathbb{1}\{J_{mt} = j\} + \tilde{\epsilon_{rt}}. \qquad (4)$$

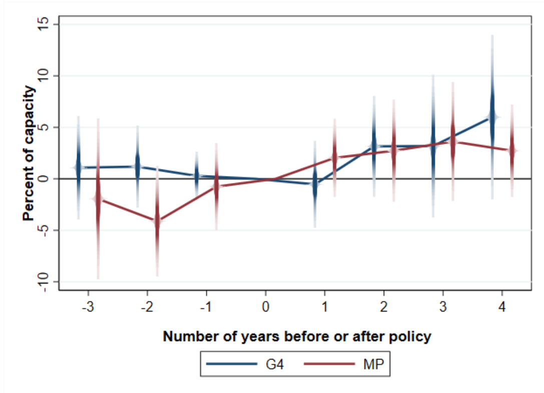
Here K_{mt} and J_{mt} are the number of periods relative to each policy; K_{mt} is the difference between year t and the first year of G4 exposure, while J_{mt} is the difference between year t and the first year the municipality is placed on the Priority List. Since our main specification uses a continuous treatment for the Cattle Agreements, we test whether $\hat{G}4_{mt}$ – the percent of slaughterhouses owned by the G4 during the period – led to higher productivity compared to municipalities that did not have any G4 slaughterhouse at that time or that will never have. Due to our specific empirical context, this test is similar in essence to a falsification test where a fictitious treatment prior to the policy should not lead to any effect. The effect should be only observable after the signature of the G4 Cattle Agreements. In the same equation, we test whether Priority List municipalities had different trends in productivity and credit prior to being formally added to the list.

To obtain a balanced panel, we focus on municipalities that had data both three years before the policy and four years after. We drop observations that are outside of this window. For our estimates of β to be unbiased in equation 3, λ_{-3} through λ_{-1} and γ_{-3} through γ_{-1} should not be different from zero. We graph the point estimates and 95 percent confidence intervals of λ_{-3} through λ_4 and γ_{-3} through γ_4 in figure 3.

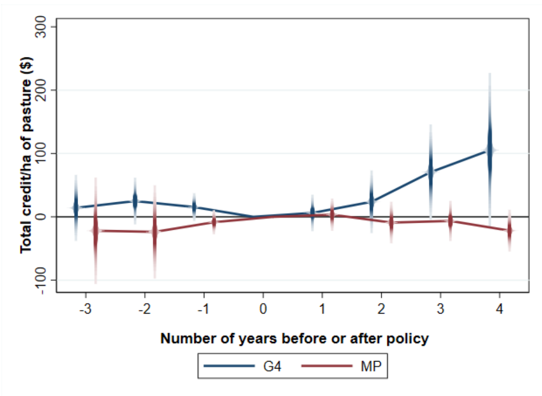
The coefficients of the pre-trends suggest that our sample choice circumvents the problem of companies selecting municipalities based on productivity and investment. Neither policy had a statistically significant lead-up effect on productivity or investment in the year immediately before treatment, and the overall trends support the statistical validity of our estimation strategy. Thus, we conclude that the municipalities that were ultimately placed on the Priority List were not on a significantly different productivity or investment trajectory than municipalities that had ever been within reach of a G4.



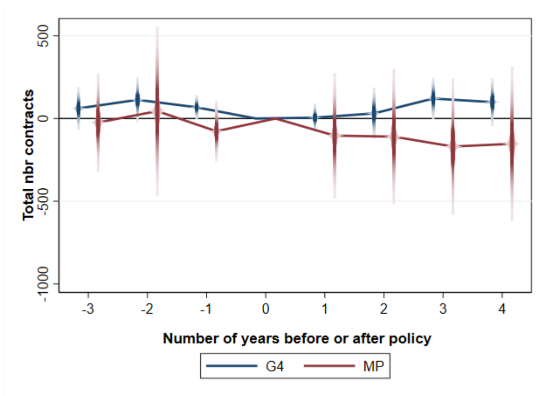
(a)



(b)



(c)



(d)

Figure 3: Leading and lagging effects of the G4 and Priority List. Estimates obtained using the specification with a balanced panel of municipalities covering the seven years surrounding the introduction of the two policies of interest.

7 Robustness checks

Here, we discuss identification challenges and support our results with falsification tests and robustness tests. We also provide complementary results on clearing and on underlying components of our measure of productivity.

7.1 Falsification test

We examine whether our results were driven simply by the presence of the G4 slaughterhouse, rather than by the G4 Cattle Agreements. After the initial enforcement of the G4 Cattle Agreements, all variation in treatment came only from openings and closings of slaughterhouses. Our results could therefore be driven by the opening of a slaughterhouse that stimulates changes in productivity, rather than by the G4 Cattle Agreements policy. Our falsification test uses municipalities outside of the Amazon biome and integrates biome specific time trends to control for differences across the four biomes outside of the Amazon.[28] Municipalities with a G4 slaughterhouse outside of the Amazon have faced all the same pressures caused by having a G4 slaughterhouse except the zero-deforestation policy, which was enforced only in the Amazon biome.

Our results support the premise that the increase in productivity and credit was due to the G4 Cattle Agreements, rather than merely the result of proximity to the G4-owned slaughterhouses. We find that exposure to the G4 had no effect on cattle productivity or the value of credit outside of the Amazon biome (table 6). In our preferred specification with biome time trends, there was an increase in contracts, although this result is only significant at the 10 percent level. Differences in biome time trends seem to explain a large proportion of the differences in the change in number of contracts. Indeed, biomes are subject to distinct agricultural development, distribution of landownership, and policy pressures that may affect their land investment dynamics (see e.g., Rausch et al. 2019; Soares-filho et al. 2014). As shown in the table that excludes this control (table B2), all results on productivity and value of credit per hectare are consistent with table 6. However, the coefficient associated with the number of contracts has a larger point estimate and is statistically more significant when we do not include biome time trends. Overall, since the estimated coefficients associated with the value of credit/ha of pasture are negative, the result tends to indicate that average value per contract decreased for those municipalities with higher G4 treatment outside the Amazon. This also suggests that our conclusions from the falsification test are not undermined.

[28] This control is implicitly used in all our regressions, but since there is only one biome in our main sample, it simply corresponds to the time fixed effects.

Table 6: Falsification test – Estimated effect of the G4 outside the Amazon on cattle productivity and credit

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4 - out of the Amazon	-0.236	-0.362	-3.553	-5.896	-206.356	-112.425	90.985**	38.972*
	(0.157)	(0.248)	(2.706)	(3.920)	(228.140)	(196.328)	(38.116)	(22.916)
Observations	16,751	16,751	16,751	16,751	16,534	16,534	16,534	16,534
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Biome x Time		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. * $p< 0.10$, ** $p<0.05$, *** $p<0.01$.

7.2 Including the municipalities that ever had a non-G4-owned slaughterhouse in the counterfactual

We loosen the definition of the sample, which to this point was restricted to those municipalities that ever had a G4-owned slaughterhouses (either in the municipality or in the 100-km buffer), and now include all municipalities that ever had a federally inspected slaughterhouse. This adds 93 municipalities to the main sample. Results are presented in table B3. We observe that the effects of both policies are much larger; in terms of heads/ha of pasture, the point estimates associated with the G4 are 2.6 times greater and almost twice for MPs, in terms of credit, the G4 is associated with 3.8 times more value/ha of pasture and 50% more contracts.[29] However, these results should be interpreted with caution as the testing of pre-policy trends suggests that municipalities within the reach of only a non-G4-owned slaughterhouse were on different trends, particularly in terms of productivity (figure B3). These results support our initial assumption that G4-owned slaughterhouses are strategically located and provide a better counterfactual than municipalities that only were within the reach of non-G4 slaughterhouses.

7.3 Sample limited to 2004 - 12

If ranchers with high productivity and high levels of investment favor areas around G4 slaughterhouses but avoid MPs, then ranchers might have left MPs and moved to G4 municipalities. This would bias our estimate of the G4 impact upward and the estimate of the Priority List downward. Similarly, if

[29]For conciseness, we did not include all results using this extended sample in the supplementary material, but they are available from the authors and in almost all cases, they show a larger effect of the policies.

G4 plants were likely to cease their slaughtering activities where the policy environment was the most restrictive, our results could be biased. To address these concerns, we limit our sample to 2004 - 12. This implicitly allows producers three years to adopt techniques that improve productivity, while limiting relocation of ranchers and slaughterhouses, as the process of opening, closing, or relocating a ranch or slaughterhouse is lengthy and bureaucratically complex. Results are presented in table B4.

This robustness test supports the conclusion that our results are not driven by endogenous sorting of cattle ranchers and openings of G4 slaughterhouses after the announcement of the policies. Indeed, we find a nearly identical response in productivity to the G4 in the short sample (although the effect on the value of credit per hectare is no longer statistically significant).

Conversely, we find a stronger productivity response to the Priority List in this time period. In the first four years of the policy, MP-only saw an increase of 0.15 head/ha of pasture compared to 0.10 over the full period, while G4-MP saw an increase of 0.21 head/ha of pasture compared to 0.17 over the full period. This is plausible, given anecdotal reports that the policy was pursued more aggressively during its early stages.[30]

7.4 Restriction to municipalities that had a G4 slaughterhouse at any time

In order to restrict our analysis to the most comparable sample, we exclude MPs that never had a G4 slaughterhouse within their buffer (table B5). Again, we find that the policies increased productivity, although we lose significance when estimating the main effect of the Priority List due to loss of observations in the set of Priority Municipalities.

7.5 Effects of distance to a G4-slaughterhouse

The theoretical model predicts that the G4 policy's effect is increasing in β (the penalty on income that ranchers incur after deforestation). While the measure of the exposure to the G4 captures this variation in β, another factor that affects the severity of the penalty is the distance from the slaughterhouse. This penalty should be highest in municipalities that are nearest to G4 slaughterhouses, as ranchers with deforestation would need to increase their transportation costs to sell to a non-G4 slaughterhouse. Here, we consider the heterogeneous effects of the G4 exposure according to the suppliers' distance to the slaughterhouse using a sample that includes all municipalities in a 140-km buffer of a G4-owned

[30] Empirically, we also note that Arima et al. (2014); Cisneros et al. (2015); Assunção and Rocha (2014); Assunção et al. (2019) restrict data from one to four years after the beginning of the policy and analyze municipalities that were added to the list before 2012 and Koch et al. (2019) limit their treatment group to the original 36 municipalities on the 2008 list exclusively.

slaughterhouse. We include three mutually exclusive indicators: first, municipalities within the 60 km buffer (G4 $<$ 60 km); next, municipalities exposed to the G4 between the 100 and 60 km buffer (G4 60-100 km); and finally, municipalities exposed to the G4 only in the 140 km buffer (G4 100-140 km). We interact these indicators with the Priority List treatment. Results are presented in table B7.

The G4 had the largest effect on productivity and credit close to the slaughterhouse. The coefficients for head/ha of pasture are 0.43 when the buffer is under 60 km, 0.32 for the 60-100 km buffer, and 0.11 for the 100-140 km buffer (statistically insignificant). The coefficients for the value of credit per hectare of pasture are 315.63 in the less than 60 km buffer, 311.32 for the 60-100 km buffer, and -15.34 for the 100-140 km buffer (also statistically insignificant). MPs increased head/ha of pasture by 0.21 and their density relative to capacity increased by 6.10 percentage points in this specification.

We find that combining the policies resulted in the largest effect in the 60 - 100 km buffer. For a municipality within the smallest buffer (less than 60 km), the interaction term suggests that addition to the Priority List had no effect on productivity if it had already been exposed to the G4. This corresponds with the theoretical model, as the stronger influence of the G4 leads more properties to choose not to deforest and be therefore unaffected by the Priority List. In the 60 - 100 km buffer, however, there is one set of ranchers who continue to deforest despite the G4. These ranchers are influenced by the Priority List, which leads to a strong effect in this buffer. Further, we find additional evidence that G4 municipalities on the Priority List had a smaller increase in credit than non-MPs.

7.6 Effect of the G4 and Priority List on clearing, pasture area, and head of cattle

Finally, we test the policy's effect on the underlying components of productivity: deforestation, total pasture area, and total head of cattle. As previously shown by Alix-Garcia and Gibbs (2017), we find no evidence that the G4 reduced clearing (table B6), despite having a significant effect on productivity. This could be because ranchers experienced relatively small amounts of degradation during the time period. They may have invested in productivity with the awareness that degradation would continue, but in the absence of the policy they would have undertaken relatively small amounts of clearing in the short time frame. We show there was a larger increase in credit for investment, which covers "lumpy" goods like tractors and infrastructure. This strengthens the likelihood that ranchers invested in productivity while considering future production seasons.

We find supportive evidence that the MPs reduced clearing. This is consistent with literature which consider the policy's effect up to 2012 (at the most recent) and find that the policy significantly reduced clearing (Assunção and Rocha, 2014; Cisneros et al., 2015; Arima et al., 2014; Assunção et al., 2019).

When we limit our sample to 2004-12, we find that MP-only had 5,146 fewer hectares of deforestation per year after the policy, while G4-MP had 6,050 fewer hectares of deforestation on average. When we consider the policy's effect through 2016, we find a smaller but still statistically and economically significant effect of 3,385 fewer hectares of deforestation per year in MP-only and 3,781 fewer hectares in G4-MP.

The ratio of the number of head of cattle to the total municipal area increased after both policies. The average G4-only municipality saw an increase of 0.023 head/ha, while an MP-only saw an increase of 0.030 head/ha, and a G4-MP saw an increase of 0.046 head/ha. However, total pasture area as a proportion of total municipal area did not change differently in response to either policy (table B8). As discussed in section 3.5, we note that while our theoretical model is limited to one period, our econometric analysis considers six years following the beginning of the G4 and eight years after the release of the first Priority List. It is plausible that initial increases in productivity motivated medium or long-run increases in herd size. The theoretical model predicts that ranchers will reduce clearing in response to both policies, and this reduction is part of what increases the capital-to-land-ratio. In reality, ranchers may have also increased productivity per hectare of pasture by abandoning pasture. We do not consider reforestation or abandonment in our measure of deforestation, but these would be captured by the total pasture area.

8 Conclusion

This article investigates how environmental policies modify the allocation of resources for agricultural production. We provide evidence that anti-deforestation policies affected input usage in the Brazilian Amazon, a region of historically low-density cattle production. Between 2008-16, both the G4 and the Priority List increased productivity (6.10% and 11.57% respectively), with the greatest increase occurring when municipalities were subject to both policies (16.39%). The G4 also increased credit uptake (most of which was for investment goods like tractors or rotational grazing), while we do not find an effect from the Priority List. Productivity and investment increased more in municipalities closer to G4 slaughterhouses (because ranchers faced the highest costs if they were excluded from the supply chain following deforestation) and with less remaining forest (because ranchers had less to gain by violating the zero-deforestation requirement), while the largest effects from the Priority List were found in municipalities with a high proportion of large ranches (as these ranches faced a greater risk of being fined should they deforest).

Our analysis brings new evidence of the impacts of environmental regulation on productivity. We are the first to examine empirically the effect of the Priority List on investment and the effect of a market exclusion policy on both productivity and investment. We expand the micromodel of Koch et al. (2019) by integrating a crucial mechanism, namely pasture degradation, and we create the first theoretical study of a market exclusion policy. We further document, both theoretically and empirically, how the fines-for-deforestation and the market exclusion policies interact. We find no evidence that these public- and private-led policies are either substitutes or complements in this context, and policy-makers can achieve higher productivity outcomes by implementing them in conjunction.

We note two caveats. First, with our municipal-level data, we are unable to precisely isolate the reason why productivity and investment increased while deforestation patterns did not change following the G4. One possible reason is that the G4 increased high-capacity confinement operations that serve as intermediaries in order to avoid direct monitoring of ranchers with deforestation by the slaughterhouses. To better understand the extent to which this could explain our results, further work should quantify the change in market power for confinements and the likelihood of new confinements near G4 slaughterhouses. Second, we cannot disentangle the changes in credit availability from any change in demand for credit. On one hand, banks could have increased the supply of credit near G4 slaughterhouses. On the other hand, credit availability could have been reduced in MPs following the policy. While this can threaten our identification, especially in the case of the G4, we argue that the falsification test results (based on a sample of municipalities with G4-owned slaughterhouses outside of the Amazon) provides credible arguments that credit supply does not necessarily increase near G4-owned slaughterhouses.

In spite of these limitations, our paper has broader implications for environmental and agricultural policies. First, we confirm that environmental policy can artificially impose land scarcity and incentivize agricultural actors to intensify their production. Second, our findings show that environmental policies that aim to decrease deforestation are not viable in the long run without increased investment in land. Indeed, pasture degradation without increased investment in land implies that – sooner or later – at least a portion of landowners will produce at unsustainable density levels and as such, will increase deforestation or leave the industry altogether. This means that policymakers should promote training and oversight to ensure that intensification spurred by land use policies is both safe and sustainable, particularly with populations that are unfamiliar with non-organic pesticides and fertilizers. Third, inclusion of all slaughterhouses in the zero-deforestation policy would bring about greater impact both to reduce deforestation and to increase productivity and investment. Fourth, public- and private-led environmental policies, particularly for developing countries, can lead to larger gains when implemented simultaneously.

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Appendix A Theoretical model: relaxing the production constraint

We consider the effect of relaxing the production constraint on our hypotheses. Now, the rancher may choose their production level, and μ (the Lagrange multiplier on the production constraint described in equation 1) no longer affects the rancher's choice of land or inputs.

When we consider a fines-for-deforestation policy in this setting, proposition 1 is unchanged. For the sake of this exercise, we update the name of the proposition:

Proposition A1: *When ranchers are not production-constrained, a policy that imposes fines for deforestation results in: (a) a reduction in newly cleared land L^n, (b) an increase in the use of inputs M, (c) an increase in the heads of cattle per hectare, $\frac{Q}{L+L^n}$, and (d) an increase in the inputs per hectare, $\frac{M}{L+L^n}$.*

First, (a) holds because the addition of the fines to equation 1 still leads ranchers to decrease their choice of L^n. In the case of (b), although the rancher no longer needs to increase M to satisfy the production constraint given the decrease in L^n, the decrease in L^{n*} increases the marginal product of M. Although ranchers increase their use of inputs to account for the decrease in clearing, total output falls unless land can be perfectly substituted with inputs. Thus, in this case, the total heads produced, Q, falls. However, the percent decrease in number of heads is less than the percent decrease in clearing because inputs offset some of the decrease in clearing. This leads to (c), and our main hypothesis regarding productivity holds. Finally, (d) is unchanged because equation 2 is not affected by the relaxing of the production constraint.

In the case of a market-exclusion policy in this setting, proposition 3 changes as follows:

Proposition A2: *When ranchers are not production-constrained, a policy that imposes a penalty on production that takes place on land with deforestation will divide properties into two groups. The first chooses $L^n = 0$ and replaces newly cleared land with additional inputs. For this group, there is (a) a reduction in newly cleared land L^n, (b) an increase in the use of inputs M, (c) an increase in the heads of cattle per hectare, $\frac{\overline{Q}}{L+L^n}$, and (d) an increase in inputs per hectare, $\frac{M}{L+L^n}$. A second group continues clearing; for this group there is (a) a reduction in L^n, (b) a reduction in M, (c) an ambiguous change in the heads per hectare, and (d) no change in the inputs per hectare.*

The discussion of the conclusions for the group that chooses $L^n = 0$ follows the discussion of the fines-for-deforestation policy, as presented above. For the group that chooses $L^n > 0$, the penalty β leads them to choose a lower level of L^n and M, leading to (a) and (b). This effect was previously offset by μ, which forced ranchers to continue at their previous levels of production. Total output will decrease, but whether the percent decrease in heads is larger or smaller than the percent decrease in clearing depends on the returns to scale of the production function. For example, in the case of the Cobb-Douglas production function with constant returns to scale, the head per hectare would be unchanged. Finally, (d) remains unchanged because equation 2 is unaffected by the relaxing of the production constraint.

Appendix B Additional tables and figures

Table B1: Estimated effect of the G4 and the Priority List on credit for operations and for investment

	Credit for operation				Credit for investment			
	Value/ha of pasture		Nbr contracts		Value/ha of pasture		Nbr contracts	
G4	19.151**	19.241***	40.055**	40.176**	21.042*	21.038*	81.687***	81.350***
	(7.141)	(7.132)	(17.458)	(17.437)	(11.260)	(11.272)	(26.243)	(26.217)
MP	9.327	10.612	12.260	13.983	0.108	0.055	15.292	10.481
	(7.928)	(7.937)	(11.415)	(11.454)	(10.785)	(11.037)	(48.773)	(49.621)
G4 × MP	-16.554*	-16.830*	-53.335***	-53.706***	10.996	11.007	-282.416**	-281.380**
	(8.774)	(8.743)	(16.052)	(16.028)	(22.009)	(22.019)	(138.869)	(138.840)
Lincom								
G4 + MP	11.924*	13.022*	-1.020	0.452	32.146*	32.101*	-185.437	-189.549
+ G4 × MP	(7.098)	(6.952)	(15.686)	(15.455)	(17.733)	(17.912)	(123.816)	(125.082)
Observations	3,093	3,093	3,093	3,093	3,093	3,093	3,093	3,093
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and their interaction. * p< 0.10, ** p<0.05, *** p<0.01.

Table B2: Robustness of the falsification test – Estimated effect of the G4 outside the Amazon on cattle productivity and credit without biome specific flexible time trends

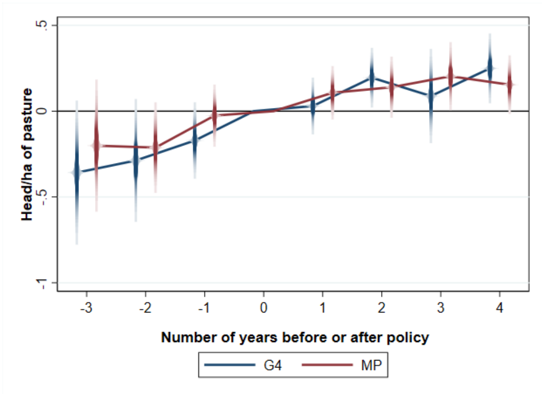
	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4 - out of the Amazon	-0.236	-0.234	-3.553	-3.515	-206.356	-210.310	90.985**	90.364**
	(0.157)	(0.157)	(2.706)	(2.699)	(228.140)	(229.280)	(38.116)	(38.324)
Observations	16,751	16,751	16,751	16,751	16,534	16,534	16,534	16,534
Pre-period mean (G4)	1.8	1.8	43.7	43.7	335.9	335.9	172.3	172.3
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. * p< 0.10, ** p<0.05, *** p<0.01.

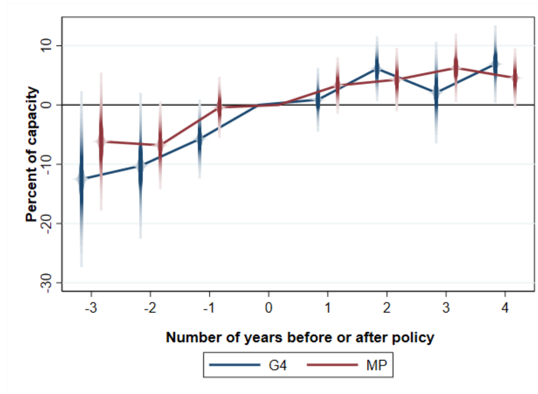
Table B3: Robustness: estimated effect of the G4 and the Priority List on cattle productivity and credit using an expanded sample with municipalities that were ever within the reach of any federally inspected slaughterhouse.

	Productivity				Credit			
	Heads/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.387***	0.396***	12.307***	12.570***	233.451**	233.743**	164.986***	164.983***
	(0.103)	(0.106)	(3.300)	(3.391)	(112.804)	(114.418)	(33.530)	(33.676)
MP	0.203**	0.189**	5.773**	5.379**	131.914	131.489	50.473	50.477
	(0.078)	(0.077)	(2.323)	(2.301)	(86.443)	(84.237)	(49.996)	(50.280)
G4 × MP	-0.150*	-0.152*	-4.471	-4.524	-185.845**	-185.904**	-308.847**	-308.847**
	(0.083)	(0.084)	(2.718)	(2.774)	(89.247)	(89.602)	(141.732)	(141.779)
Lincom								
G4 + MP	0.439***	0.433***	13.609***	13.425***	179.521	179.328	-93.389	-93.387
+ G4 × MP	(0.117)	(0.117)	(3.786)	(3.806)	(110.343)	(109.431)	(132.393)	(132.540)
Observations	4,240	4,240	4,240	4,240	4,156	4,156	4,156	4,156
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

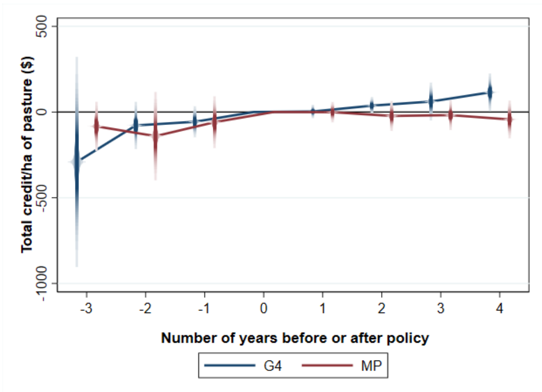
Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and their interaction. * p< 0.10, ** p<0.05, *** p<0.01.



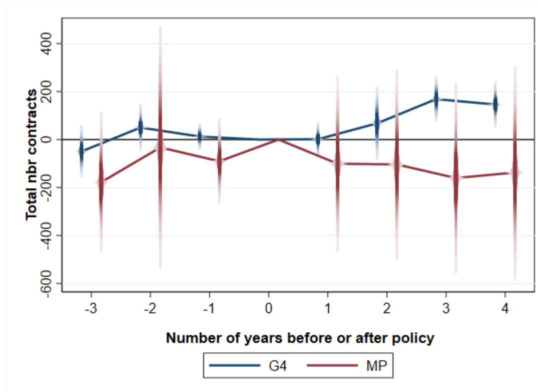
(a)



(b)



(c)



(d)

Figure B1: Alternative specification that tests for pre-policy effects using the expanded sample that includes all municipalities that were ever within the reach of any federally inspected slaughterhouse. Leading and lagging effects of the G4 and Priority List. Estimates obtained using the specification with a balanced panel of municipalities covering the seven years surrounding the introduction of the two policies of interest.

Table B4: Sample limited to 2004-12 – Estimated effect of the G4 and the Priority List on cattle productivity and credit

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.167*	0.164*	5.254*	5.147*	27.916	28.246	106.263***	103.617**
	(0.088)	(0.088)	(2.769)	(2.770)	(19.424)	(19.343)	(38.688)	(38.577)
MP	0.163***	0.147**	4.357***	3.887**	9.911	11.384	-8.881	-20.676
	(0.056)	(0.055)	(1.617)	(1.573)	(13.071)	(13.127)	(57.332)	(58.347)
G4 × MP	-0.079	-0.075	-2.580	-2.467	-47.339***	-47.690***	-314.368*	-311.553*
	(0.086)	(0.086)	(2.956)	(2.951)	(17.449)	(17.485)	(156.706)	(155.928)
Lincom								
G4 + MP	0.251**	0.235**	7.030**	6.568**	-9.511	-8.059	-216.986	-228.612
+ G4 × MP	(0.110)	(0.109)	(3.178)	(3.150)	(19.567)	(19.302)	(150.959)	(155.850)
Observations	2,176	2,176	2,176	2,176	2,171	2,171	2,171	2,171
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and their interaction. * p< 0.10, ** p<0.05, *** p<0.01.

Table B5: Robustness to excluding MPs that were been within the reach of a G4: Estimated effect of the G4 and the Priority List on cattle productivity and credit

	Productivity				Credit			
	Heads/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4	0.162***	0.161***	4.791**	4.783**	62.306***	62.355***	114.914***	114.801***
	(0.060)	(0.060)	(1.874)	(1.883)	(21.327)	(21.323)	(27.499)	(27.464)
MP	0.101	0.081	2.441	1.903	0.387	3.863	-18.288	-26.218
	(0.062)	(0.061)	(1.815)	(1.823)	(11.561)	(11.267)	(61.675)	(63.664)
G4 × MP	-0.039	-0.032	-0.872	-0.667	-52.165***	-53.495***	-244.910	-241.876
	(0.061)	(0.061)	(2.144)	(2.138)	(17.005)	(17.059)	(146.104)	(145.737)
Lincom								
G4 + MP	0.223***	0.211**	6.361**	6.019**	10.528	12.723	-148.284	-153.293
+ G4 × MP	(0.082)	(0.082)	(2.535)	(2.550)	(19.773)	(19.471)	(125.922)	(127.577)
Observations	3,040	3,040	3,040	3,040	2,989	2,989	2,989	2,989
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and the interaction. * p< 0.10, ** p<0.05, *** p<0.01.

Table B6: Estimated effect of the G4 and the Priority List on clearing for pasture

	2004-16				2004-12			
	Clearing (kha)		Clearing/ha		Clearing (kha)		Clearing/ha	
G4	-0.211	-0.185	0.002*	0.002*	-0.892	-0.592	0.004	0.004*
	(0.791)	(0.795)	(0.001)	(0.001)	(0.880)	(0.878)	(0.002)	(0.003)
MP	-3.733**	-3.385**	0.000	-0.000	-5.565***	-5.146***	-0.000	-0.001
	(1.612)	(1.661)	(0.001)	(0.001)	(1.808)	(1.876)	(0.002)	(0.002)
G4 × MP	-0.340	-0.416	-0.001	-0.000	-0.483	-0.778	-0.002	-0.002
	(1.490)	(1.525)	(0.001)	(0.001)	(2.399)	(2.419)	(0.002)	(0.003)
Lincom								
G4 + MP + G4 × MP	-4.285*	-3.986	0.002	0.002	-6.940***	-6.516***	0.002	0.001
	(2.319)	(2.401)	(0.002)	(0.002)	(2.108)	(2.210)	(0.003)	(0.003)
Observations	3,081	3,081	3,081	3,081	2,133	2,133	2,133	2,133
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and the interaction. * p< 0.10, ** p<0.05, *** p<0.01.

Table B7: Effects of the G4 and the Priority List on cattle productivity and credit according to the municipality's distance to a G4-slaughterhouse

	Productivity				Credit			
	Head/ha of pasture		Percent of capacity		Value/ha of pasture		Nbr contracts	
G4 < 60 km	0.419***	0.427***	13.359***	13.591***	315.351*	315.626*	151.131***	152.512***
	(0.115)	(0.120)	(3.742)	(3.911)	(157.851)	(159.802)	(36.692)	(36.962)
G4 60-100 km	0.305**	0.317**	9.502**	9.864**	310.890*	311.317*	173.819***	175.961***
	(0.122)	(0.127)	(4.078)	(4.254)	(163.314)	(166.193)	(57.641)	(57.948)
G4 100-140 km	0.115	0.107	3.174	2.937	-15.073	-15.338	190.118***	188.787***
	(0.254)	(0.255)	(8.139)	(8.158)	(118.402)	(119.898)	(66.395)	(67.294)
MP	0.214***	0.198***	6.050***	5.560***	145.103	144.546	11.130	8.329
	(0.072)	(0.070)	(2.103)	(2.066)	(102.285)	(98.624)	(50.920)	(51.286)
G4 < 60 km	-0.278**	-0.281**	-8.726**	-8.820**	-232.180*	-232.289*	-355.315	-355.862
× MP	(0.107)	(0.109)	(3.638)	(3.701)	(116.827)	(117.607)	(238.996)	(239.435)
G4 60-100 km	0.038	0.046	2.270	2.521	-205.084*	-204.800*	-150.048*	-148.624
× MP	(0.120)	(0.120)	(4.050)	(4.079)	(120.454)	(118.770)	(88.844)	(88.803)
G4 < 100-140 km	-0.050	-0.025	-0.769	0.010	87.642	88.535	-47.555	-43.074
× MP	(0.288)	(0.293)	(8.945)	(9.071)	(130.734)	(135.618)	(89.134)	(89.077)
Lincom								
G4 < 60 km + MP	0.355**	0.343**	10.682**	10.332**	228.275	227.883	-193.054	-195.021
+ G4 × MP	(0.144)	(0.144)	(4.666)	(4.704)	(145.371)	(143.011)	(218.724)	(219.844)
G4 60-100 km + MP	0.557***	0.561***	17.822***	17.945***	250.910*	251.062*	34.900	35.667
+ G4 × MP	(0.126)	(0.130)	(4.315)	(4.423)	(145.959)	(147.125)	(51.588)	(51.402)
G4 100-140 km + MP	0.278	0.280	8.455	8.508	217.673*	217.743*	153.693	154.042
+ G4 × MP	(0.188)	(0.189)	(5.216)	(5.252)	(123.127)	(123.668)	(115.805)	(115.607)
Observations	3,625	3,625	3,625	3,625	3,569	3,569	3,569	3,569
Active SIFs		X		X		X		X
Protected areas		X		X		X		X
Municipality FE	X	X	X	X	X	X	X	X
Time FE	X	X	X	X	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on main effects and interaction effects for G4 and MP at each distance bin. * p< 0.10, ** p<0.05, *** p<0.01.

Table B8: Estimated effect of the G4 and the Priority List on pasture area and head of cattle per hectare of municipal area

	Pasture/ha		Head/ha	
G4	-0.006	-0.006	0.041**	0.041**
	(0.011)	(0.011)	(0.016)	(0.016)
MP	0.010	0.009	0.031**	0.030**
	(0.009)	(0.010)	(0.013)	(0.013)
G4 × MP	0.005	0.005	-0.017	-0.017
	(0.012)	(0.012)	(0.025)	(0.025)
Lincom				
G4 + MP + G4 × MP	0.009	0.008	0.055**	0.054**
	(0.014)	(0.014)	(0.023)	(0.023)
Observations	3,146	3,146	3,144	3,144
Active SIFs		X		X
Protected areas		X		X
Municipality FE	X	X	X	X
Time FE	X	X	X	X

Note. Unit of observation is the municipality. Robust standard errors are in parentheses and are clustered at the microregion level. Lincom estimates the linear combination of the coefficients on G4, MP, and the interaction. * p< 0.10, ** p<0.05, *** p<0.01.