Forest conservation effects of Brazil's zero deforestation agreements undermined by leakage

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Abstract

Supply chain interventions, which include certification schemes and zero-deforestation commitments that aim to produce environmentally and socially beneficial outcomes, are increasingly common, but evidence on their efficacy is scarce. We quantified avoided deforestation from Brazil's zero-deforestation cattle agreements by exploiting variation in the policy's rollout and the acquisition of slaughterhouses by the agreements' signatories from 2007 to 2015 in the Amazonian states of Mato Grosso and Pará. We found no average impact of the agreements on forest cover in the regions surrounding signatory slaughterhouses by the end of 2014. Our results show avoided deforestation of about 6% from the agreements on properties that enrolled early in the rural environmental land registry, however forest loss increased commensurately on those properties that registered later, thus washing out the positive conservation effects. Our results also highlight that slaughterhouses bought plants in regions with higher deforestation both before and after the agreement, suggesting that companies are not avoiding these important hotspots. We conclude that the agreements have led to avoided deforestation on registered properties, whose boundaries are transparent and publicly accessible, but that more robust reductions in deforestation will require additional action. The agreements could be made more effective by tracking cattle movements between properties and expanding monitoring to include all properties in the supply chains, as well as ensuring that all slaughterhouses monitor.

Keywords: Brazil, avoided deforestation, supply-side governance, cattle, leakage, impact evaluation

1 Introduction

Deforestation contributes 10% of global anthropogenic greenhouse gas emissions, and has the potential to provide as much as 40% of the emissions cuts needed to mitigate climate change through its carbon sink properties (Baccini et al. 2012, Harris et al. 2012). The main drivers of tropical deforestation are conversion of land to agricultural and pastoral uses, and it has been suggested that a large part of this deforestation is driven by export demand (Rudel et al. 2009, DeFries et al. 2010, Gibbs et al. 2010, Henders et al. 2015). In response to pressure from consumer groups and non-governmental organizations (NGOs), a variety of private sector interventions were developed that intend to provide goods with certified environmental quality - among these are wood, palm oil, biofuels, soy, and beef (Walker et al. 2013, Newton et al. 2013, Lambin et al. 2014). These certification schemes, deforestation moratoria, commodity roundtables, and public company commitments all rely on some type of market pressure to help ensure more forest conservation or sustainable land use. Despite increased international attention and high-levels of investment over the past decade, little is known about how these supply-chain interventions impact forests (Lambin et al. 2017). Most previous studies have been qualitative, and few have assessed forest conservation outcomes using rigorous counterfactuals. The current study estimates the impact of Brazil's zero deforestation cattle agreements, which have the potential to have a significantly impact global deforestation.

After peaking in the mid-2000s, Brazil's deforestation rate has dropped in recent years, but remains the second highest country in absolute deforestation, and some indicates evidence that rates are again increasing (Watts 2015, INPE 2016). Expansion of cattle pasture continues to be associated with up to 80% of Brazil's deforestation, particularly in the states of Mato Grosso and Pará (INPE/EMBRAPA 2012, De Sy et al. 2015), which were responsible for 60% of beef production in the Amazon region as of 2007 (IBGE 2015). Even though 80% of its beef is consumed domestically, Brazil is currently the second largest exporter of beef in the world (FAS/UDSA 2016), and exports of cattle from the Legal Amazon have

risen 18 fold since 2000.

For the past decade, Brazil's government has expanded environmental policies and enforcement. Strategies have included updating the federal Forest Code in 2012, the use of satellite-based deforestation monitoring to enforce illegal deforestation, expanded incentives for environmental registration, and permits to conduct economic activities in rural areas (Barreto & Araújo 2012, Nepstad et al. 2014). However, effectiveness has been limited by uneven enforcement of laws, and limited cooperation across government agencies (Barreto & Araújo 2012, Gibbs et al. 2015). These challenges have drawn the attention of international environmental organizations and other stakeholders, who have developed innovative policies that attempt to influence all actors in the beef supply chain.

In July 2009, in response to increasing pressure from the Brazilian government and international NGOs, individual meatpacking companies in the Amazonian state of Pará began signing legally binding "Terms of Adjustment of Conduct" ("MPF-TAC") agreements to stop purchasing from properties with deforestation above legal limits (Ministério Público Federal 2009, 2013*a*,*b*). In October 2009, the largest meatpacking companies in Brazil – Marfrig, Minerva, JBS, and Bertin (subsequently bought by JBS) additionally signed the "G4" zero-deforestation agreement with Greenpeace (Greenpeace International 2009). These agreements spread through other Amazonian states, and currently cover over 75% of the federally inspected slaughterhouses (SIFs) that are legally allowed to export beef from the Legal Amazon (67 out of 88 SIFs as of July 2016). The potential scope for impact from the activities of these companies is large: in 2015, Marfrig, JBS, and Minerva owned over half of the federally inspected slaughterhouses in the two states that we study (IBGE 2015). JBS alone is responsible for 50% of the cattle slaughtered in the Legal Amazon.

Both agreements mandate meatpacking companies to block sales from properties with deforestation occurring after 2009, with accusations of slave labor, with embargoes for illegal deforestation, and those not eventually registered in the Rural Environmental Registry (CAR by its Portuguese acronym), a state registry which stores a map containing geo-referenced

property boundaries for satellite monitoring (State of Pará 2006, 2008, State of Mato Grosso 2008, State of Pará 2016). To date, they both govern only those properties that sell directly to slaughterhouses, and have not yet expanded governance to those properties that might have housed cattle during earlier stages of the production process.

The agreements differ, however, in their allowable deforestation limits and in their implementation rules. The MPF-TAC follows the Brazilian Forest Code in defining illegal deforestation as exceeding 20% of a property's forest area (Ministério Público Federal 2013*a*,*b*), while the G4 prohibits any clearing. Furthermore, the G4 agreement requires signatories to set up monitoring systems, which they have done using deforestation maps produced by the Brazilian government (Instituto Nacional de Pesquisas Espaciais 2014), while those companies that have signed only the "MPF-TAC" have just recently begun setting up deforestation monitoring systems, and only for some companies.

Our paper is the first to rigorously evaluate the avoided deforestation impact of these supply chain commitments. Our estimation strategy included unit and time fixed effects and exploited both the overall rollout of the agreements as well as the gradual acquisition of slaughterhouses owned by signatories of the agreements in order to identify their impact on deforestation in the Amazonian states of Mato Grosso and Pará. We measured the effect of the agreements on forest cover between 2007 and 2014. Our counterfactual was the deforestation trend before the policy was applied in slaughterhouse supply zones that were eventually affected by the agreements. This strategy helps to minimize the confounding effects of both firm-level decisions to sign agreements, as well as cattle-supplier decisions to sell to signatory processors. It also means that our impact estimates take account of localized leakage.

Our work speaks most directly to previous studies on a related policy – forest certification (Auld et al. 2008). Analysis of the impacts of certification have been mixed: from apparently ineffective in Mexico (Blackman et al. 2015) to relatively effective in Indonesia (Miteva et al. 2015) and Chile (Heilmayr & Lambin 2016). Our work differs from these studies in both

focus, since we examine a different type of supply-chain intervention, and in methodology, since by using only land that was eventually affected by the policy, we propose a different approach to addressing the problem of unobservable factors driving policy impacts.

Although no other papers have analyzed the avoided deforestation effects of the cattle agreements, previous work on the agreements in Pará estimated that JBS slaughterhouses incentivized CAR registration and began to block purchases from ranchers with deforestation following the implementation of the G4 and the MPF-TAC (Gibbs et al. 2015). However, this analysis also noted the possibility of leakage to unmonitored properties. The present paper quantifies this local displacement, and thus contributes to the scant empirical assessments of deforestation displacement in developing countries. To date, the work on deforestation leakage has focused on protected areas (Robalino 2007, Arriagada et al. 2012, Robalino et al. 2017) and payments for ecosystem services programs (Alix-Garcia et al. 2012)[1]. The present paper is unique in its assessment of deforestation leakage emanating from a supply-chain agreement.

2 Methods

2.1 Study area and sample

Our analysis focused on the state of Pará and the portion of Mato Grosso that falls in the Amazon biome. These two states constituted more than half of all the forest in the Legal Amazon from 2004 to 2014 (INPE 2016). Production in these areas is increasingly oriented towards export – mostly of soy and beef, but occasionally other crops. Farms tend to be large, with median registered property sizes of 93.9 hectares in Mato Grosso and 63.1 in Pará as of 2014. They are also among the states with the biggest increase in cattle production since 2000 (McManus et al. 2016).

[1]There is a large literature on cross-border deforestation and carbon emissions leakage that parallels the land use literature but is beyond the scope of the present work.

We created a stratified random sample of points, with equal numbers of points in both states, which resulted in slight oversampling in Mato Grosso. Our unit of analysis was the point, and all estimations were weighted by the proportion of the study area that falls in each state, allowing us to interpret our results as population averages. Since points lack area, we assigned characteristics of the layers on which they fell to each point.

We avoided two challenges by using the point as the analysis unit rather than an entire property or a grid cell of arbitrary size. The first was that results could be interpreted directly as the average effect across the landscape rather than the effect for a property with average characteristics, without re-weighting by property size. This was useful for assessing the full avoided deforestation impacts rather than property-level responses to policy. The second advantage came in the assignment of property boundaries to the points, which each have an easily attributable first year of application to the CAR. This is not the case with properties, which can potentially have shifts or overlaps in boundaries over time that make it difficult to assign a unique date of first application to a property.

2.2 Outcome

The outcome of interest was if a point remained forested at the end of the year. To measure forest cover, we used PRODES deforestation maps (30 m resolution) created by the Brazilian Institution for Space Research (INPE). Annual data exists from 2001 to present, though for our study, we examined program impact during years 2007 to 2014, and used earlier years to examine pre-trends. Because PRODES drops areas once deforested, it could not be used to measure afforestation or re-clearing of secondary forest. We dropped points that were not forested in 2007 from our main analysis. In addition, after points were identified as deforested, subsequent values were set to missing. This created an unbalanced panel but avoided augmenting the sample size with data that contained no meaningful variation.

2.3 Policy variable

There are various challenges to identifying the causal impact of the zero deforestation policies. First, firms choose to participate in the agreements; second, farmers choose whether or not they wish to sell cattle to participating slaughterhouses; and third, cattle supply chains often involve several properties. This last point is of particular importance because monitoring only occurs on the property selling directly to the slaughterhouse. For these reasons, a simple comparison of land use by suppliers selling to slaughterhouses owned by signatory firms to those selling to non-signatory firms would yield incorrect assessments of the policy impact. This comparison would lead to a confounded result because signatory firms may have chosen to locate in areas with more or less productivity (and hence more or less deforestation risk), and because farmers who chose to sell cattle to signatory firms might be more or less productive. For example, if signatory firms are located in areas with more deforestation risk, and if more productive farmers choose to sell to such firms, this comparison would result in an estimate that looked like the agreements caused deforestation. Furthermore, limiting the analysis to direct suppliers would have excluded other properties involved in producing the cattle during different stages and not assessed the overall effect of the agreements. Finally, one could not simply compare suppliers before and after the implementation of the agreements both because of the endogeneity of the supply choice and because of the confounding nature of time trends.

We took several steps to overcome these issues. First, we limited our analysis to areas that were eventually influenced by the signatory slaughterhouses affected by the agreement. This eliminated confounding factors that determined both the willingness of supplying ranchers to participate in the policy by selling to signatory slaughterhouses and the propensity of slaughterhouses to locate in areas with higher deforestation rates. We also considered only properties with the potential to sell to a signatory company by virtue of being located in their supply zones. This means that our estimates were inclusive of potential leakage that might occur if cattle are raised on one property and sold from another, provided such exchanges

occurred within the supply zone.

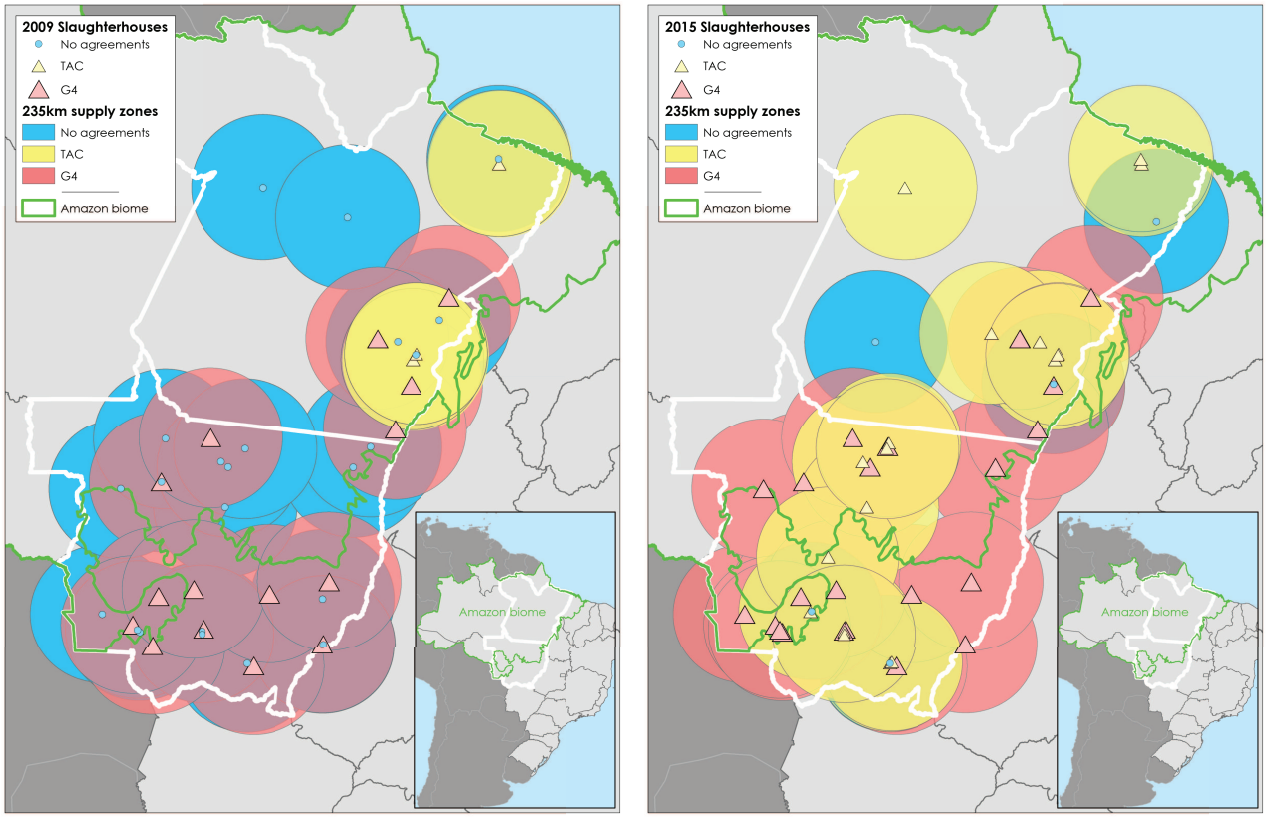
The key covariate in our estimation was whether or not a point was likely to have been affected by cattle agreements. In order to construct this measure, we established "supply zones" around all 62 slaughterhouses in the Amazon Biome portion of Mato Grosso and Pará that were federally inspected between 2009 and 2015. These "SIF" slaughterhouses are responsible for 90% of the slaughter of cattle in the two states that we study. We defined a supply zone as a circle around each slaughterhouse point with a radius the size of the 90th percentile distance (235 km) from all suppliers known to have sold to export slaughterhouses within the sample. To establish the actual distance from each property selling point to the slaughterhouse, we mapped the locations of all JBS suppliers following Gibbs et al. (2015), which accounted for 80% of the G4 plants in 2014. We used a circle rather than the precise outer envelope of all points that supplied to a particular slaughterhouse to help circumvent the endogeneity of the producer's decision to sell cattle to specific slaughterhouses. As robustness checks, we also examined supply zones defined at the 75th and 50th percentile distances from suppliers known to have sold to JBS slaughterhouses. These distances were 145 and 75 km, respectively[2].

A point may have fallen within the supply zones of several slaughterhouses, as shown in Figure 1, which illustrates a key source of variation in the data. A given point's exposure to the agreements varied over time, both because there were no cattle agreements prior to 2009, so there was variation from 2008 to 2009 as a result of the initial signing of agreements, and because the signatories purchased additional existing slaughterhouses over time. For example, in 2009, we observed few slaughterhouses in northern Mato Grosso that were G4 signatories, but by 2015, almost all slaughterhouses in this region had been acquired by G4 signatory firms. Maps and summary statistics for the 145 and 75 km supply zones are shown in the appendix, figures F1 and F2, and table E5.

To evaluate the intensity of policy pressure, we measured the "exposure" to different

[2]The smaller zones significantly reduced the sample sizes. In the 235 km supply zones, there are 16,862 points, in the 145 km supply zones, 8,203 points, and in the 75 km supply zones, 2,531 points.

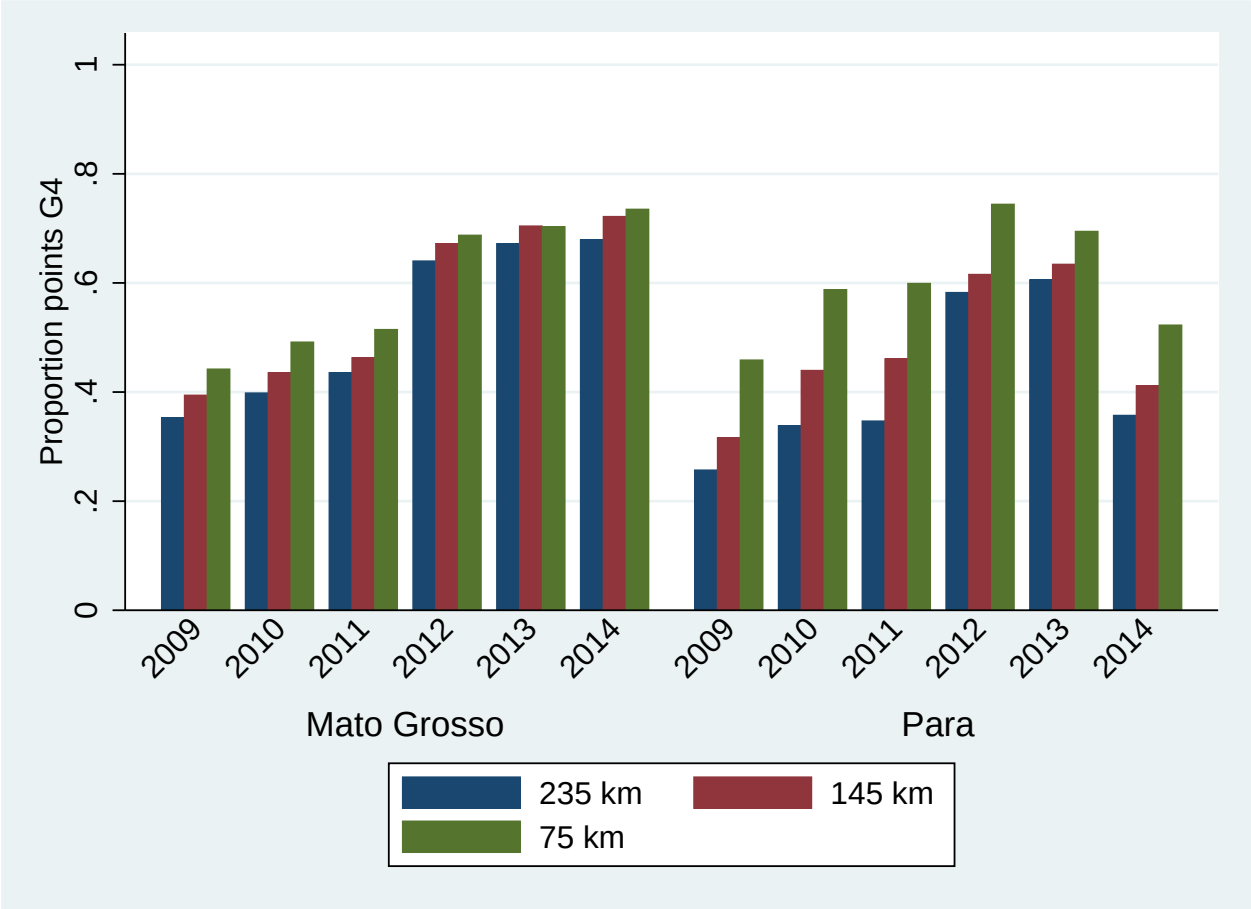
Figure 1: Study location and supply zones



The map shows the study area, which includes the Amazon Biome within Mato Grosso and Pará. The large circles represent 235 km supply zones around slaughterhouses. The slaughterhouse designations are: TAC (signed TAC agreement), G4 (signed TAC and G4), and none (signed no agreement by 2015).

types of slaughterhouses for each point. The exposure variable measured the proportion of slaughterhouses owned by G4 or MPF-TAC signatory companies that a point was exposed to in a given year. Figure 2 shows the average of this variable for points falling into the three supply zone sizes that we analyzed[3]. We also used a simpler treatment variable that turns from zero to one in the year that the first slaughterhouse associated with a point is owned by a G4 signatory company.

Figure 2: Variation in treatment exposure across time and states for different supply zones



The graph shows the mean of the proportion of G4 slaughterhouses to which a point is exposed in different supply zones. "Exposure" is calculated as the sum of the number of slaughterhouses whose owner had signed the G4, divided by the number of active export slaughterhouses. Similar graphs for the MPF-TAC can be found in the Appendix.

[3]Figure F3 shows the equivalent graph for MPF-TAC signatories

2.4 Estimation strategy

The basic estimator was a fixed effects linear probability model. The inclusion of unit fixed effects controlled for all time-invariant characteristics (land quality, distance to city, etc.), observable and unobservable. In addition, time by state effects absorbed state-specific temporal shocks, e.g., changes in state-level regulation that may have affected all points equally. All of the estimations included a control for the log-transformed number of slaughterhouses within whose supply zone a point fell, signatory or not. We also included interaction terms between the year effects and municipal cattle densities in 2007, as well as whether or not a point was located in an indigenous, conservation, or INCRA resettlement area.

The counterfactual comparison depends upon comparing points that had lower values of exposure to the cattle agreements during periods of time in which the exposure was increasing for other points. This effectively means that later- (or never-) exposed points provided the counterfactual for points exposed to the policy in early years. One worry with this approach is that the slaughterhouses exposed earlier to the policy might be located in more or less productive areas, and hence more or less prone to deforestation. This "selection problem" could imply that later signatories were not in fact a valid comparison group. To explore the potential role of selection, we exploited three different subsamples, where each provided a slightly different potential counterfactual comparison group.

The three samples were comprised of: (1) all points that fell into the supply zone of slaughterhouses approved for export ("SIFs"); (2) points that were within the supply zone of any slaughterhouse owned by companies that signed either the G4 or the MPF-TAC by 2015 ("MPF-TAC"); and (3) only points within supply zones of those slaughterhouses owned by companies that signed the G4 agreement only (and thus have implemented rigorous company-level monitoring systems – "G4"). We describe these samples in more detail in section Appendix B.

As a way to help assess the validity of comparison groups, we tested whether or not the early versus late signatory regions exhibited different deforestation behavior prior to

the agreements. Section Appendix B shows the results from this exercise, which indicates that the counterfactual provided by the "G4" sample was likely to be the most reliable, while the early and late signatory groups in the first and second subsamples are significantly different from each other prior to the policy. Therefore, we emphasize the G4 sample in the main text. Interestingly, however, these tests also show the role of slaughterhouse choice – slaughterhouses tend to be located in areas with significantly more deforestation prior to the agreements (Table C1 Section Appendix B).

We used a similar specification to examine heterogeneous effects of the expansion of the agreements on properties in the environmental registry (CAR). Because landowners choose whether and when to register their properties, it is likely that simple comparisons of registrants with non-registrants would not yield relible estimates of the impact of the interaction between registration and the cattle agreements. For example, it is likely landowners who chose to register may have had different production goals than those that did not. This approach relied on ever-registered by year time effects to control for differences in trends across these two populations.

Second, we reduced the sample to only those properties ever registered for CAR and exploited the time variation in registration to identify differential impacts. In the latter case, those who registered later for the CAR served as the counterfactual for those who register earlier. Section Appendix D describes this methodology in more detail, and shows tests for differences across the ever- or early-registered and non- or late-registered properties suggesting that both these approaches generated reasonable counterfactuals.

Finally, in order to better understand leakage mechanics, we created a series of dummy variables indicating the year in which a property registered for the CAR. The indicator variables did not change over time. We then interacted these with the proportion of slaughterhouses affecting a point that were G4 in a given year, and ran the same estimation as above. The estimates on each of these interaction terms showed the effect of increasing exposure to the agreements on land eventually registered in different years.

3 Results

3.1 Result 1: Forest conservation impacts are zero on average

Our analysis indicats that there is no impact of the agreements on average between 2009 and 2014, regardless of the sample that we analyzed (Table 1). In our best counterfactual sample (G4), the point estimates were precisely estimated zeros (columns (7)-(9)). Robustness checks using the 145 and 75 km supply zones show similar results (Tables E6 and E7). Our results are also robust to including a dummy variable indicating whether or not a municipality was "blacklisted" for illegal deforestation (see discussion in Appendix).

3.2 Result 2: Forest conservation impacts are positive for CAR properties relative to non-CAR properties

The zero average effect could have obscured important heterogeneity in our results. We expected the effects of the agreements to be stronger on those properties that were monitored by the slaughterhouses for compliance with the agreement. In many cases, the CAR was used to provide property boundaries within which monitoring could take place, and obtaining a CAR was a pre-requisite for selling to slaughterhouses whose owners were signatory to the G4 and MPF-TAC agreements. However, the process of obtaining the CAR and the deadlines related to the cattle agreements varied by state.

The CAR registration process began earlier in Mato Grosso, and its program initially had more rigorous requirements (Rausch & Gibbs 2016, L'Roe et al. 2016). In terms of deadlines directly related to the cattle agreements, direct suppliers were required to have the CAR by February 2010 in Pará, whereas in Mato Grosso the deadline was May 2016. Consequently, nearly 100% of JBS suppliers in Pará had the CAR by 2014, while only about 20% of JBS suppliers in Mato Grosso had the CAR by this time (Gibbs et al. 2015)[4]. The area covered

[4]We also had points in our data that contained "2005" as the start dates for CAR properties in Mato Grosso, but as this date could indicate mapping anytime 2005 or earlier, we dropped these points in our

Table 1: Average impact of cattle agreements across different subsamples, 235 km supply zones

	Dependent variable: Forest = 1/0								
	SIFs			TAC			G4		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Prop of TAC SIFs, 235 km	-0.001			-0.001			-0.002		
	(0.002)			(0.002)			(0.002)		
	[0.001]			[0.001]			[0.002]		
Prop of G4 SIFs, 235 km	0.000	-0.000		0.000	-0.000		0.003	0.001	
	(0.002)	(0.001)		(0.002)	(0.001)		(0.002)	(0.001)	
	[0.001]	[0.001]		[0.001]	[0.001]		[0.002]	[0.001]	
In G4 supply zone, 235 km			-0.001			-0.001			0.001
			(0.001)			(0.001)			(0.001)
			[0.001]			[0.001]			[0.001]
Ln(number SIFs, 235 km)	0.003***	0.003**	0.004**	0.004***	0.003***	0.004***	0.004***	0.004**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]	[0.001]	[0.002]
Time effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time x covariates	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	163000	163000	163000	161600	161600	161600	131799	131799	131799
Adjusted R^2	0.008	0.008	0.008	0.008	0.008	0.008	0.009	0.009	0.009

Unit of observation is the point. The estimator fixed effects with effects at the point level, and time effects for each year and state. Standard errors in parentheses are clustered at the municipal level. Standard errors in square brackets are Conley (2008) spatial errors. Subsamples are labeled in the second row of the table. * p< 0.10, ** p<0.05,*** p < 0.01.
Time-interacted covariates include indigenous area, conservation area, INCRA, and 2007 municipal cattle densities.

by the CAR properties is quite large across both states. By 2014, between 40 and 50% of all points fell in registered CAR properties across both states, depending upon the supply zone of interest, though coverage was much lower in 2009 (see Table E5)[5].

We found that the properties registered earlier in the CAR had less deforestation relative to those that registered later (Table 2). Increasing the proportion of slaughterhouses affecting a point from zero to one, as would be the case if a point was only exposed to one slaughterhouse and it was purchased by a G4 company, resulted in a 0.7 percentage point reduction in the probability of deforestation relative to those properties that were not registered in CAR (Table 2, Column 2). Similar patterns were observed in the smaller supply zones, though in all cases these differences were only statistically significant at the 10% level.

3.3 Result 3: Leakage and laundering from early to later CAR registrants undermined policy impacts

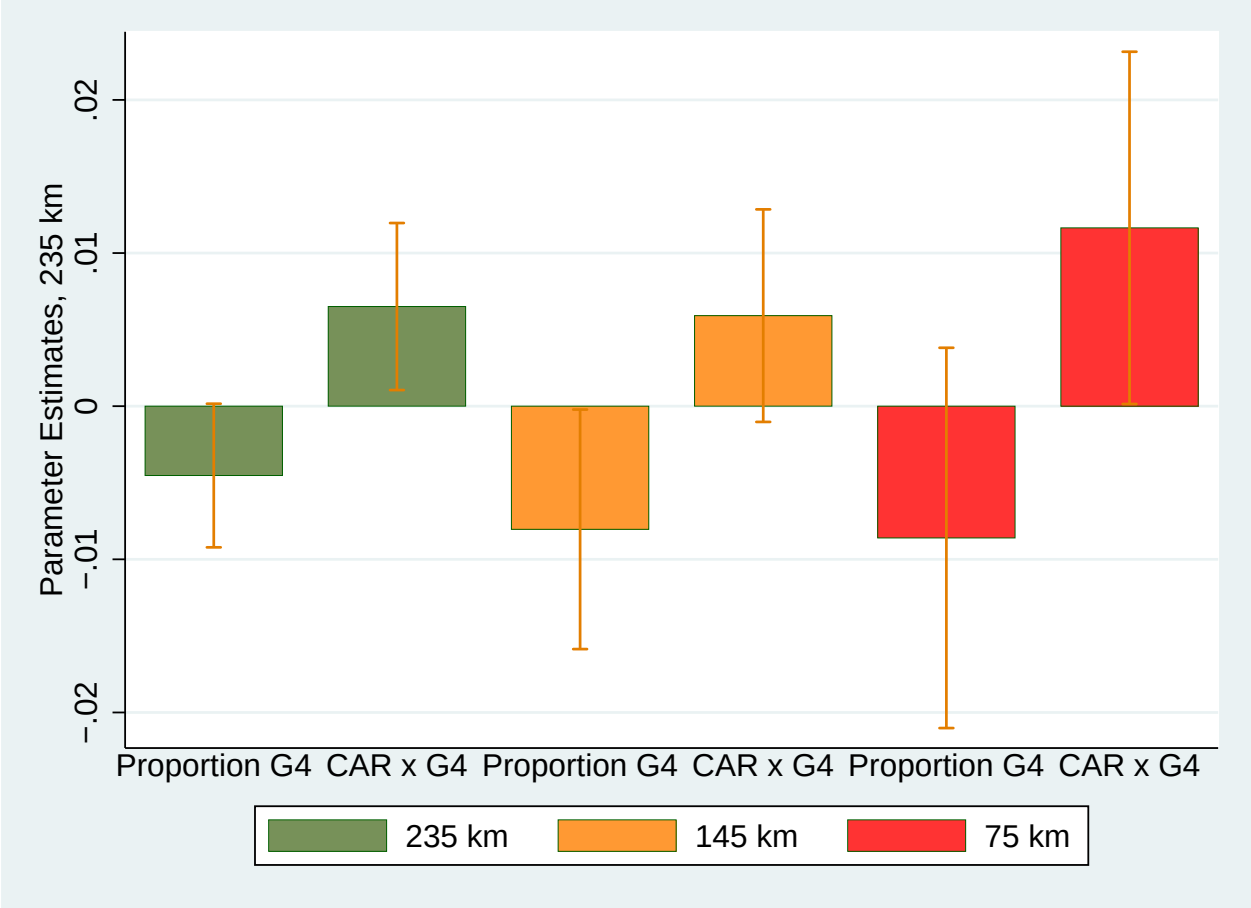
As G4 companies expanded, forest cover decreased on later-registered properties, and was more likely to be present on early registrants relative to later registrants (see columns (2)-(4)). The baseline effect of the policy on these later registrants was to increase deforestation by 0.5 percentage points (column (2), Table 2). Note that this effect was similar in magnitude to the pre-policy deforestation rate: between 2005 and 2006, 0.7 percent of points within the G4 235 km supply zones were deforested. The combination of these two effects – the impact of increasing G4 plus the additional impact of being on a CAR property – was positive but statistically insignificant: $-0.005 + 0.007 = 0.002$ (se 0.002). We did not see similar leakage trends when we compared all properties registered by 2014 to those that were eligible for CAR but did not register by 2014 (columns (5)-(7)). Leakage was estimated only between properties that eventually registered for CAR. Figure 3 visualizes this leakage by showing

estimation.

[5]JBS offers their own online property mapping tool for suppliers to use in lieu of the CAR in Mato Grosso that allows for monitoring but does not provide the public transparency as afforded by the CAR boundaries that are accessible for auditing purposes.

the effect of increasing the G4 on properties not yet registered ("prop G4") as well as the additional effect of that same increase on a registered property ("prop G4 x CAR").

Figure 3: Average effect of an increase in the proportion of G4 SIFs on CAR properties using different sized supply zones



Graphs bars show point estimates and 90% confidence intervals from the estimations table 2. The first two bars are from column (2), the second two bars from column (3), and the last two bars from column (4).

To disaggregate the CAR effect, Figure 4 shows the change in the probability of forest cover on registered properties in different cohorts as the proportion of signatory slaughterhouses increases. The figure illustrates that increased G4 exposure conserved forest cover in properties registered in or before 2010, and simultaneously decreased forest cover in cohorts registering later. For the earliest registering cohorts, the result of a one standard deviation increase in G4 exposure increases the probability of forest cover by 0.2 percentage points, a

Table 2: G4 sample with CAR interactions

	Dependent variable: Forest = 1/0						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Prop of G4 SIFs (235 km)	0.001	-0.005			-0.002		
	(0.001)	(0.003)			(0.003)		
	[0.001]	[0.003]			[0.003]		
Prop of G4 SIFs (145 km)			-0.008*			-0.002	
			(0.005)			(0.003)	
			[0.005]			[0.003]	
Prop of G4 SIFs (75 km)				-0.009			-0.000
				(0.007)			(0.004)
				[0.006]			[0.004]
CAR x Prop G4 (235 km)		0.007**					
		(0.003)					
		[0.002]					
CAR x Prop G4 (145 km)			0.006				
			(0.004)				
			[0.004]				
CAR x Prop G4 (75 km)				0.012*			
				(0.007)			
				[0.006]			
CAR by 2014 x Prop G4					0.002		
(235 km)					(0.003)		
					[0.002]		
CAR by 2014 x Prop G4						-0.001	
(145 km)						(0.005)	
						[0.005]	
[1em] CAR by 2014 x Prop G4							-0.002
(75 km)							(0.006)
							[0.004]
Time effects	yes	yes	yes	yes	yes	yes	yes
Time x Covariates	yes	yes	yes	yes	yes	yes	yes
Observations	125067	43365	24828	8452	65528	38820	14665
Adjusted R^2	0.010	0.014	0.016	0.018	0.015	0.016	0.016

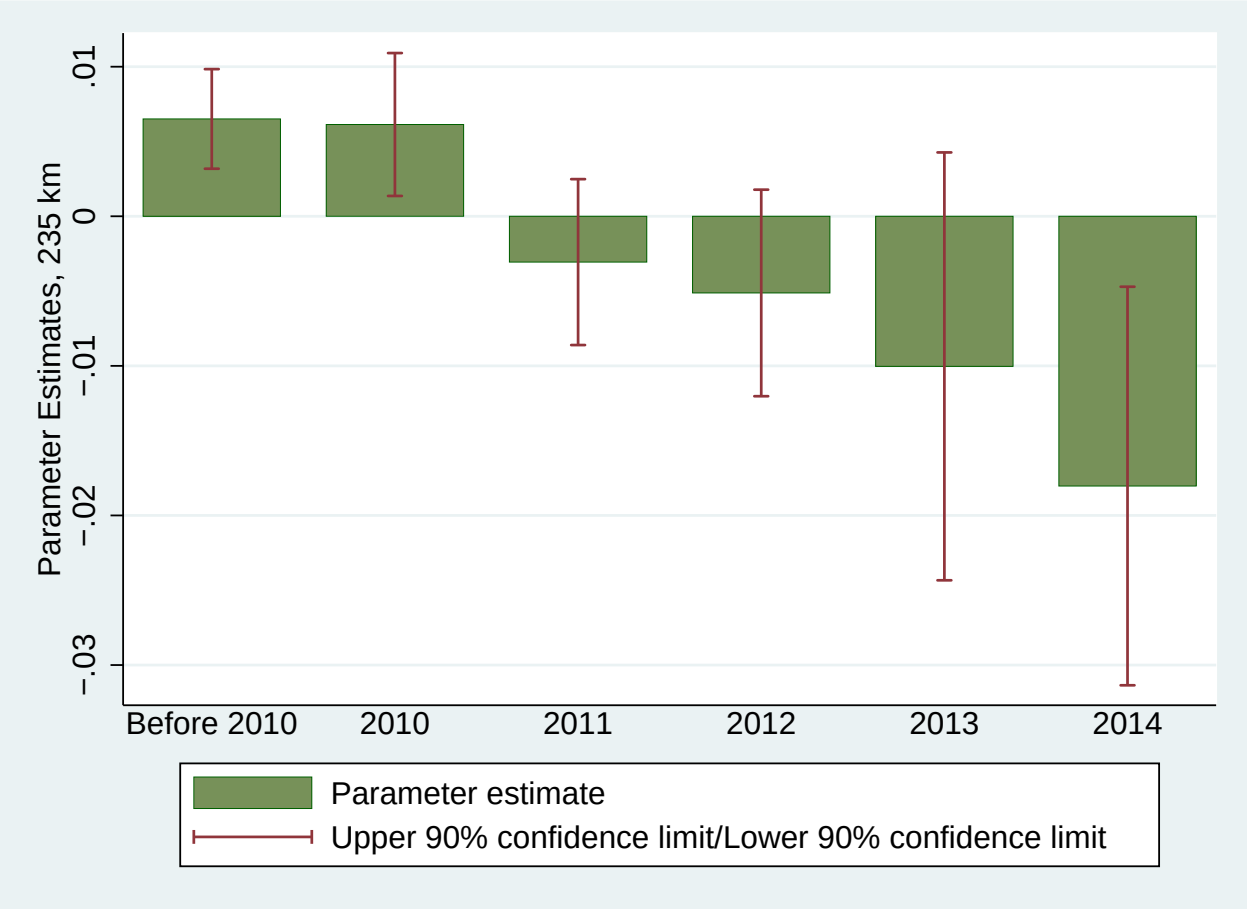
Unit of observation is the point. The estimator fixed effects with effects at the point level, and time effects for each year and state, and for year by 2007 cattle density. Standard errors in parentheses are clustered at the municipal level, while standard errors in parenthesis are Conley (2008) spatial errors.* p< 0.10, ** p<0.05,*** p < 0.01. Samples in columns (1) - (4) are limited to those points that registered for the CAR by 2014. Columns (5)-(7) include all points that were eligible to register for CAR, as well as CAR x year dummies.

bit more than one third of the yearly baseline forest loss rate in this subsample. The effect was similar for those registered in 2010, with no effect for 2011, 2012 or 2013 registering cohorts, though the signs do become negative. Those registered in 2014 saw a decrease in forest cover of 0.6 percentage points for the same increase in G4 exposure. Similar patterns occurred in the 145 and 75 km supply zones.

Points registered in CAR by 2010 or earlier constitute 52% of the points in our sample, and those registered in 2014 totaled around 10%. The total area in forest in 2007 represented by the CAR sample within the 235 km supply zones was nearly 34,000,000 ha. The background deforestation rate over the study period implies 339,000 ha of forest lost over 5 years. Therefore, the 0.2 percentage point avoided deforestation effect of the CAR registrants up through 2010 resulted in approximately 21,500 ha (6%) of forest conserved. However, this effect was almost entirely wiped out by the approximately 20,000 ha of deforestation displaced to the cohort that registered in 2014.

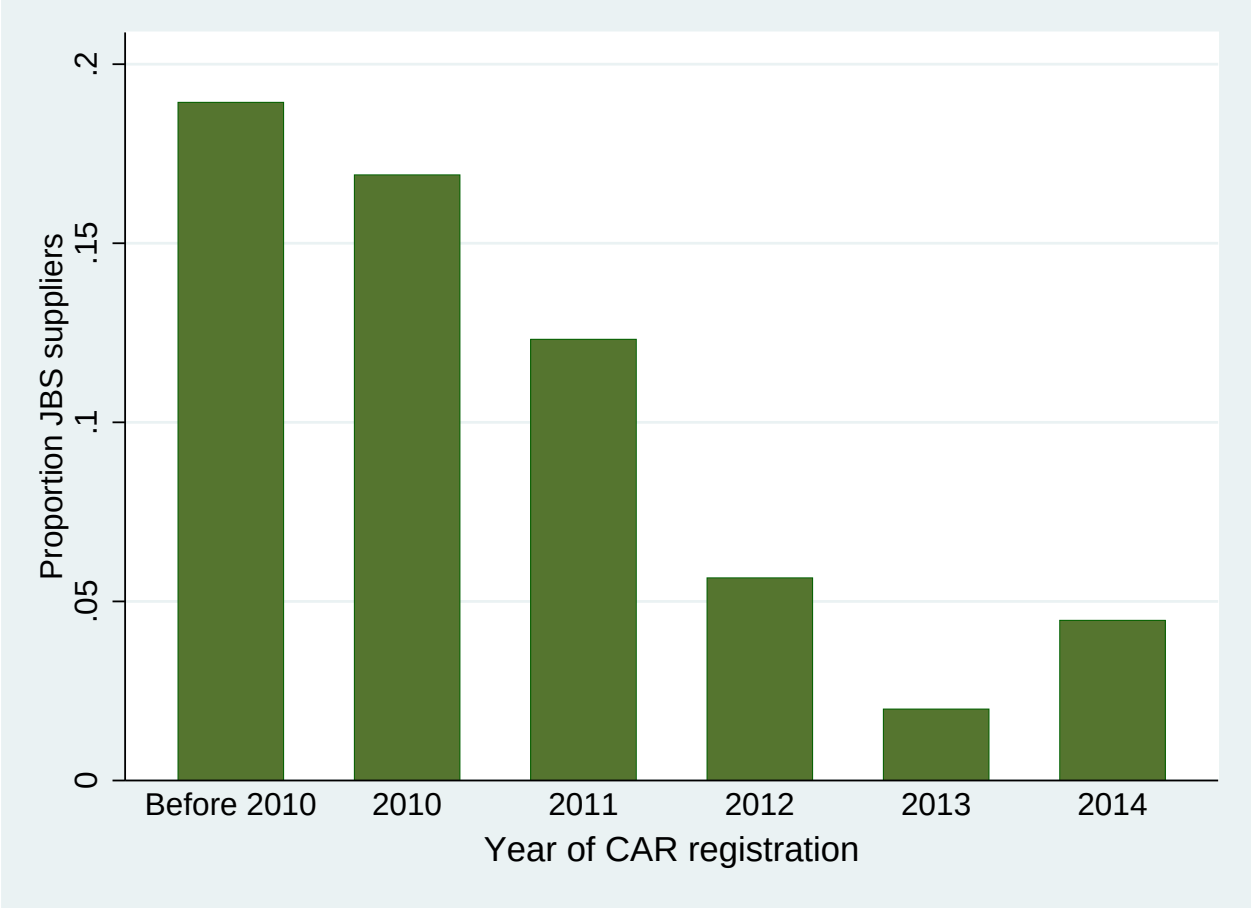
Not all CAR properties within the supply zones are directly influenced by G4 companies. To better assess the role of the G4 in influencing behavior on CAR properties, we linked the points in our database to JBS's public traceability system to understand whether our points fell on those properties that sold directly to JBS. By the end of 2014, JBS owned 80% of G4 slaughterhouses in both states (47% of all SIFs in Mato Grosso and 31% of all SIFs in Para). Within the G4 supply zones we analyzed, we estimated that between 20 and 30% of the area was in properties that supplied to JBS. Furthermore, their pattern of registration suggests that these direct suppliers mostly registered during the cohorts that are responsible for the avoided deforestation (Figure 5).

Figure 4: Marginal effect on forest of an increase in the proportion of G4 SIFs on forests located on CAR properties that registered in different years



Graphs bars show point estimates and 95% confidence intervals from the estimation in column (1) of table E9. Only coefficients from CAR cohort by G4 exposure are shown.

Figure 5: Year of CAR registration for JBS suppliers within our G4 study sample



The bars show the proportion of JBS supplying points out of all CAR-registered points in a given registration cohort.

4 Discussion and conclusion

4.1 Study limitations

It is important to note the limitations of our study. We assessed impacts on forest cover through the end of 2014, and it is possible that stronger effects could be observed with a longer time horizon, given the lag time as the companies established deforestation monitoring systems. Most plants did not begin monitoring until 2011, and 2012 is the first year that JBS showed significant changes in market exclusion in the state of Pará (Gibbs et al. 2015). Thus, it is possible that a study assessing avoided deforestation through the end of 2016 or later would identify forest conservation. The counterfactual in our estimations was also limited geographically. The results do not generalize to the entire forested area in the states that we analyzed, nor do they generalize to the entire Amazon Basin. Nonetheless, our supply zones do include areas with the highest deforestation rates in Brazil, the suppliers most likely to sell to SIF slaughterhouses, and those companies with G4 and MPF-TAC agreements. Thus, it is highly unlikely that we would observe impacts (except perhaps leakage) to areas outside of our study supply zones.

The majority of the our study area is covered by properties not directly influenced by the G4 agreement because they are selling to other plants or are involved in other parts of the cattle supply chain. Across both states, between 70 and 80 percent of the area in the supply zones was comprised of properties not selling directly to JBS slaughterhouses. However, this phenomenon is unlikely to attenuate results, provided that there are no other policies that vary in intensity in the same way that our treatment variable varied. However, it is likely to increase the standard errors in the estimation. We did not estimate the effect of the policy on known JBS suppliers for the same reason that we did not isolate our analysis to suppliers: the choice of supplying to a G4 company is endogenous to the deforestation decision, and would most likely have resulted in estimated impacts that showed the agreements causing deforestation. Furthermore, JBS was not the sole buyer of cattle over our study period,

although towards the end of the period they were the majority buyer.

Because our estimation relied on year-to-year variation in exposure to the agreements, it may have missed part of the impact. This is because properties that deforested after 2009 but were not exposed to the policy until later may not have responded to the policy. For example, a property that deforested in 2009 but was not within the influence zone of a G4 slaughterhouse until 2011 would be unlikely to respond between 2011 and 2012, since their 2009 deforestation would have eliminated the possibility that they could sell to the G4 slaughterhouse in 2011. In order to test whether policy responses differed according to past deforestation behavior, we interacted deforestation aggregated over the property associated with a point between 2009 and a given year with the measure of exposure a year later. This information is only available for properties with boundaries, so we were limited to examining only CAR registrants. We found no evidence of any impact at all or of differential impact within properties with prior deforestation in these specifications (Table E8). Thus we do not believe that this caused underestimation.

4.2 Assessing the outcomes of the zero-deforestation cattle agreements

We showed that on average, the zero deforestation cattle agreements had no effect on forest cover across the supply zones surrounding slaughterhouses. However, more forest was conserved on early-registering CAR properties, which were the ones most likely to be influenced by the cattle agreements. Though the G4 meatpacking companies did monitor all supplying properties, including those that are not enrolled in the CAR (using either a radius around a centroid or proprietary "easy map" tools provided by the companies), the majority of the points falling on JBS suppliers in our study zones were registered during our study period. The forest conservation effect occurred only on CAR properties possibly because they are publicly transparent and fully traceable, which could mean that companies were more likely to avoid non-compliant CAR properties and that the ranchers owning CAR properties

were more likely to be influenced by other policies and aware of the potential deforestation monitoring on their property by both public and private efforts (Alix-Garcia et al. 2017). Non-CAR properties, on the other hand, experienced less monitoring and less pressure to comply with the G4 and other environmental laws.

Displacement of deforestation may occur through a number of mechanisms. Our results specifically show that displacement from CAR properties that enrolled earlier to those that enrolled later may explain the overall zero effect of the cattle agreements. The estimations also suggest that there is not displacement of deforestation to never-registered but eligible properties, though the evidence is not unequivocal. There are many opportunities for displacement because the full cattle life cycle is complex – cattle are frequently moved between multiple properties prior to final sale – but the slaughterhouses currently monitor only the property from which they make a direct purchase (Gibbs et al. 2015, Tinoco 2016). In addition, there are middlemen who purchase cattle from many producers, and then sell them through their own, deforestation-free property. Direct cattle laundering, where ranchers intentionally move fattened cattle from a non-compliant property with embargoes or deforestation to a compliant property only for the purpose of sale, has been reported by multiple sources (Gibbs et al. 2015, Tinoco 2016). Furthermore, leakage of non-compliant properties to other nearby non-G4 plants that do not monitor for deforestation also occurs (Gibbs et al. 2015).

As meatpacking companies move to comply with supply chain commitments, one might expect that they would avoid regions with high deforestation when locating new plants (as suggested by (Nepstad et al. 2014)). However, our results show that the G4 slaughterhouses continued to buy plants in deforestation hotspots. This may indicate that the companies are not under enough pressure from the agreements to avoid these higher risk regions, but also highlights the potential influence of the cattle agreements in locations of low or high deforestation rates.

Policy modifications that broaden the scope of the agreements could help reduce laun-

dering and increase their forest conservation effects. The first, but most complex possibility, is to expand the implementation of the cattle agreements to include the entire supply chain and track all movements of cattle eventually sold to participating slaughterhouses, in order to verify that every property involved in their life cycle was free of deforestation. This is likely the only way to eliminate the role of cattle laundering and deforestation leakage to other parts of the supply chain. Full supply chain mapping could be accomplished through ear tags, which is the only option to track individual animals, but is costly. Such a system has been successfully implemented in Uruguay since 2006 (Boland et al. 2007). The other option is the Guide to Animal Transport (GTA) data that is used to track animal sanitation and health. However, the GTA data is not publicly available, which has prevented its use to date.

In the immediate term, tracking those properties selling to direct suppliers (first tier indirect suppliers) and assessing compliance on a producer-level rather than property-level could help to reduce laundering. By monitoring all properties owned by a producer, the impact of market exclusion would be stronger and laundering more challenging. Previously, ranchers could easily maintain both mapped and unmapped properties. However, the 2012 Forest Code mandated registration for all properties and the national system now boasts 98% coverage nationwide (CAR 2016). These steps would obviously not eliminate all gaming of the system by all producers, but do significantly increase accountability and transparency throughout the supply chain. According to our assessment of avoided deforestation on early CAR properties, this could mean that we may observe more forest conservation impacts from the cattle agreements in the near future. Expanding monitoring to all slaughterhouses would also significantly reduce leakage to non-G4 plants and send a stronger market signal to ranchers.

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Appendix A Estimation strategy

The basic estimator was a fixed effects linear probability model, with fixed effects at the point level (γ_p), as well as time effects that varied by state (θ_{st}). The inclusion of unit fixed effects controlled for all time-invariant characteristics (land quality, distance to city, etc.), observable and unobservable. In addition, time by state effects absorbed state-specific temporal shocks, for example, changes in state-level regulation, in the case that they affected all points equally.

We label the variable for intensity of exposure to the cattle agreements E_{pmst} in the equation below. This variable is specific to each point p, in a given municipality m, state s and year t. All of the estimations included a control for the log total number of slaughterhouses within whose supply zone a point fell (X_{pt}), signatory or not. We also included interaction terms between the year effects and cattle densities in 2007, as well as whether or not a point was located in an indigenous, conservation, or INCRA area. The outcome variable (F_{pmst}) was measured from 2007 to 2014. Note that because we drop observations after they are deforested, this model is similar to a discrete time duration model. Standard errors were clustered at the municipality level, allowing for arbitrary serial and spatial correlation of shocks within municipalities. In the main tables, we also present spatially weighted standard errors (Conley 2008), though these are not appreciably different from those clustered at the municipality level.

$$\mathrm{F}_{pmst} = \alpha_0 + \delta E_{pt} + X_{pt}\alpha_1 + \gamma_p + \theta_{st} + \epsilon_{pmst} \tag{1}$$

The parameter of interest was δ, which measured the impact of increasing exposure to the policy. Note that the counterfactual comparison in this estimation depended upon comparing points that have lower values of E during periods of time in which the value of E was changing for other points. The identification of this impact relies on variation from year to year. This is not necessarily a full reflection of the policy, which prohibits

deforestation after 2009. Because of this, the specification above may have underestimated the true impact of the policy. To give insight into the extent of underestimation, we include a specification that measures the amount of deforestation within a given property that took place between 2009 and time t in the data, and interact this with our measure of policy exposure. This interaction term should be negative and significant if the policy impact is reduced on properties that had deforestation after the policy was implemented but before their exposure to it intensified. This robustness check is discussed in Section 4.1.

An important potential confounder in our estimation may be the priority municipality program which blacklists municipalities for excessive deforestation (Assunçao & Rocha 2014, Sills et al. 2015, Bowman 2016). However, including it does not change the results. We also find that a fixed-effects regression identifying the correlation between our treatment variable and the blacklist variable that remains after controlling for year by state effects shows no statistically significant relationship between the two. The point estimate is 0.07 with a standard error of 0.07. Because we are concerned that the blacklisting variable is endogenous to the deforestation process, as is carefully documented by Assunçao & Rocha (2014), we do not include it in our main estimations.

Appendix B Sub-samples

The identification of impact in our estimation comes from comparing points that had lower values of exposure to the G4 and MPF-TAC agreements during periods of time in which the exposure was increasing for other points. The relevant counterfactual varied with the sample of points included in the estimation. One important concern is that slaughterhouses that were exposed earlier to the policy might be located in more or less productive areas, and hence more or less prone to deforestation. This "selection problem" may imply that later signatories are not in fact a valid comparison group. We exploited three different subsamples to illustrate the potential role of selection and identify impact. The three samples were as

follows:

1. "SIFs": This sample included all points that fell into the supply zone of slaughterhouses approved for export. The counterfactual in the estimation therefore included points in the zone of slaughterhouses that were never subject to the agreements. If the slaughterhouses that were and were not acquired by signatory companies were located in places that were different from each other then this sample would not provide a reliable counterfactual.

2. "MPF-TAC": This sample included points that were within the supply zone of any slaughterhouse that signed either the G4 or the MPF-TAC by 2015. This sample excluded points outside of agreement signatory supply zones. Identification came from changes in deforestation in the moment when slaughterhouse owners either signed an agreement, or when a slaughterhouse was purchased by a company that had signed an agreement. In this case, supply zones with later commitments provided the counterfactual for those who signed earlier.

3. "G4": This sample isolated the analysis to only those slaughterhouses owned by companies that signed the G4 agreement (and thus have implemented rigorous company-level monitoring systems). We considered this sample to provide the best counterfactual because only producers selling to these G4 slaughterhouses risked market exclusion if they cleared any forest after 2009, and hence were directly affected by the agreements. In this case, points within the supply zones of G4 slaughterhouses that were acquired more recently provided the counterfactual for those owned by G4 signatory companies in early years.

The key assumption of this strategy is that points that were affected by the agreements later can provide a good comparison group to those that were exposed earlier. While in principle this assumption is untestable, we present below some suggestive tests for pre-

agreement differences in deforestation behavior across the relevant comparison groups within each subsample.

Appendix C Pre-trends for supply zones

The following estimations included only points that were forested in 2001, and were estimated over the years 2001-2008, inclusive. As with the impact estimation, they contain fixed effects for points, and fixed effects for years interacted with state, cattle density in 2000, and whether or not the point was in a settlement, indigenous, or conservation area. Points were dropped from the sample after deforestation occurred.

The results show where companies choose to expand slaughterhouse operations (Table C1). Estimation using the entire sample of points in both states, both inside and outside of supply zones (column (1)), showed that in general, slaughterhouses are located in areas that have measurably higher levels of deforestation risk than points outside of the zones – the time trend for these points is -0.001 (se 0.000). Points in supply zones of MPF-TAC slaughterhouses had marginally significantly different trends from other points within the municipalities (0.001 se 0.001), while those exposed to the early signatories of the MPF-TAC have significantly higher rates of deforestation (-0.004 se 0.001). Points that were eventually exposed to the G4 agreements (-0.001 se 0.001) had more deforestation, and early G4 signatories had slightly more forest cover over time than later signatories (0.002 se 0.001) in the overall sample.

Column (2) restricts analysis to points within export slaughterhouse supply zones (our subsample 1. above). The time trend here can be interpreted as the deforestation trend for all the supply zones in our sample. Points exposed to signatories of MPF-TAC or G4 agreements had a higher probability of having forest cover over time (0.001 se 0.001), while early signatories had significantly less forest cover over time (-0.003 se 0.001). G4-exposed points had a stronger forest loss time trend (-0.001), while early signatory points had more

forest cover (0.002).

Column (3) shows similar difference in the subsample of those points that were eventually exposed to MPF-TAC agreements (subsample 2.). Points exposed to early signatories of the MPF-TAC are located in areas with higher risk of deforestation than later ones. Furthermore, points exposed to G4 have an additional negative forest trend, though those points exposed to the G4 early have somewhat more positive forest trends. This implies that estimation run using sample (2), for example, might show that the MPF-TAC has induced deforestation when it has not, because its forest loss over time tends to be more negative than the overall SIF sample, especially for early signatories ($0.001 - 0.003 = -0.002$). The additional effect of the G4 may also be falsely estimated to be deforestation-inducing (since $-0.001 - 0.001 - 0.003 + 0.002 = -0.001$).

Finally, there was no statistically significant difference between "early" signatories[6] and late ones (the counterfactual in this case) when the analysis was restricted to points that fall within the supply zone of a slaughterhouse that was eventually owned by a G4 signatory (column (4)). Because early TAC and early G4 signatory exposure is highly correlated, we cannot include a separate time trend for MPF-TAC in column (4). Column (4) implies that the counterfactual that exploits variation in time across slaughterhouses that were eventually acquired by G4 companies is likely to be more reliable than in the other two subsamples.

The pre-trends for the smaller 145 and 75 kilometer supply zones (Tables C2 and C3) show similar patterns, although in these cases there are not statistically significant differences in early versus late exposed points for the three key subsamples. This suggests that analysis of these subsamples may provide unbiased estimates of impacts, though valid for only very limited areas.

[6]Early signatories include those points that had exposure to agreements of between .30 and .40 by 2010. These thresholds were chosen so that about half the points in each pre-trend sample fell within the "early" category.

Table C1: Pre-trends for 235 km supply zones

	Dependent variable: Forest= 1/0			
	All points	SIFs	TAC	G4
	(1)	(2)	(3)	(4)
Year	-0.004***	-0.004***	-0.003***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Has SIF x year	-0.000			
	(0.000)			
MPF-TAC or G4 x year	0.000	0.000		
	(0.001)	(0.001)		
G4 x year	-0.001*	-0.001*	-0.001*	
	(0.001)	(0.001)	(0.001)	
Early MPF-TAC x year	-0.004***	-0.003***	-0.003***	
	(0.001)	(0.001)	(0.001)	
Early G4 x year	0.002*	0.002*	0.002*	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Time effects	yes	yes	yes	yes
Time x Covariates	yes	yes	yes	yes
Observations	270528	174729	173329	142799
Adjusted R^2	0.027	0.029	0.029	0.030

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. All estimations include time effects. * p< 0.10, ** p<0.05, *** p < 0.01. Only points with forest in 2001 included. Estimation includes data through 2008. Time-interacted covariates include: indigenous area, conservation area, and INCRA.

Table C2: Pre-trends for 145 km supply zones

	Dependent variable: Forest= 1/0			
	All points	SIFs	TAC	G4
	(1)	(2)	(3)	(4)
Year	-0.003***	-0.005***	-0.004**	-0.004**
	(0.001)	(0.002)	(0.002)	(0.001)
Has SIF x year	-0.003*			
	(0.002)			
MPF-TAC or G4 x year	0.001	0.002		
	(0.002)	(0.002)		
G4 x year	-0.002*	-0.002	-0.002	
	(0.001)	(0.001)	(0.001)	
Early MPF-TAC x year	-0.002	-0.002	-0.001	
	(0.002)	(0.002)	(0.002)	
Early G4 x year	0.001	0.001	0.001	0.000
	(0.002)	(0.002)	(0.002)	(0.001)
Time effects	yes	yes	yes	yes
Time x Covariates	yes	yes	yes	yes
Observations	237702	80965	78658	62803
Adjusted R^2	0.029	0.035	0.035	0.037

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. All estimations include time effects. * p< 0.10, ** p<0.05, *** p < 0.01. Only points with forest in 2001 included. Estimation includes data through 2008. Time-interacted covariates include: indigenous area, conservation area, and INCRA area.

Table C3: Pre-trends for 75 km supply zones

	Dependent variable: Forest= 1/0			
	All points	SIFs	TAC	G4
	(1)	(2)	(3)	(4)
Year	-0.004***	-0.009***	-0.005	-0.005
	(0.001)	(0.002)	(0.003)	(0.003)
Has SIF x year	-0.003			
	(0.002)			
MPF-TAC or G4 x year	0.001	0.004		
	(0.002)	(0.003)		
G4 x year	-0.002	-0.003*	-0.003	
	(0.002)	(0.002)	(0.002)	
Early MPF-TAC x year	-0.006*	-0.004	-0.004	
	(0.003)	(0.003)	(0.003)	
Early G4 x year	0.004	0.004	0.004	0.000
	(0.004)	(0.004)	(0.004)	(0.002)
Time effects	yes	yes	yes	yes
Time x Covariates	yes	yes	yes	yes
Observations	237702	28115	25812	19882
Adjusted R^2	0.029	0.045	0.046	0.046

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. All estimations include time effects. * p< 0.10, ** p<0.05, *** p < 0.01. Only points with forest in 2001 included. Estimation includes data through 2008. Time-interacted covariates include: indigenous area, conservation area, and INCRA area.

Appendix D CAR pre-trends

We used a similar specification to examine heterogeneous effects of the agreements' expansion on properties in the environmental registry (CAR). One challenge with considering effects on CAR properties is that landowners who chose to register may have different production goals than those that did not. In particular, CAR points may have been more likely to have had deforestation prior to registration, suggesting that CAR-registrants were on more agriculturally productive land. This point is examined in more detail in our companion paper on this topic (Alix-Garcia et al. 2017). We addressed this endogeneity issue in two ways. First, we used a specification that included all the points in our previous G4 subsample (the smallest subsample), as well as an interaction term between whether or not a point was in a property that registered for the CAR by 2014. This variable is labeled "CAR by 2014" in the tables. This specification also included CAR by year time effects, allowing CAR properties to have different time trends than non-CAR properties. Second, we attempted to circumvent the CAR endogeneity problem by restricting our sample to those properties within the supply zones that had registered for the CAR by 2014, and allowed the differential effect for CAR properties to be identified by temporal variation. This variable is labeled as "CAR" in the tables. In this case, those who registered later for the CAR served as the counterfactual for those who register earlier. In light of the pre-trend results for the slaughterhouse subsamples, we restricted our analysis to the G4 subsample.

As with the G4 impact estimation, the causal impact of CAR in this setting relied on a parallel trend assumption: that properties who applied for the CAR later (or never applied) would have behaved similarly to properties that applied earlier (or applied at all) in the absence of the program. We conducted three tests of this assumption: the first used the full sample of points within G4 supply zones, and interacted a dummy variable for whether or not a point ever registered for CAR with indicator variables for the year. The second restricted the analysis to those points that would have been "eligible" to register for the CAR (land in protected and indigenous areas is not allowed to participate in the program),

and the third uses only points within G4 supply zones that ever registered for CAR, and tested whether or not those that registered "early" (before 2011) had different pre trends than those that registered later. Using the forest cover data from 2001 to 2006, we failed to reject equivalent trends for CAR/non-CAR eligible and early/late CAR properties (Table D4). When we compare trends between those that eventually registered and the broader set of points in the sample (column (1)), the results clearly show that these are not comparable groups – those who are eligible for CAR were more likely to have deforested between 2001 and 2006. However, columns (2) and (3) show no statistically significant differences between the registrants and the counterfactual group, suggesting that both the eligible but unregistered (column (2)) and the late-registered (column (3)) had similar pre-program deforestation activity to the ever- or early-registered groups.

Table D4: Tests for differential pre-trends for CAR properties

	Dep. var.: Forested at year's end Data 2001-2005				
	(1)	(2)	(3)	(4)	(5)
Time x registered pre-2010	0.001	-0.001	-0.001		
	(0.001)	(0.001)	(0.001)		
2002 x registered pre-2010				0.010	
				(0.007)	
2003 x registered pre-2010				0.010	
				(0.007)	
2004 x registered pre-2010				0.008	
				(0.008)	
2005 x registered pre-2010				-0.002	
				(0.011)	
Time x registered 2007					0.004
					(0.006)
Time x registered 2008					-0.001
					(0.004)
Time x registered 2009					-0.001
					(0.005)
Time x registered 2010					0.001
					(0.005)
Time x registered 2011					0.001
					(0.005)
Time x registered 2012					0.000
					(0.006)
Time x registered 2013					0.004
					(0.005)
Time effects	yes	yes	yes	yes	yes
Time x Para	no	yes	yes	yes	yes
Time x soy	no	no	yes	yes	yes
Observations	40221	40221	40221	41911	41911
Adjusted R^2	0.036	0.037	0.045	0.091	0.091

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. * p< 0.10, ** p<0.05, *** p < 0.01. Observations weighted to reflect sample design. Data only includes points with in 2001, and points which eventually registered for CAR.

Appendix E Extra tables

Table E5: Summary statistics for sampled points

	(1) TAC 235	(2) G4 235	(3) TAC 145	(4) G4 145	(5) TAC 75	(6) G4 75
Percent forested points, 2001	0.616	0.582	0.494	0.462	0.337	0.337
Percent forested points, 2007	0.544	0.528	0.451	0.438	0.326	0.330
Ln(Km nearest SIF)	4.785	4.741	4.448	4.431	3.939	4.002
CAR by 2014	0.430	0.453	0.492	0.514	0.537	0.545
Municipal cattle per ha, 2007	0.286	0.339	0.430	0.522	0.638	0.762
Km to nearest highway	95.948	96.145	85.277	81.582	67.791	60.780
Km to nearest city	63.316	60.048	47.175	45.227	31.534	32.024
Slope in degrees	10.463	10.041	10.309	10.370	9.731	9.846
Point in indigenous territory	0.193	0.205	0.116	0.117	0.055	0.063
Conservation	0.143	0.092	0.091	0.050	0.033	0.008
Point in INCRA settlement	0.154	0.129	0.174	0.142	0.169	0.174
Prop of TAC SIFs, 235 km	0.868	0.845				
Prop of G4 SIFs, 235 km	0.402	0.477				
In G4 supply zone, 235 km	0.595	0.707				
Prop of TAC SIFs, 145 km			0.819	0.791		
Prop of G4 SIFs, 145 km			0.437	0.537		
In G4 supply zone, 145 km			0.594	0.729		
Prop of TAC SIFs, 75 km					0.807	0.755
Prop of G4 SIFs, 75 km					0.473	0.624
In G4 supply zone, 75 km					0.560	0.740
Observations	37944	31947	22995	18731	10120	7662

All numbers reflect 2014 averages, unless otherwise noted. The sample shown is the full sample of stratified random points from Pará and Mato Grosso. Analysis of pre-trends uses only points with forest in 2001, and the impact sample uses only points with forest in 2007.

Table E6: Average impact of cattle agreements across different subsamples, 145 km supply zones

	Dependent variable: Forest = 1/0								
	SIFs			TAC			G4		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Prop of TAC SIFs, 145 km	0.006*			0.007**			0.001		
	(0.003)			(0.003)			(0.005)		
Prop of G4 SIFs, 145 km	-0.009**	-0.004		-0.009**	-0.004		-0.003	-0.001	
	(0.004)	(0.003)		(0.004)	(0.003)		(0.006)	(0.002)	
In G4 supply zone, 145 km			-0.003			-0.003			0.001
			(0.002)			(0.003)			(0.002)
Ln(number SIFs, 75 km)	0.000	0.002	0.002	-0.000	0.002	0.002	-0.001	-0.000	-0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Time effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time x covariates	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	50492	50492	50492	49431	49431	49431	42789	42789	42789
Adjusted R^2	0.017	0.017	0.017	0.017	0.017	0.017	0.019	0.020	0.019

Unit of observation is the point. The estimator fixed effects with effects at the point level, and time effects for each year and state. Standard errors are in parentheses and are clustered at the municipal level. Subsamples are labeled in the second row of the table. * p< 0.10, ** p<0.05,*** p < 0.01. Time-interacted covariates include indigenous area, conservation area, INCRA, and 2007 municipal cattle densities.

Table E7: Average impact of cattle agreements across different subsamples, 75 km supply zones

	Dependent variable: Forest = 1/0								
	SIFs			TAC			G4		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Prop of TAC SIFs, 75 km	-0.006			-0.005			0.007		
	(0.005)			(0.005)			(0.006)		
Prop of G4 SIFs, 75 km	0.003	-0.001		0.003	-0.001		-0.008	-0.002	
	(0.005)	(0.002)		(0.005)	(0.002)		(0.005)	(0.002)	
In G4 supply zone, 75 km			-0.001			-0.001			-0.001
			(0.002)			(0.002)			(0.003)
lnnumSIFs75	0.003	0.001	0.001	0.004	0.003	0.003	0.005	0.006	0.006
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)
Time effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
Time x covariates	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	21215	21215	21215	19169	19169	19169	16003	16003	16003
Adjusted R^2	0.020	0.020	0.020	0.020	0.020	0.020	0.021	0.021	0.021

Unit of observation is the point. The estimator fixed effects with effects at the point level, and time effects for each year and state. Standard errors are in parentheses and are clustered at the municipal level. Subsamples are labeled in the second row of the table. * p< 0.10, ** p<0.05,*** p < 0.01. Time-interacted covariates include indigenous area, conservation area, INCRA, and 2007 municipal cattle densities.

Table E8: Differential impacts on properties with deforestation post-2009

	Dependent variable: Forest = 1/0		
	(1)	(2)	(3)
Prop of G4 SIFs, 235 km	0.000		
	(0.002)		
Prop G4 x post-2009 defor	-0.006		
	(0.009)		
Prop of G4 SIFs, 145 km		-0.005	
		(0.004)	
Prop G4 x post-2009 defor		-0.006	
		(0.006)	
Prop of G4 SIFs, 75 km			-0.004
			(0.004)
Prop G4 x post-2009 defor			0.480
			(0.358)
Any property pts deforested, 2009 to t-1	0.001	0.006	-0.491
	(0.010)	(0.010)	(0.357)
Time effects	yes	yes	yes
Time x Covariates	yes	yes	yes
Observations	40225	22874	7804
Adjusted R^2	0.014	0.015	0.023

Unit of observation is the point. The estimator fixed effects with effects at the point level, and time effects for each year and state, and for year by 2007 cattle density. Standard errors are in parentheses and are clustered at the municipal level.* p< 0.10, ** p<0.05,*** p < 0.01. Samples are limited to those points that registered for the CAR by 2014.

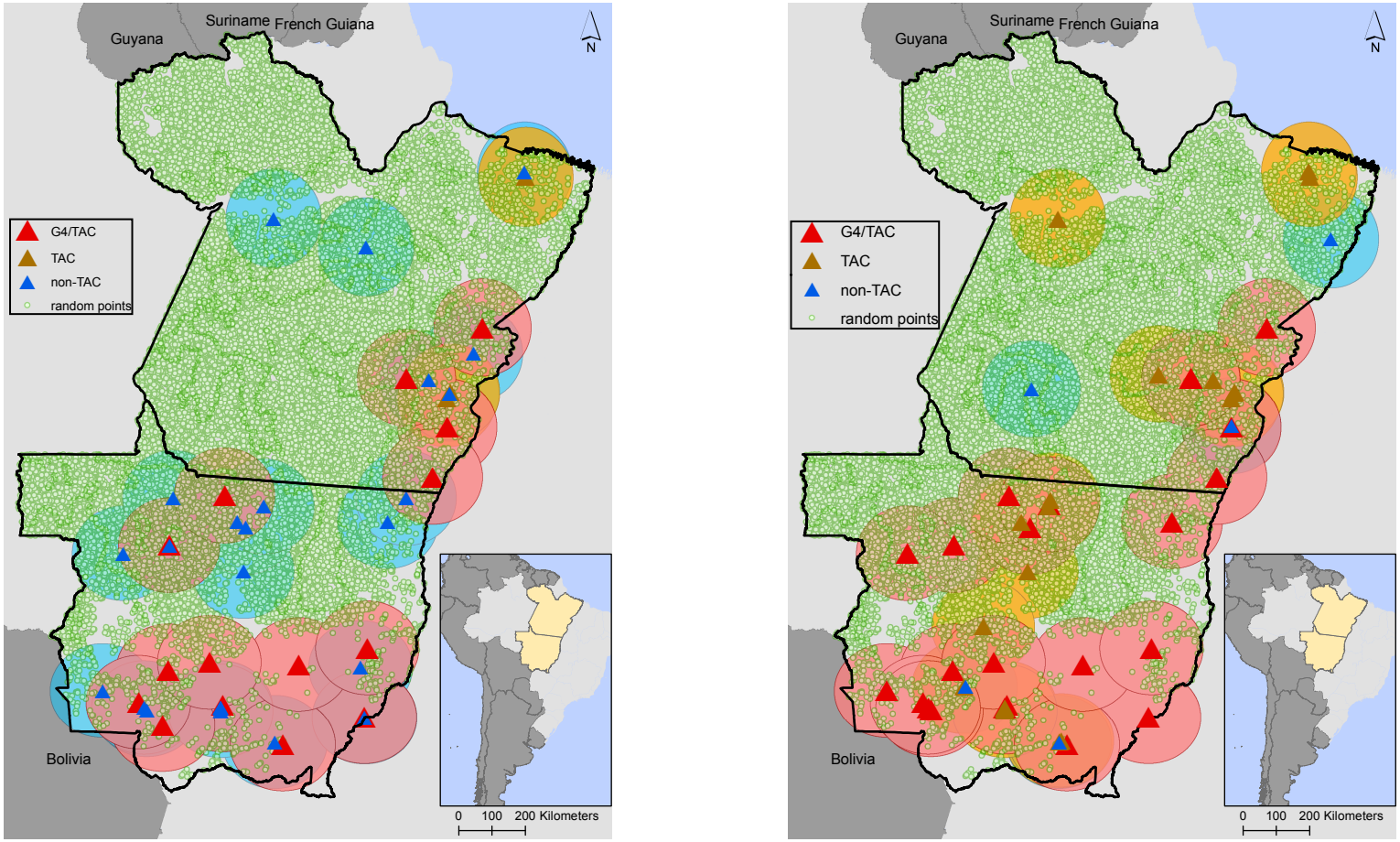
Table E9: Impact of increasing G4 exposure by year of CAR registration

	Dependent variable: Forest = 1/0		
	(1)	(2)	(3)
CAR before 2010 x prop. G4, 235 km	0.007***		
	(0.002)		
CAR 2010 x prop. G4, 235 km	0.006**		
	(0.003)		
CAR 2011 x prop. G4, 235 km	-0.003		
	(0.003)		
CAR 2012 x prop. G4, 235 km	-0.005		
	(0.004)		
CAR 2013 x prop. G4, 235 km	-0.010		
	(0.009)		
CAR 2014 x prop. G4, 235 km	-0.018**		
	(0.008)		
CAR before 2010 x prop. G4, 145 km		0.004	
		(0.003)	
CAR 2010 x prop. G4, 145 km		0.003	
		(0.004)	
CAR 2011 x prop. G4, 145 km		-0.004	
		(0.004)	
CAR 2012 x prop. G4, 145 km		-0.021**	
		(0.010)	
CAR 2013 x prop. G4, 145 km		-0.030*	
		(0.015)	
CAR 2014 x prop. G4, 145 km		-0.015**	
		(0.006)	
CAR before 2010 x prop. G4, 75 km			0.004
			(0.004)
CAR 2010 x prop. G4, 75 km			0.010***
			(0.004)
CAR 2011 x prop. G4, 75 km			-0.007
			(0.008)
CAR 2012 x prop. G4, 75 km			-0.008
			(0.015)
CAR 2013 x prop. G4, 75 km			-0.041
			(0.028)
CAR 2014 x prop. G4, 75 km			-0.007
			(0.009)
Time effects	yes	yes	yes
Time x Covariates	yes	yes	yes
Observations	43365	24828	8452
Adjusted R^2	0.015	0.018	0.019

Unit of observation is the point. The estimator fixed effects with effects for each year and state, and for year by 2007 cattle density. Standard errors are in parentheses and are clustered at the municipal level.* p< 0.10, ** p<0.05,*** p < 0.01. Samples are limited to those points that registered for the CAR by 2014.

Appendix F Extra figures

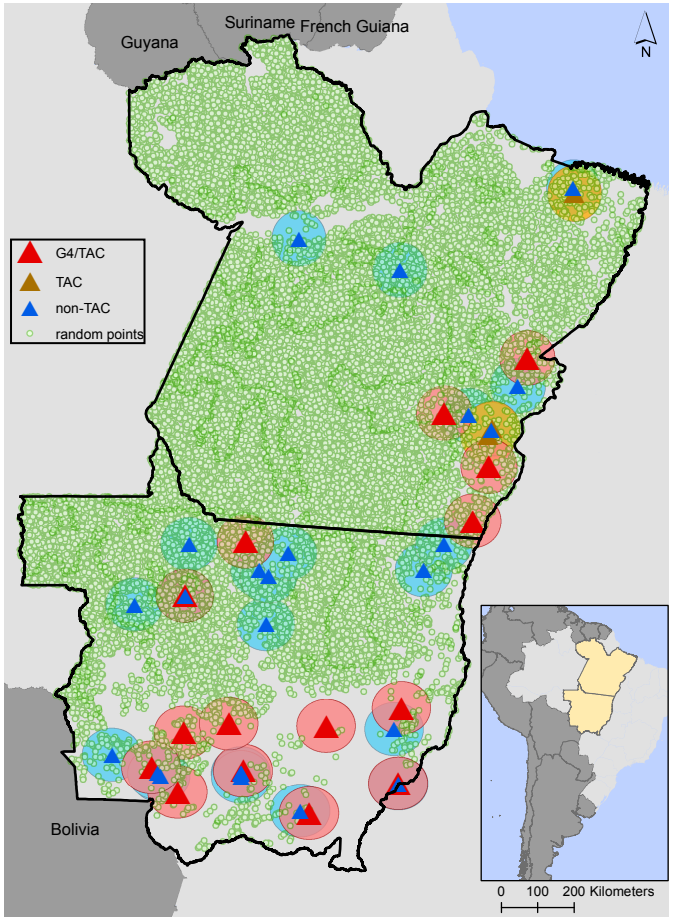
Figure F1: Study location, sample, 145 km supply zones



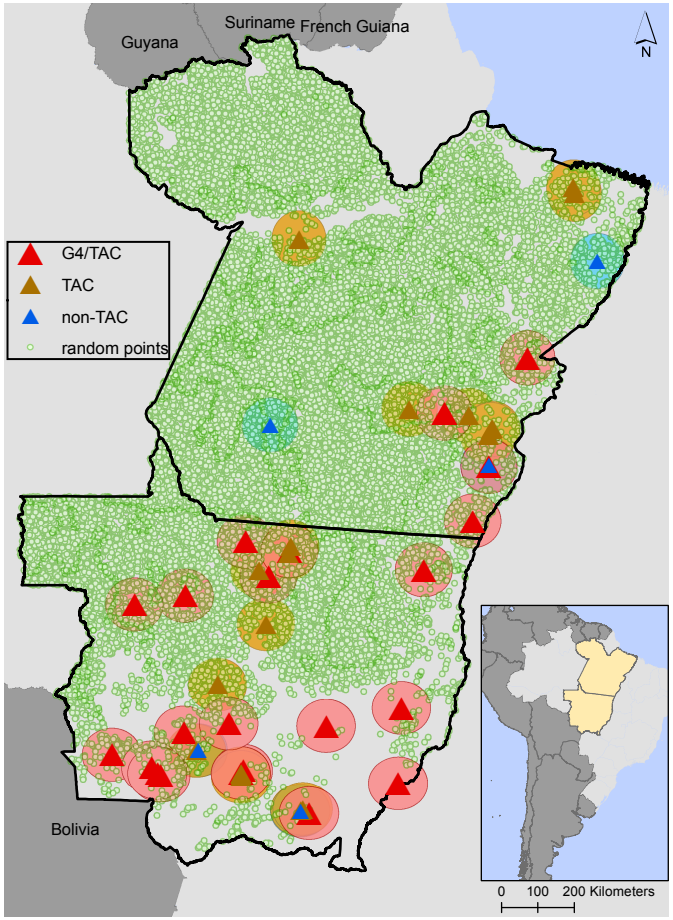
(a) 2009

(b) 2015

Figure F2: Study location, sample, 75 km supply zones



(a) 2009



(b) 2015

Figure F3: Variation in MPF-TAC/G4 signatory exposure over time

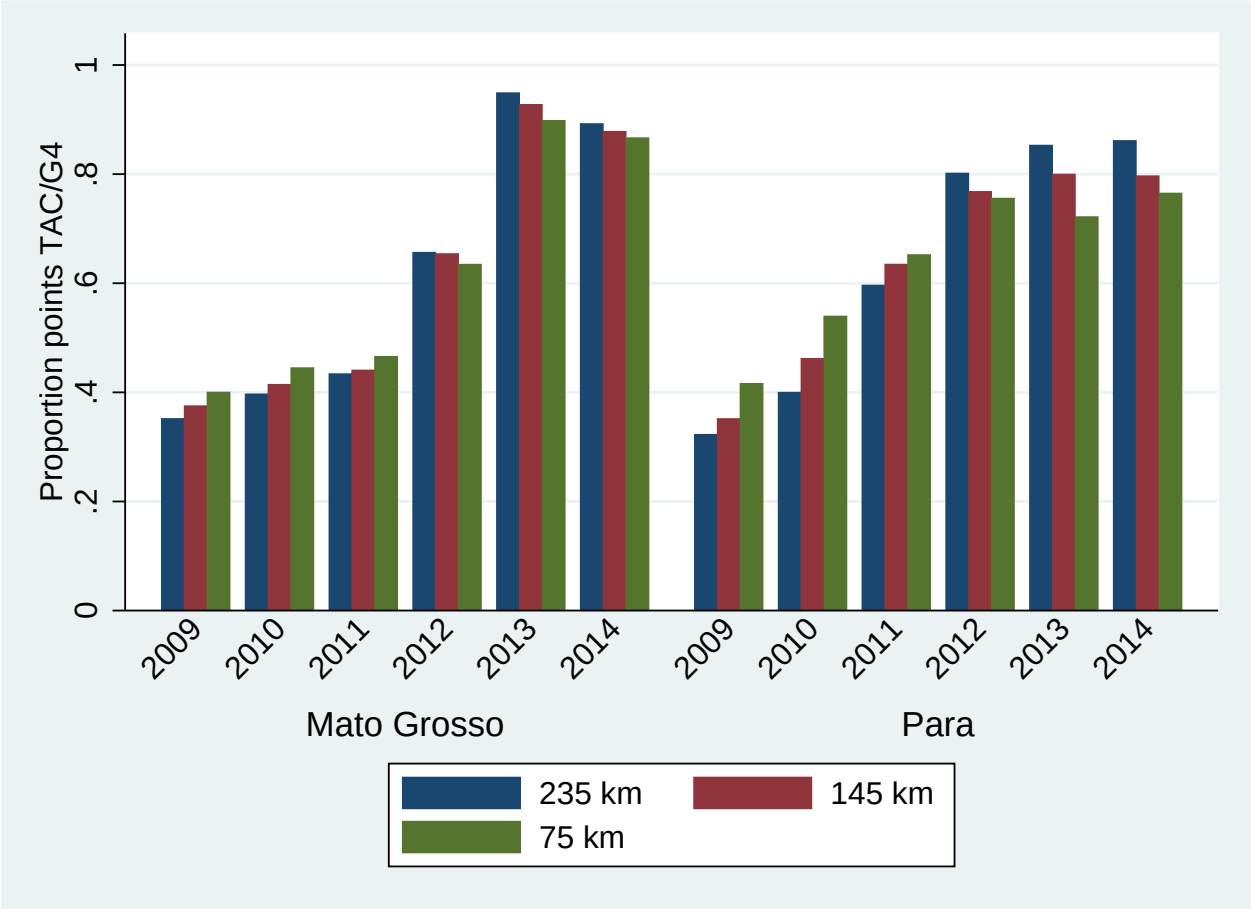


Figure F4: Trends, 235 km sample

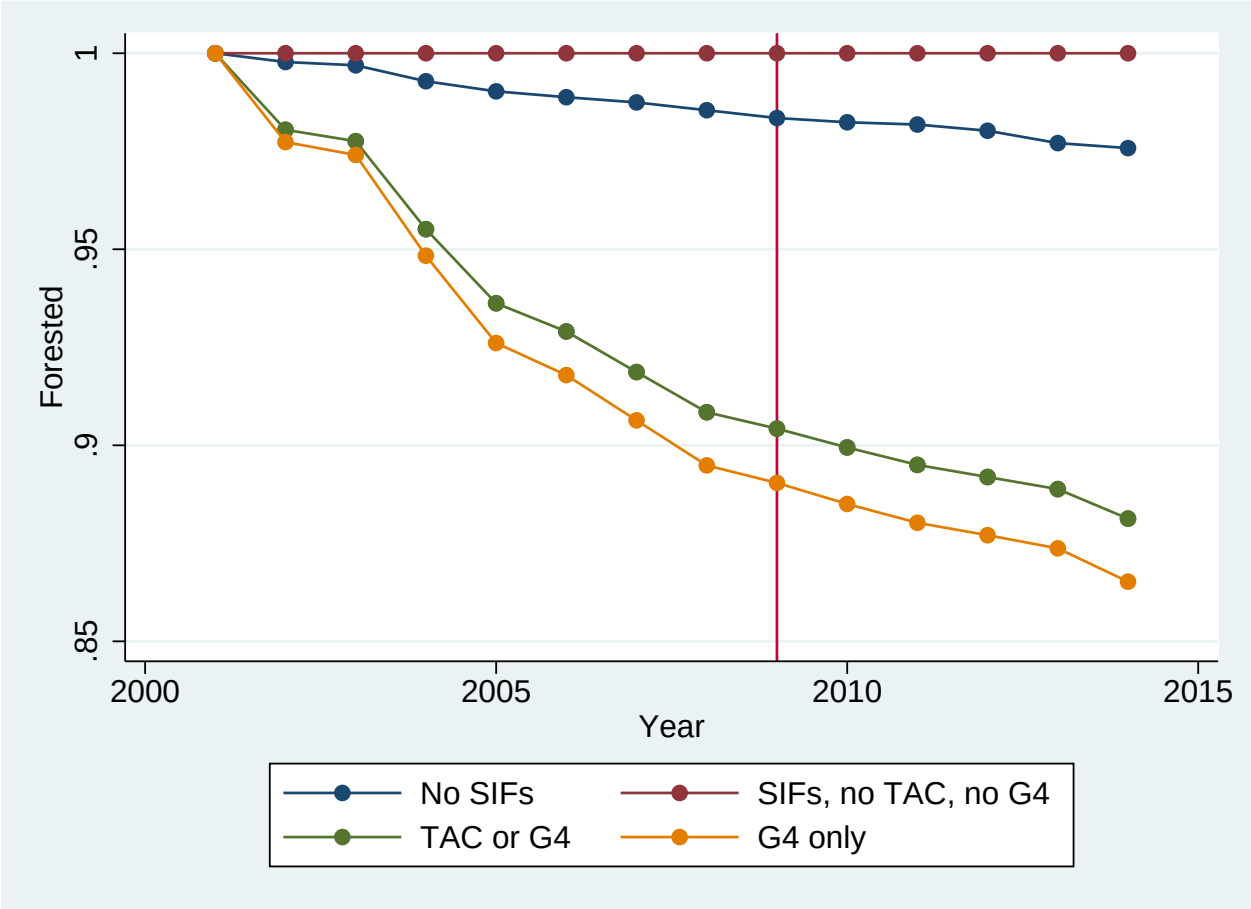


Figure F5: Trends, 145 km sample

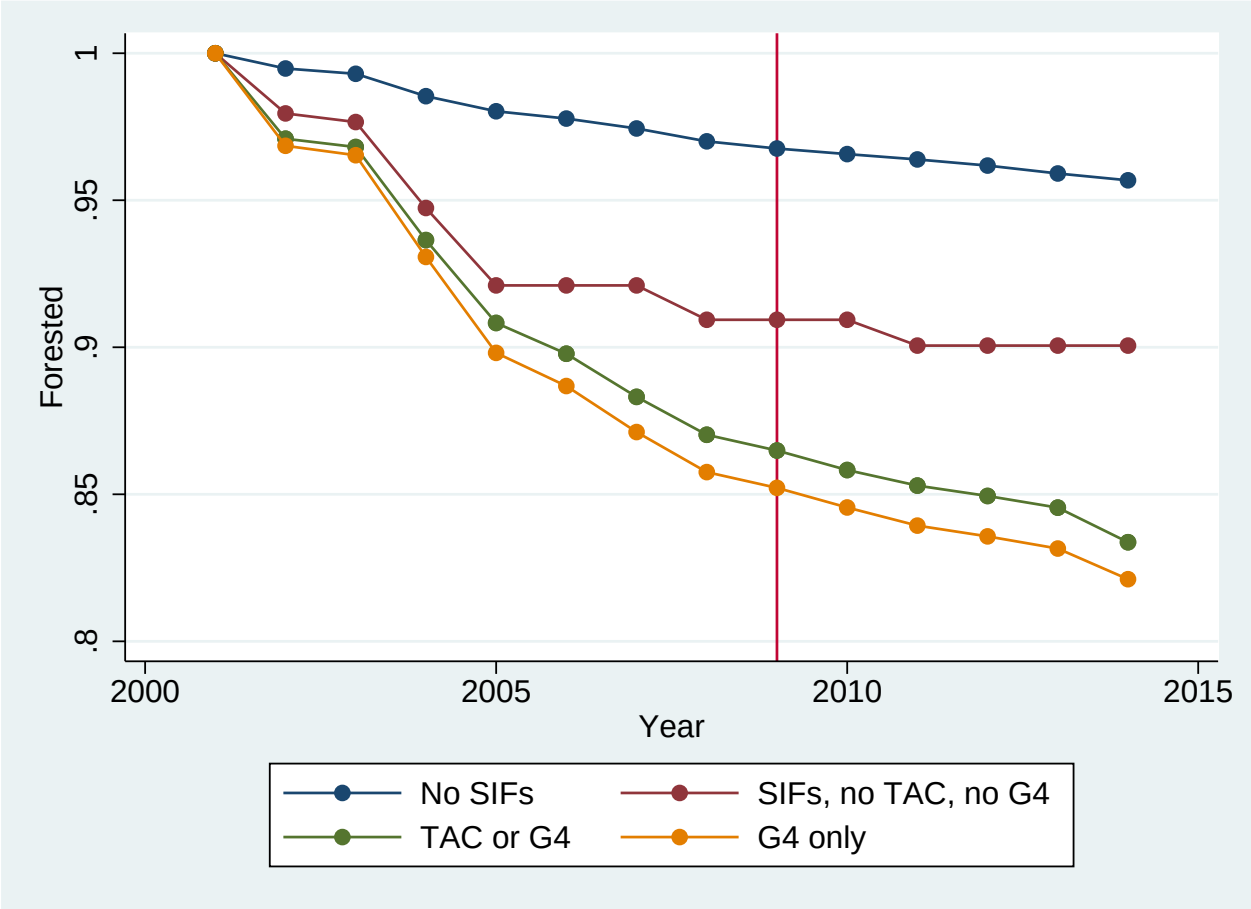


Figure F6: Trends, 75 km sample

