Could Credit Save the Amazon Forest?*

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Abstract

This paper investigates how rural credit shapes agricultural land use and forest conservation in Brazil. We combine farm-level evidence with a dynamic general equilibrium model of land use. We first link administrative loan records, interbank payments, and satellite imagery. Using a staggered difference-in-differences design, we find that farms in the Legal Amazon shift from pasture toward crops, increase spending on machinery and fertilizer, and retain more forest following first credit receipt, relative to farms that have not yet received credit. We then develop a dynamic model with crops, pasture, endogenous forest cover, and land rental markets which we calibrate to the Legal Amazon to evaluate how conditioning rural credit on environmental compliance affects conservation and agricultural production. In partial equilibrium, with land rents held fixed, raising borrowing costs for noncompliant farms or restricting credit to compliant farms increases long-run forest cover by 13–17%. General equilibrium adjustments reduce these gains to approximately 2%, while agricultural output remains virtually unchanged. As landowners conserve forest, the supply of cleared land falls and rents rise. Higher rents increase the income landowners forgo by retaining forest, offsetting most of the direct conservation incentive.

Keywords: Agricultural finance, land use, forestry, conservation policy.

JEL Codes: Q14, Q15, Q23, Q28.

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1 Introduction

For decades, Brazil has sought to protect the Amazon rainforest from agricultural clearing through satellite monitoring, strict enforcement, and protected areas. At the same time, the government channels billions of dollars in subsidised credit to farmers every year. Credit can finance machinery, fertilizer, and pesticides, enabling farmers to intensify production and shift from pasture towards crops, reducing the land required for production. The same investments can also raise the marginal productivity of agricultural land and make further clearing more profitable. Whether credit spares forest depends on how these changes in the demand for agricultural land interact with enforcement of the Forest Code and the financial incentives for compliance (Azevedo et al. 2017). We therefore ask how formal rural credit shapes land use and forest conservation when enforcement of environmental regulation is limited, and whether conditioning credit on environmental compliance can preserve forest while sustaining agricultural output.

To address these questions, we combine farm-level evidence on credit, input purchases, and land use with a dynamic general equilibrium model of heterogeneous farms whose production, financing, and conservation decisions are linked through land rental markets. We first construct a panel linking confidential credit records from the Central Bank of Brazil with satellite imagery for more than two million registered rural properties. Interbank payment records provide additional information on spending on agricultural inputs. Using a staggered difference-in-differences design, we compare changes following farms' first receipt of rural credit with changes on farms that have not yet received credit. In the Legal Amazon, farms shift land from pasture towards crops and retain more forest, with the estimated increase in the forest share reaching approximately two percentage points ten years after first credit receipt. Spending on machinery and fertilizer also increases, consistent with credit financing more intensive agricultural production. We document similar shifts towards crops and higher input spending in the Amazon biome and the Cerrado, and broadly similar patterns across groups defined by farm size and borrower ownership type.

The model incorporates heterogeneous landowners who choose between working outside agriculture, growing crops, and raising cattle. Landowners adjust forest cover through costly deforestation and reforestation, while active farmers rent cleared land, invest in mechanization that reduces land requirements, and borrow against their assets to finance production. A farm operates as compliant only if the farmer's own plot and any plots from which it rents land meet the Forest Code's Legal Reserve requirement. We calibrate the model to the Legal Amazon and evaluate several reforms: higher borrowing spreads for noncompliant farms; credit restricted to compliant farms; a higher Legal Reserve requirement; and higher fines for forest shortfalls. We also evaluate the higher Legal Reserve requirement in combination with each credit reform and with higher fines. These experiments allow us to compare credit conditionality with more stringent environmental regulation and assess how the instruments interact. Credit conditionality increases the value of retaining sufficient forest to comply, including for landowners who rent out their land or may enter farming following future changes in productivity.

We calibrate the model to the Legal Amazon[1] using rural property records, satellite imagery, and Agricultural Census data. We target several moments including the distribution of farm size, land-use patterns, differences in capital intensity between crop and cattle farms, borrowing participation, changes in forest cover, and compliance with the Forest Code. The model predicts that conditioning rural credit on environmental compliance increases long-run forest cover by approximately 2 percent. Increasing the Legal Reserve requirement by ten percentage points raises forest cover by 1.4 percent, whereas a ten percent increase in the fine per hectare of forest shortfall produces a gain of only 0.1 percent. Combining the higher Legal Reserve requirement with either credit reform increases forest cover by 3.2–3.3 percent, the largest gains among the policies examined. Agricultural output falls by no more than 0.02 percent across the experiments.

We show that abstracting from equilibrium adjustments in land rental markets can lead to misleading conclusions about both the magnitude and the direction of conservation effects. Holding land rents fixed at baseline levels, the credit reforms increase forest cover by 13–17 percent, compared with approximately 2 percent when rents adjust. As landowners retain more forest, the supply of cleared land contracts and rents rise. Higher rents increase the income landowners forgo by retaining forest, offsetting much of the direct conservation incentive. They also encourage farmers to mechanise and produce on less land, helping sustain agricultural output. For the higher Legal Reserve requirement, equilibrium adjustments reverse the response: forest cover falls by approximately 23 percent at fixed rents but increases by 1.4 percent when land markets clear.

Related Literature. Our paper connects to several strands of the literature. First, our work builds on the literature studying the links between rural credit and deforestation in the Brazilian Amazon (Binswanger 1991, Berger et al. 2026). Closest to our research design is Assunção et al. (2020), who aggregate data from the rural credit system to the municipality level and find that conditioning subsidised rural credit in the Amazon on compliance with legal titling requirements and environmental regulations substantially reduced deforestation rates. Ruggiero et al. (2026) also use municipality-level data and find that the effect of credit on deforestation differs between loans for cattle ranching and loans for crop farming, and between remote and more accessible municipalities. We depart from the municipality-level evidence by using novel farm-level data that trace loans, input purchases, and land use changes to individual farms, directly observing whether farms that receive credit clear forest or intensify production.

Second, our work relates to the literature on agricultural technology and deforestation. Under the Borlaug hypothesis, higher yields can spare forest by reducing the land needed for agricultural production (see Balboni et al. 2023, for a recent survey). Consistent with this view, subsidies for fertilizer and seeds reduced deforestation in Malawi (Abman & Carney 2020). However, new technology also raises the return to farming, and genetically engineered soy seeds increased deforestation in Brazil through cropland expansion (Carreira et al. 2024). Cavalcanti & Kamkar (2026) help reconcile the two sets of findings by showing that the effect of productivity gains on deforestation depends on

[1]The Legal Amazon (*Amazônia Legal*) is a region defined by Brazilian law for regional development planning. It covers approximately 59 percent of Brazil's territory, encompassing eight states in full and part of Maranhão. Its boundaries extend beyond the Amazon biome to include areas of the Cerrado and Pantanal.

the agricultural productivity of forest land relative to the vacant land available for expansion. In the Amazon, Kamkar & Chertman (2026) show that higher foreign demand for beef and soy may pull farms into pasture and away from modern technology if the cost of deforestation is low. Conversely, conservation policies that raise the cost of clearing lead ranchers to intensify cattle production (Koch et al. 2019, Moffette et al. 2021). Within this literature, closest to our work is Szerman et al. (2026), who show that a productivity gain from rural electrification led credit-constrained farmers in Brazil to move land from pasture to crops and to protect more native vegetation. In our data, farms that receive rural credit make a similar shift from pasture to crops, spend more on machinery and fertilizer, and keep more forest. Thus, our evidence suggests that credit can finance intensification rather than expansion into forest.

Third, we relate to a large literature on environmental policies and deforestation, which finds that policy instruments such as satellite monitoring and stricter enforcement can reduce deforestation (Assunção et al. 2015, 2023, Assunção et al. 2023, Burgess et al. 2018, Harding et al. 2021). Souza-Rodrigues (2019) provides a structural framework for estimating the demand for deforestation in the Amazon and finds that taxes on agricultural land can be highly cost-effective in preserving the rainforest. Araujo et al. (2026) estimate the efficient level of forest conservation in the Amazon accounting for the carbon externality. Dominguez-Iino (2026) finds that a tax on agribusiness buyers with market power is a poorly targeted substitute for a tax on farmers. Other structural models study how transport infrastructure and global trade shape deforestation (Araujo et al. 2025, Gollin & Wolfersberger 2025, Farrokhi et al. 2025). We depart from this literature by modelling rural credit as a conservation instrument, with borrowing terms that can depend on whether a farm complies with the Legal Reserve.

Fourth, our treatment of credit in the model follows the macroeconomic literature on financial frictions and development. Collateral constraints distort occupational choice (Buera et al. 2011) and the allocation of capital across heterogeneous producers (Moll 2014). Farm-size distortions and frictions in land and capital markets lower agricultural productivity (Adamopoulos & Restuccia 2014, Adamopoulos et al. 2022, Chen et al. 2022). Models with collateral constraints are also used to evaluate credit subsidies and development policy (Buera et al. 2013, Itskhoki & Moll 2019). In general equilibrium, factor prices can absorb much of the direct effect of credit reforms (Antunes et al. 2008, Buera et al. 2021), and a contraction in microcredit lowered local wages in India (Breza & Kinnan 2021). Our model builds most directly on Cavalcanti et al. (2021), who combine a limited-enforcement borrowing constraint with borrowing spreads in a continuous-time model calibrated to Brazilian credit-registry data. In our setting, land rents adjust to credit policy and absorb much of its effect on forest cover.

2 Background

Brazil operates one of the largest agricultural credit programmes in the world. The National Rural Credit System (*Sistema Nacional de Crédito Rural*, SNCR) was created by Law 4,829 of 1965 and channels credit to farmers through Banco do Brasil, Banco da Amazônia, Banco do Nordeste, the

National Bank for Economic and Social Development, and a wide network of commercial banks and rural credit cooperatives. Operating rules are set by the National Monetary Council (CMN) and codified by the Central Bank of Brazil in the Rural Credit Manual, which fixes eligible borrowers, credit lines, interest rates, and documentation requirements (Banco Central do Brasil 2024). The annual budget is announced each July in the *Plano Safra* and reached roughly R$400 billion in the 2024/25 crop year, of which R$76 billion was earmarked for family agriculture (Ministério da Agricultura, Pecuária e Abastecimento (MAPA) 2024). Interest rates on many lines sit well below market rates, and the National Treasury covers the wedge through explicit equalisation payments to lenders, so the SNCR stands as the single largest fiscal instrument directed at Brazilian agriculture (OECD 2025).

Inside the Amazon Biome, access to subsidised rural credit is formally conditional on documentation of legal land title and environmental compliance. Since CMN Resolution 3,545 of February 2008, farmers seeking subsidised credit in the Amazon Biome must present a valid rural property registration and evidence of environmental regularity, and all banks operating within the SNCR were required to enforce the rule from July 2008 (Conselho Monetário Nacional 2008, Assunção et al. 2015). In practice, banks enforce the land-ownership requirement strictly but treat the environmental requirement more loosely, and a farmer can qualify by showing that the compliance process is under way rather than complete (Assunção et al. 2020). Even so, the reform produced a measurable contraction of credit inside the biome. Assunção et al. (2020) estimate that credit concessions from 2009 through 2011 were roughly 16 percent below the counterfactual, with the effect concentrated in cattle-related loans and larger contracts. Enforcement runs through the *Cadastro Ambiental Rural* (CAR), a georeferenced digital registry of rural properties introduced at the state level in Mato Grosso in 2008 and in Pará in 2009 and consolidated nationally under the 2012 Forest Code (Azevedo et al. 2017, Soares-Filho et al. 2014). Registration in CAR is a precondition for accessing subsidised rural credit (Azevedo et al. 2017), and by August 2016 the national system had registered 3.7 million rural properties covering 387 million hectares (Azevedo et al. 2017). Roughly 53 percent of Brazil's native vegetation sits on private property (Soares-Filho et al. 2014), so the joint administration of CAR and the SNCR is the main channel through which the state observes farm-level land use and conditions credit on it.

The Forest Code itself sets a legal reserve of native vegetation that each rural property must maintain. In the Amazon Biome the reserve is 80 percent of the property, a threshold in place since 1996 (Nepstad et al. 2014), and in other biomes the baseline is 20 percent (Soares-Filho et al. 2014). The 2012 reform preserved these thresholds yet granted an amnesty for illegal clearing that had taken place before July 2008. The area of illegally deforested land no longer requiring restoration under the new Code fell from 50 to 21 million hectares, a 58 percent reduction in the aggregate environmental debt, achieved primarily by forgiving small properties, which account for 90 percent of Brazilian rural holdings (Soares-Filho et al. 2014). Restoration on properties with pre-2008 debt remains rare, and only 6 percent of CAR-registered producers with legal reserve deficits have reported action to restore them (Azevedo et al. 2017).

Agricultural expansion is the principal driver of forest loss in the Brazilian Amazon. Cattle pasture and soybean cultivation are the two main historical drivers, and cattle pasture accounts for the

largest share of newly cleared land (Nepstad et al. 2014, Barona et al. 2010). Deforestation in the Legal Amazon peaked at more than 27,000 square kilometres in 2004 and fell to about 7,000 square kilometres by 2009 (Assunção et al. 2015), reaching a low of 4,571 square kilometres in 2012, an 84 percent decline from the peak (Silva Junior et al. 2021). Over the same period the federal government moved along three tracks, expanding monitoring and law enforcement through the DETER satellite system and the environmental agency IBAMA, enlarging the network of protected areas to 47 percent of the Amazon by 2012, and conditioning rural credit on environmental compliance through Resolution 3,545 (Assunção et al. 2015, Nepstad et al. 2014). The decline reversed after 2013, and by 2020 annual clearing in the Legal Amazon had climbed back to 11,088 square kilometres, the highest rate of the decade and 182 percent above the 3,925 square kilometre target that Brazil had set for that year under the 2009 National Policy on Climate Change (Silva Junior et al. 2021).

The neighbouring Cerrado has followed a different trajectory. Legal protection there is weaker, since the Forest Code permits agricultural use of 65 to 80 percent of a property with Cerrado vegetation (Rausch et al. 2019), and voluntary agreements such as the Soy Moratorium of 2006 and the Cattle Agreement of 2009 do not apply. By 2015 roughly 41 percent of native Cerrado vegetation had been cleared for agriculture, and soybean cultivation accounted for 22 percent of clearing over 2003 to 2014 (Rausch et al. 2019). Forest Code compliance is considerably lower on Cerrado soy farms, where 51 percent have cleared beyond legal limits compared with 11 percent of other farms (Rausch et al. 2019). Altogether, the three geographies we study in the empirical analysis, the Amazon Biome, the wider Legal Amazon, and the Cerrado, cover the frontier where formal rural credit meets the largest remaining stocks of tropical forest and savanna vegetation in Brazil.

3 Reduced-Form Evidence

To investigate how formal rural credit affects farm-level land use and agricultural intensification, we employ a staggered difference-in-differences design that leverages the differential timing of properties entering the formal credit system. We construct a comprehensive panel dataset tracking over two million registered rural properties between 2000 and 2020, merging confidential loan-level disbursements from the Central Bank of Brazil with high-resolution satellite imagery from MapBiomas and interbank payment records. This property-level approach allows us to compare land cover outcomes and input expenditures on treated farms against a control group of not-yet-treated farms at each event time. By observing the exact distribution of pasture, crops, and forest within the boundaries of each farm, we can directly test whether credit access drives agricultural expansion into forested areas or facilitates a shift toward capital-intensive production on existing cleared land. We further substantiate these physical land-use changes by analyzing the near-universe of electronic wire transfers to isolate farm-level spending on capital goods and fertilizers.

3.1 Data Construction

We use confidential data from the Central Bank of Brazil to construct a novel panel dataset that combines formal rural credit, land use, and input purchases at the level of the individual rural property.

First, we obtain information on rural credit from the *Sistema de Operações do Crédito Rural* (SICOR), which records every loan issued from 2012 onwards, and from its predecessor the *Registro Comum de Operações Rurais* (RECOR), which allows us to extend the record back to 2000. Across SICOR and RECOR we observe more than 8 million unique borrowers, each identified by a Brazilian tax code (a CNPJ for firms or a CPF for individuals).To obtain property level information, we exploit the fact that since 2012, farmers are required to register their property in the *Cadastro Ambiental Rural* (CAR) in order to access formal rural credit, so that every loan recorded in SICOR carries the CAR identifier of the property it finances. The CAR is a georeferenced registry established by the 2012 Forest Code that currently covers more than six million properties, provides us with the exact geospatial property boundaries. Since RECOR predates the Forest Code and does not contain information on the underlying properties, we match borrowers within RECOR with their property recorded in SICOR. This allows us to extend the panel back to 2000 by attributing every loan recorded in RECOR to the property or properties operated by the same borrower in SICOR. The resulting mapping links approximately 3.0 million unique borrowers to 2.4 million rural properties. [2]

Second, we match the property boundaries with annual satellite imagery from MapBiomas, which provides land cover classification at a 30×30 meter resolution across the entire Brazilian territory between 2000 and 2024. By overlaying the georeferenced CAR shapes onto the MapBiomas rasters, we recover the area allocated each year to every land use within a given property, including forest formation, pasture, soybeans, and other crops.

Laslty, we use confidential clearing house data from the Brazilian Payment System between 2003 and 2020, which allow us to trace the input purchases made from each borrower account in our dataset which we then aggregate to the property level. The Brazilian Payment System, contains cross-bank electronic transfers of *Transferências Eletrônicas Disponíveis* (TEDs), which are wire transfers used for the majority of payments in Brazil, processed through the *Sistema de Transferência de Reservas* (STR) and the *Sistema de Transferência de Fundos* (SITRAF). From these payments we construct three property-level measures of spending. Total expenditure records all outgoing transfers from a borrower's account in a given year and reflects the overall scale of farm spending. To capture specific production inputs, we further isolate capital and fertilizer expenditure. Capital expenditure groups together purchases of agricultural and construction machinery, vehicles, and electrical equipment, while fertilizer expenditure groups together purchases from producers and wholesalers of fertilizers and other agricultural chemicals. We assign each payment to one of these categories using the CNAE economic activity code of the receiving counterparty (see Appendix Table A.4).

[2]Linking borrowers to properties involves two distinct sources of multiplicity. First, within a single credit operation, multiple borrowers can appear as co-obligors of the same loan. This is especially common in RECOR, where a typical loan identifier is recorded against an average of 11.9 borrowers (up to 358), reflecting how cooperatives and group obligations are stored. In SICOR, by contrast, virtually every loan corresponds to a single borrower. To avoid double-counting disbursements when projecting credit onto properties, we restrict the loan-level data to operations linked to a single borrower. This drops roughly 20% of distinct loans, almost all of them in RECOR. Second, a borrower can operate several properties and a property can be associated with several borrowers. On average, a borrower is linked to 1.4 registered properties and a property to 1.7 borrowers, and roughly 80% of borrower–property pairs are non-unique in at least one direction. We therefore define the credit received by a property in a given year as the average annual credit across the borrowers linked to it, where each borrower's annual credit is the sum of all loans they receive in that year.

Table 1 summarises the Legal Amazon sample by farm size quintile. Farms in the Legal Amazon are overwhelmingly livestock-oriented: pasture is the dominant land use across every size class, taking up between 45% and 69% of registered area, while cropland is a small share of land use in the Legal Amazon and is mostly concentrated on the largest farms. Forest cover rises with farm size, from about 17% in the smallest quintile (Q1) to 34% in the second-largest (Q4), so most Forest in the Legal Amazon is within mid- and large-sized farms. The Legal Amazon frontier is dominated by cattle and Forest, with crop cultivation playing a secondary role.

Access to formal credit and spending on fertilizer and capital inputs both increase with farm size. Only 3–6% of smaller farm-years record any rural credit, compared with 11% for the top quintile, whose average loan is roughly an order of magnitude larger than that of the smallest quintile (Q1). Payments to fertilizer and capital-goods suppliers are also concentrated among large farms, and the top quintile (Q5) spends around 50 to 100 times more on fertilizer and capital than farms in Q1–Q3. The distribution of formal credit and input spending in the Legal Amazon is thus highly skewed toward large properties.

Table 1: Descriptive Statistics by Farm Size Quintiles — Legal Amazon

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Freq.	Forest	Pasture	Crops	P(Credit)	Credit	Credit/ha	P(Payment)	Expend.	Expend./ha	Fertilizer	Capital
Q1 (Smallest)	0.19	0.17	0.69	0.06	0.03	24,636	20,427	0.21	5,273	2,563	799	111
		(0.27)	(0.35)	(0.18)	(0.16)	(302,270)	(905,253)	(0.41)	(370,351)	(401,999)	(45,397)	(8,253)
Q2	0.20	0.25	0.62	0.05	0.05	40,031	1,963	0.27	6,975	363	1,387	164
		(0.29)	(0.33)	(0.15)	(0.21)	(1,821,276)	(91,919)	(0.45)	(1,033,714)	(52,706)	(202,598)	(25,565)
Q3	0.20	0.30	0.60	0.04	0.06	38,190	866	0.30	3,036	70	512	91
		(0.29)	(0.32)	(0.12)	(0.23)	(186,375)	(4,358)	(0.46)	(103,699)	(2,404)	(18,186)	(4,558)
Q4	0.20	0.34	0.54	0.04	0.06	76,147	900	0.29	9,592	108	1,823	277
		(0.30)	(0.31)	(0.15)	(0.24)	(315,153)	(3,569)	(0.45)	(465,489)	(4,804)	(68,958)	(11,053)
Q5 (Largest)	0.20	0.30	0.45	0.09	0.11	432,824	815	0.33	245,134	313	52,791	9,402
		(0.28)	(0.31)	(0.21)	(0.31)	(3,675,721)	(7,394)	(0.47)	(6,389,645)	(7,739)	(1,186,456)	(435,363)
Observations		16,385,191				995,097				4,629,638		
Farms		1,016,196				203,155				275,994		

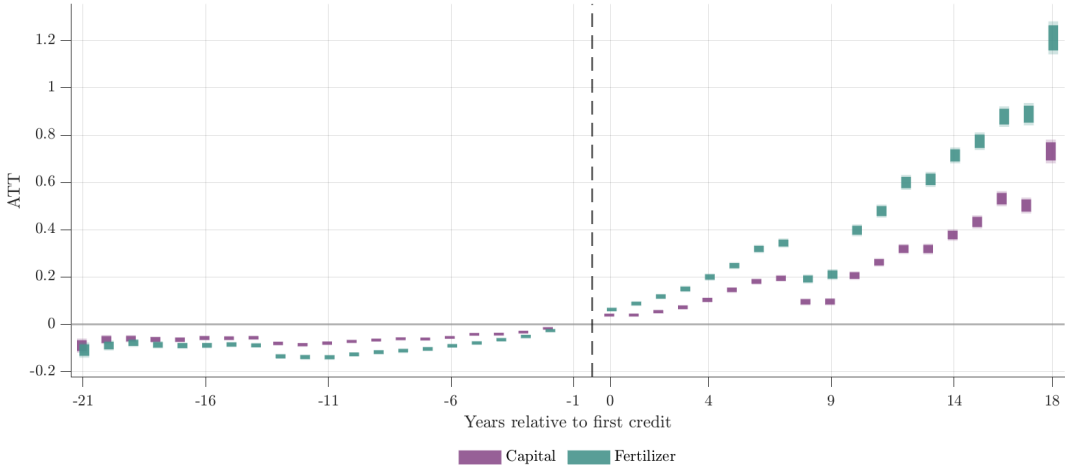
Notes: All statistics computed at the farm-year observation level (2003–2020). Standard deviations in parentheses. Quintiles based on registered farm size (hectares). Land use shares computed as fraction of total property area (Crops exclude Aquaculture). P(Credit) is the share of farm-year observations with positive credit. Credit and Credit/ha are means over farm-year observations where credit was received (real 2003 USD). P(Payment) is the share of farm-year observations where the farm has a link in the payment system. Expenditure, *Fertilizer*, and *Capital* are outgoing farm payments classified by creditor CNAE sector (real 2003 USD); means are taken over farm-year observations with a payment system link (independent of credit receipt).

We also provide summary statistics for different regions including all of Brazil in the Appendix (Tables A.1–A.3). The Amazon Biome is even more forested and pasture-heavy than the Legal Amazon average, with Forest shares of 18 to 39% across quintiles and cropland below 4%. Only 3 to 9% of farms receive rural credit in a given year, the lowest of the three regions. The Cerrado is Brazil's cropland heartland, and consistently we find roughly a quarter of area in crops in every quintile, 4 to 18% of farms receiving rural credit in a given year against 3 to 9% in the Amazon Biome, and per-hectare input spending in the top quintile roughly 4.5 times that of the Amazon Biome, at USD 635 per hectare against USD 140. Nationally, these regional patterns mix, with less Forest and more Crops than the Legal Amazon and 4 to 14% of farms receiving rural credit in a given year, close to the Cerrado.

3.2 Dynamic Effects of Rural Credit on Land Use and Input Spending

We estimate the effect of receiving formal rural credit on land use and input spending using the staggered difference-in-differences estimator of Callaway & Sant'Anna (2021), which identifies group-time average treatment effects on the treated ATT(g,t) for treatment cohort g at calendar year t, and remains valid under heterogeneity across cohorts and event time. We aggregate the ATT(g,t) into dynamic event-time coefficients relative to the year in which a farm first receives credit, so that point estimates represent dynamic effects relative to the reference period (long differences). The comparison group at each event time consists of farms that have not yet received rural credit. All estimates reported here are for the Legal Amazon. Results are consistent for the Amazon Biome and the Cerrado, across farm-size splits, across borrower ownership type, and under an alternative $\log(1+x)$ transformation of payments, all reported in the Appendix.

Figure 1: Staggered Difference-in-Differences: Payment Outcomes — Legal Amazon



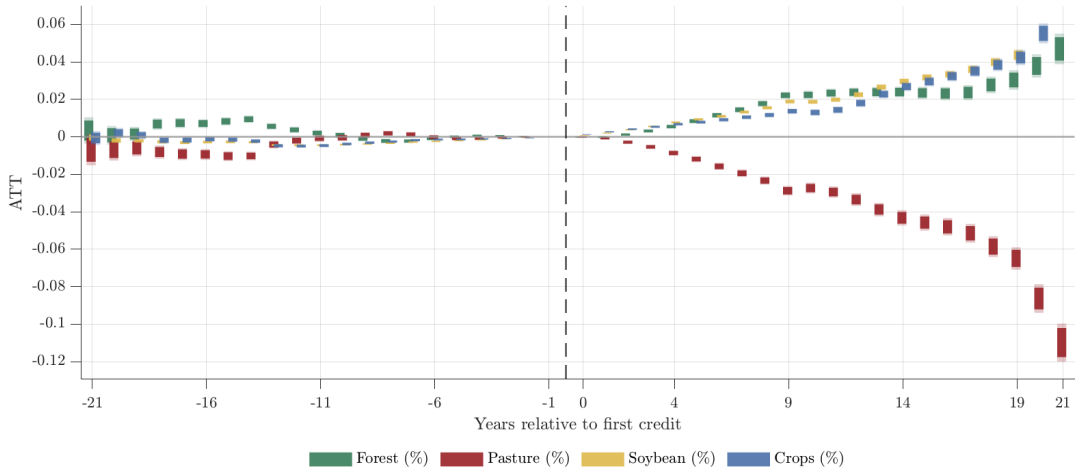
Notes: Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z+\sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure 1 shows the dynamic ATT estimates for *Capital* and *Fertilizer*, both transformed by the inverse hyperbolic sine $\sinh^{-1}(z) = \ln\left(z+\sqrt{z^2+1}\right)$ (Chen & Roth 2024). *Capital* captures durable investment goods such as tractors, harvesters, and silos, while *Fertilizer* captures the variable inputs a farmer buys each planting season, fertilizers, agrochemicals, and seeds. Rural credit in Brazil is designed to finance *Capital* and *Fertilizer* directly, through working-capital lines (*custeio*) for fertilizers and agrochemicals and investment lines (*investimento*) for machinery, so a positive treatment effect on both outcomes reflects the design of the programme itself. We document that receiving credit raises input spending persistently, for close to two decades. Pre-treatment coefficients are essentially flat and centred on zero, consistent with parallel trends between treated and not-yet-treated farms.

Post-treatment effects jump immediately after credit access and continue to grow, with a farm's first receipt of credit still raising its input spending eighteen years later, as far as our panel allows us to look. By year +10 the *Fertilizer* response reaches about 40% relative to the not-yet-treated control mean and averages roughly 54% over the full post-treatment horizon, while the *Capital* response reaches about 20% at year +10 and averages roughly 31%. *Fertilizer* thus responds considerably more strongly than *Capital*, consistent with credit relaxing a working-capital constraint that binds most tightly on recurrent per-season inputs rather than on lumpier machinery.

Figure 2 shows the corresponding dynamic ATT estimates for land use shares. Pre-treatment coefficients are again essentially flat, supporting the parallel trends assumption. After receiving credit, treated farms reallocate area away from land-intensive pasture and towards more capital-intensive crops. Pasture share falls persistently by about 3 to 3.5 percentage points on average, Soybean share rises by about 2 percentage points, and Crops share rises by about 1 to 2 percentage points. Forest share on treated farms rises by roughly +2 percentage points by year +10 relative to not-yet-treated controls. The same broad pattern holds in the Amazon Biome and the Cerrado (Figures A.1–A.3).

Figure 2: Staggered Difference-in-Differences: Land Use — Legal Amazon



Notes: Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1+\text{Capital})$ and $\log(1+\text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

We report an extensive battery of checks and heterogeneity cuts in the Appendix. Full baseline dynamic ATT estimates cover land use and, as an alternative to the main-text $\sinh^{-1}$ transformation, $\log(1+\text{Capital})$ and $\log(1+\text{Fertilizer})$ payments for the Amazon Biome, Legal Amazon, and Cerrado (Figures A.1–A.3). We split the sample by farm size, above and below four fiscal modules (Figures A.4–A.9). We further split by borrower ownership type, individual against firm (Figures A.10–

A.12). Descriptive statistics for the full sample, the Amazon Biome, and the Cerrado appear separately (Tables A.1–A.3). We extend the main-text $\sinh^{-1}$ payment specification to the Amazon Biome and Cerrado and to the farm-size splits (Figures A.13–A.20).

4 The Model

Environment. Time is continuous, $t \geq 0$. The economy is populated by a continuum of infinitely-lived heterogeneous individuals of measure one, who can choose at any instant to be either workers or farmers. There is a single non-agricultural good, which serves as the numeraire. This good can be used for consumption, investment or land intensification and is produced competitively. There are two agricultural goods: crops, c, and pasture, p. Farmers are heterogeneous in sector-specific productivities, $\mathbf{z}_t = (z_{c,t}, z_{p,t})$, where $z_{i,t} \geq 1$ for $i \in \{c, p\}$. Productivities are redrawn at Poisson rate γ_z. When a redraw occurs, the new vector $\mathbf{z}'$ is drawn from a Pareto invariant distribution $\Gamma(\mathbf{z})$, independently of the past. The joint distribution Γ has finite first moments. Each individual is endowed with a fixed plot of land of size $s > 0$, whose distribution is exogenous and fixed over time. Forest cover is $f_t \in [0, s]$, and land available for agricultural use is

$$\tilde{l}_t = s - f_t.$$

Total land s is fixed, but forest cover evolves endogenously through deforestation and reforestation. In addition, there is a competitive land rental market that allows farmers to adjust the operational scale of their farms relative to their land endowment. Individuals also differ in asset holdings $a_t \geq 0$. Workers have identical labor productivity, normalized to one, and supply labor inelastically.

Preferences. Individuals have flow utility over consumption of agricultural goods $(c_{c,t}, c_{p,t})$ and the non-agricultural good $c_{n,t}$:

$$u(c_{c,t}, c_{p,t}, c_{n,t}) = \sigma_c \log c_{c,t} + \sigma_p \log c_{p,t} + (1 - \sigma_c - \sigma_p) \log c_{n,t},$$

where $\sigma_c > 0$, $\sigma_p > 0$, and $\sigma_c + \sigma_p < 1$. Lifetime utility is

$$\mathbb{E}_0 \int_0^\infty e^{-\rho t} u(c_{c,t}, c_{p,t}, c_{n,t})\, dt,$$

where $\rho > 0$ is the continuous-time discount rate.

The non-agricultural sector. The non-agricultural good $Y_{n,t}$ is produced by a representative firm, which uses capital $K_{n,t}$ and labor $N_{n,t}$, with the following constant returns to scale technology:

$$Y_{n,t} = A_n K_{n,t}^{\alpha_n} N_{n,t}^{1-\alpha_n}, \qquad A_n > 0, \quad \alpha_n \in (0, 1).$$

The representative firm chooses $K_{n,t}$ and $N_{n,t}$ to maximize profits, implying that

$$r_t = \alpha_n \frac{Y_{n,t}}{K_{n,t}} - \delta, \qquad w_t = (1 - \alpha_n) \frac{Y_{n,t}}{N_{n,t}},$$

where r_t is the risk-free return, w_t is the wage, and δ is the depreciation rate of the capital stock.

Agricultural technology. A farmer producing good $i \in \{c, p\}$, with productivity z_{it}, uses capital services k_{it}, labor n_{it}, and land l_{it}, and chooses an intensification level $v_i \geq 1$. Output is

$$y_{it} = z_{it}^{1-\psi_i} \left(\min\{k_{it}, \theta_i v_{it} l_{it}\}^{\alpha_i} n_{it}^{1-\alpha_i}\right)^{\psi_i}, \qquad \alpha_i, \psi_i \in (0,1), \quad \theta_i > 0, \tag{1}$$

The variable $v_{it} \geq 1$ captures agricultural intensification through the use of variable inputs, such as fertilizers and pesticides. A higher v_{it} raises effective land, $\theta_i v_{it} l_{it}$, and therefore reduces the land required to support a given level of capital services. Intensification is thus modeled as land augmenting, with flow cost

$$\Phi_i(v_{it}) = \phi_i \mathbf{1}\{v_{it} > 1\} + (v_{it} - 1)^{\xi_i}, \qquad v_i \geq 1, \quad \xi_i > 1, \quad \phi_i > 0.$$

Here, ϕ_i is the fixed flow cost of operating above the baseline intensification level, while $(v_{it} - 1)^{\xi_i}$ captures convex variable expenditure. Since $\Phi_i(1) = 0$, the baseline choice $v_{it} = 1$ entails no additional intensification cost.

Forest dynamics. Deforestation and reforestation are control variables. Let $d_t \geq 0$ denote the deforestation flow and $m_t \geq 0$ denote the reforestation flow. Their flow costs are

$$C^d(d_t, f_t) = \left[\zeta_{d,0} + \zeta_{d,1}\left(1 - \frac{f_t}{s}\right)\right] d_t + \frac{\zeta_{d,2}}{2}\frac{d_t^2}{s}, \tag{2}$$

and

$$C^r(m_t, f_t) = \left[\zeta_{r,0} + \zeta_{r,1}\left(1 - \frac{f_t}{s}\right)\right] m_t + \frac{\zeta_{r,2}}{2}\frac{m_t^2}{s}. \tag{3}$$

We assume $\zeta_{d,0}, \zeta_{r,0} \geq 0$ and $\zeta_{d,1}, \zeta_{r,1}, \zeta_{d,2}, \zeta_{r,2} > 0$. These cost functions capture two features. First, adjustment is convex in the flow of land conversion, reflecting increasing marginal costs of large-scale deforestation or reforestation within a period. Second, marginal costs depend on the current forest share f_t/s. When forest cover is abundant, deforestation is relatively cheap because the most accessible and productive areas are cleared first; as forest becomes scarce, further deforestation becomes increasingly costly. Conversely, reforestation is more costly in highly degraded environments, where soil quality, seed availability, and natural regeneration are limited. Between idiosyncratic forest shocks, forest cover evolves according to

$$\dot{f}_t = m_t - d_t, \qquad f_t \in [0, s]. \tag{4}$$

In addition to endogenous forest adjustment through deforestation and reforestation, forest cover is also affected by exogenous shocks. These shocks capture unintended changes in forest cover arising from events such as fires, extreme weather, pests, or natural regeneration. More specifically, at Poisson rate γ_f, forest cover receives an idiosyncratic shock εs, where $\varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}]$. After a shock,

$$f_t^+ = \mathbf{f}_{[0,s]}(f_t + \varepsilon s) \equiv \min\{s, \max\{0, f_t + \varepsilon s\}\}.$$

Forest cover follows a jump-drift process: between shocks it evolves according to (4), and at Poisson arrival times it jumps to f_t^+. Setting $\gamma_f = 0$ eliminates the exogenous forest shocks, while $\gamma_f > 0$ allows these shocks to generate cross-sectional dispersion in forest cover.

The Forest Code. The Forest Code represents an enforcement mechanism to preserve the environment. Let $\beta_t = f_t/s$ denote the forest share of plot s. A plot complies with the Forest Code if $\beta_t \geq \bar{\beta}$, where $\bar{\beta} \in [0,1]$. If the plot does not comply, its owner pays the flow penalty

$$\zeta_e(\bar{\beta}s - f_t)\mathbf{1}\{f_t < \bar{\beta}s\}, \qquad \zeta_e \geq 0.$$

This penalty applies to the owner of the land, regardless of whether the owner operates as a farmer or works in the non-agricultural sector. A producing farm is compliant only if the farmer's own plot complies and any land rented in comes from compliant plots. A non-compliant producing farm also faces a proportional penalty and retains the fraction $1 - \zeta_e^y$ of its gross output revenue, where $0 \leq \zeta_e^y < 1$. Since rented land may or may not comply with the Forest Code, there are two land rental markets: one for compliant land, with rental price q_t^C, and one for non-compliant land, with rental price q_t^{NC}. Both penalties are monetary fines denominated in the non-agricultural good. All fine revenue finances government consumption of that good.

Financial intermediation. A continuum of financial intermediaries with unit mass offers agents the option of depositing assets at the competitive interest rate r_t or borrowing to finance capital and intensification expenditures. Borrowing by farmers is subject to a spread $\tau \geq 0$ and to financial frictions arising from imperfect enforcement in credit markets, which give rise to a collateral constraint with leverage parameter $\lambda \geq 1$. The spread covers real intermediation costs in units of the non-agricultural good, so financial intermediaries make zero profits. In the benchmark, financing costs and leverage constraints are the same for compliant and non-compliant farms. In the counterfactual analysis, we will consider credit policies conditional on compliance with the Forest Code. The prefinancing period for flow inputs is normalized to one unit of time. Prepaid intensification expenditures therefore constitute working capital and are included in aggregate asset holdings. Farmers face a collateral constraint that limits total capital and prepaid land intensification expenditures to a multiple of their own assets:

$$k_{it} + \Phi_i(v_{it}) \leq \lambda a_t. \tag{5}$$

When $v_{it} = 1$, the constraint reduces to $k_{it} \leq \lambda a_t$, which is similar to the leverage constraint used by Moll (2014).

Static Farm Problem. From now on, to simplify notation, we omit the time index t. Given the environment, farmers make several decisions in each instant in time. Let $\tilde{p}_i$ denote the price of agricultural good $i \in \{c, p\}$. A farmer can operate either as a compliant farm or as a non-compliant farm, denoted by $j \in \{C, NC\}$. If $j = C$, the farmer uses land that complies with the Forest Code and faces the rental price q^C. If $j = NC$, the farmer uses land that does not comply with the Forest Code and faces the rental price q^{NC}. A non-compliant operation faces an output penalty, so that $p_i^C = \tilde{p}_i$ and $p_i^{NC} = (1 - \zeta_e^y)\tilde{p}_i$.

Operational land is denoted by $l_i^j \geq 0$ and may differ from the farmer's agricultural land endowment $\tilde{l} = s - f$. Let $\beta = f/s$. Rental income from the farmer's own plot depends on its compliance with the Forest Code, while the rental cost of operated land depends on the compliance status of the

producing farm. The flow-profit problem is

$$\begin{aligned}\pi_i^j(a,\mathbf{z},s,f) = \max_{k_i,v_i,n_i,l_i^j} \Big\{ & p_i^j y_i - w n_i - q^j l_i^j - (r+\delta)k_i - (1+r)\Phi_i(v_i) \\ & - \tau \max\{k_i + \Phi_i(v_i) - a, 0\} \\ & + \left[q^C \mathbf{1}\{\beta \geq \bar{\beta}\} + q^{NC}\mathbf{1}\{\beta < \bar{\beta}\}\right] \tilde{l} \Big\},\end{aligned} \tag{6}$$

subject to (1), (5), $l_i^j \geq 0$, and $v_i \geq 1$. In any optimum with positive production,

$$k_i = \theta_i v_i l_i^j.$$

Recall that a producing farm is compliant only if the farmer's own plot complies and any land rented in comes from compliant plots. When $q^{NC} < q^C$, a farmer with a compliant plot could rent in land at rate q^{NC} and rent out its own agricultural land at rate q^C. The producing farm would then be considered non-compliant, while rental income from the farmer's own plot would continue to be valued at q^C. Let $\mathbf{1}_{b,i} = \mathbf{1}\{k_i + \Phi_i(v_i) > a\}$. When $k_i + \Phi_i(v_i) > a$, the farmer borrows the amount $k_i + \Phi_i(v_i) - a$. Since internal funds are fungible across capital and intensification expenditures, only total external finance matters for costs. The objective can therefore be written equivalently as if the spread applies to both k_i and $\Phi_i(v_i)$, with the term $\tau \mathbf{1}_{b,i} a$ offsetting the portion financed with internal funds. Using $k_i = \theta_i v_i l_i^j$, the farmer's problem can be written as choosing $\{k_i, v_i, n_i\}$ to maximize

$$\begin{aligned}\pi_i^j = p_i^j z_i^{1-\psi_i} k_i^{\alpha_i\psi_i} n_i^{(1-\alpha_i)\psi_i} - \left[(r+\delta+\tau\mathbf{1}_{b,i}) + \frac{q^j}{\theta_i v_i}\right] k_i \\ - (1+r+\tau\mathbf{1}_{b,i})\Phi_i(v_i) - w n_i + \left[q^C\mathbf{1}\{\beta \geq \bar{\beta}\} + q^{NC}\mathbf{1}\{\beta < \bar{\beta}\}\right]\tilde{l} + \tau\mathbf{1}_{b,i} a.\end{aligned}$$

For a given v_i, define the effective unit cost of capital-land services:

$$\tilde{r}_i^j(v_i; r, q^j, \tau, \mathbf{1}_{b,i}) = (r+\delta+\tau\mathbf{1}_{b,i}) + \frac{q^j}{\theta_i v_i}. \tag{7}$$

When the expenditure constraint is slack and the borrowing status is locally fixed, optimal capital and labor demands are

$$k_i^j(v_i) = z_i \left[\psi_i p_i^j \left(\frac{1-\alpha_i}{w}\right)^{(1-\alpha_i)\psi_i} \left(\frac{\alpha_i}{\tilde{r}_i^j(v_i; r, q^j, \tau, \mathbf{1}_{b,i})}\right)^{1-(1-\alpha_i)\psi_i}\right]^{\frac{1}{1-\psi_i}},$$

$$n_i^j(v_i) = \frac{1-\alpha_i}{\alpha_i}\frac{\tilde{r}_i^j(v_i; r, q^j, \tau, \mathbf{1}_{b,i})}{w} k_i^j(v_i), \qquad l_i^j(v_i) = \frac{k_i^j(v_i)}{\theta_i v_i}.$$

Output and flow profits are

$$y_i^j(v_i) = z_i^{1-\psi_i}\left(k_i^j(v_i)\right)^{\alpha_i\psi_i}\left(n_i^j(v_i)\right)^{(1-\alpha_i)\psi_i},$$

$$\begin{aligned}\pi_i^j(v_i) = (1-\psi_i)p_i^j y_i^j(v_i) - (1+r+\tau\mathbf{1}_{b,i})\Phi_i(v_i) + \tau\mathbf{1}_{b,i} a \\ + \left[q^C\mathbf{1}\{\beta \geq \bar{\beta}\} + q^{NC}\mathbf{1}\{\beta < \bar{\beta}\}\right]\tilde{l}.\end{aligned}$$

When the expenditure constraint is slack and borrowing status is locally fixed, an interior intensification choice $v_i > 1$ satisfies

$$\frac{q^j}{\theta_i v_i^2} k_i^j(v_i) = (1+r+\tau\mathbf{1}_{b,i})\xi_i(v_i - 1)^{\xi_i - 1}. \tag{8}$$

The fixed flow cost ϕ_i does not enter this interior first-order condition, but affects profits and financing requirements. The farmer compares maximized profits from feasible choices $v_i > 1$, including the fixed flow cost, with maximized profits at $v_i = 1$. Consequently, the baseline choice $v_i = 1$ may be optimal.

Before turning to occupational choice, it is useful to establish that the intensification problem is well behaved. With a fixed flow cost, the farmer compares the baseline choice $v_i = 1$ with intensification choices $v_i > 1$. The next proposition combines the existence and conditional uniqueness results for the cases in which the expenditure constraint is slack and in which it binds. The algebra is reported in Appendix D.

Proposition 1 (Existence and conditional uniqueness of optimal intensification)**.** *Fix sector $i \in \{c, p\}$ and compliance status $j \in \{C, NC\}$. Maintain positive input and financing costs, with $q^j > 0$.*

1. *Consider farmers with positive production for whom the expenditure constraint is slack and borrowing status $\mathbf{1}_{b,i} \in \{0, 1\}$ is locally fixed, with $k_i + \Phi_i(v_i) \neq a$. On the smooth adopting branch $v_i > 1$, the interior first-order condition has at least one solution. Such a solution is a candidate only if it satisfies the expenditure constraint and the assumed borrowing status. There is at most one such solution if*

$$\left(\frac{\alpha_i \psi_i}{1 - \psi_i} - 1\right) q^j \leq 2(r + \delta + \tau \mathbf{1}_{b,i})\theta_i.$$

   In particular, a sufficient condition for uniqueness is

$$\psi_i(1 + \alpha_i) \leq 1.$$

   The baseline choice $v_i = 1$ remains a candidate and must be compared with feasible adopting choices, including candidates at financing boundaries.

2. *Consider farmers for whom expenditure is at a financing boundary, so that*

$$k_i + \Phi_i(v_i) = \chi a,$$

   where $\chi = 1$ at the self-financing boundary and $\chi = \lambda$ at the collateral boundary. For $\chi a \geq 0$, an optimal intensification choice on this boundary exists. If $\chi a \leq \phi_i$, the only feasible choice is $v_i = 1$. If $\chi a > \phi_i$, the optimal choice conditional on adoption is unique and has positive capital. This choice must be compared with $v_i = 1$. The choice between adoption and the baseline is unique unless the two yield the same profit.

If expenditure is at a financing boundary, write

$$k_i + \Phi_i(v_i) = \chi a,$$

where $\chi = 1$ at the self-financing boundary and $\chi = \lambda$ at the collateral boundary. Then

$$k_i^{\chi,j}(v_i) = \chi a - \Phi_i(v_i), \qquad l_i^{\chi,j}(v_i) = \frac{\chi a - \Phi_i(v_i)}{\theta_i v_i}.$$

For a given v_i, labor demand is

$$n_i^{\chi,j}(v_i) = \left[(1-\alpha_i)\psi_i\, p_i^j z_i^{1-\psi_i} \left(\chi a - \Phi_i(v_i)\right)^{\alpha_i\psi_i} \frac{1}{w}\right]^{\frac{1}{1-(1-\alpha_i)\psi_i}},$$

and profits are

$$\begin{aligned}\pi_i^{\chi,j}(v_i) = {} & \left[1-(1-\alpha_i)\psi_i\right] p_i^j y_i^{\chi,j}(v_i) - (r+\delta)\left(\chi a - \Phi_i(v_i)\right) \\ & - \frac{q^j}{\theta_i v_i}\left(\chi a - \Phi_i(v_i)\right) - (1+r)\Phi_i(v_i) - \tau(\chi-1)a \\ & + \left[q^C \mathbf{1}\{\beta \geq \bar{\beta}\} + q^{NC}\mathbf{1}\{\beta < \bar{\beta}\}\right]\bar{l}.\end{aligned}$$

The farmer chooses $v_i \geq 1$, subject to $\Phi_i(v_i) \leq \chi a$, to maximize $\pi_i^{\chi,j}(v_i)$, comparing the baseline choice with feasible choices above the baseline.

All feasible candidates across financing regimes, including the baseline $v_i = 1$, are compared, and the farmer chooses the one yielding the highest profit.

Proposition 2 (Comparative statics of intensification)**.** *Fix sector $i \in \{c, p\}$ and compliance status $j \in \{C, NC\}$. Suppose the relevant intensification choice $v_i > 1$ is interior and locally unique, as characterized in Proposition 1, satisfies the strict second-order condition, and is strictly preferred to the baseline $v_i = 1$. The following comparative statics are local, holding other parameters and prices fixed, and apply while the adopting choice remains optimal and the financing regime is unchanged.*

1. *If the expenditure constraint is slack and borrowing status $\mathbf{1}_{b,i}$ is locally fixed, intensification decreases with the financing cost $r + \tau\mathbf{1}_{b,i}$, decreases with the wage w, increases with the effective output price p_i^j, and is independent of assets a and borrowing capacity λ. The effect of the land rental price q^j is ambiguous.*

2. *If the expenditure constraint binds, so that $k_i + \Phi_i(v_i) = \chi a$, intensification increases with q^j, increases with w, decreases with p_i^j, increases with assets a, and increases with χ. Conditional on χa, intensification does not depend on r or τ.*

The proof is in Appendix D.1. The proposition shows that financial frictions affect intensification through different channels depending on whether the expenditure constraint binds. With slack expenditure, higher financing costs reduce intensification directly. With a binding expenditure constraint, financing costs affect profits but not the allocation of the fixed expenditure budget between capital services and intensification, conditional on χa. The fixed flow cost can also generate discrete changes in adoption, which are not described by these local comparative statics.

Proposition 3 (Intensification adoption and operated land)**.** *Fix sector $i \in \{c, p\}$, compliance status $j \in \{C, NC\}$, and assets $a > 0$, holding other states and prices fixed.*

1. *At the same binding expenditure boundary*

$$k_i + \Phi_i(v_i) = \chi a > \phi_i,$$

any feasible intensification choice $v_i > 1$ uses less operated land than the baseline choice $v_i = 1$:

$$l_i^{\chi,j}(v_i) < l_i^{\chi,j}(1).$$

2. *Suppose the farmer initially chooses $v_i = 1$ at the self-financing boundary $\chi = 1$, and after an improvement in credit conditions chooses $v_i > 1$ with the collateral constraint binding, $\chi = \lambda > 1$. Operated land falls if and only if*

$$(\lambda - 1)a < \Phi_i(v_i) + (v_i - 1)a.$$

The proof is in Appendix D.2. At a fixed expenditure budget, intensification reduces operated land. When credit expands that budget, the land-saving effect must outweigh the expansion in financing capacity. The result concerns operated land; its implications for forest cover depend on land rental and forest-adjustment decisions.

Occupational Choice. At each instant, the individual chooses the occupation with the highest flow income. Let $\beta = f/s$. If the plot complies with the Forest Code, the individual may operate a compliant farm, operate a non-compliant farm, or work. If the plot does not comply, the individual may operate only a non-compliant farm or work. Flow income is

$$\begin{aligned} I(a, \mathbf{z}, s, f) = {} & \mathbf{1}\{\beta \geq \bar{\beta}\} \max\left\{ \max_{i \in \{c,p\}} \pi_i^C(a, \mathbf{z}, s, f),\ \max_{i \in \{c,p\}} \pi_i^{NC}(a, \mathbf{z}, s, f),\ w + q^C(s - f) \right\} \\ & + \mathbf{1}\{\beta < \bar{\beta}\} \max\left\{ \max_{i \in \{c,p\}} \pi_i^{NC}(a, \mathbf{z}, s, f),\ w + q^{NC}(s - f) \right\} \\ & - \mathbf{1}\{\beta < \bar{\beta}\} \zeta_e(\bar{\beta} s - f). \end{aligned}$$

The associated policy indicators are $o_i^C(a, \mathbf{z}, s, f)$, $o_i^{NC}(a, \mathbf{z}, s, f)$, and $o^W(a, \mathbf{z}, s, f)$.

Dynamic Problem. Given flow income $I(a, \mathbf{z}, s, f)$, individuals choose consumption, savings, deforestation, and reforestation. The asset law of motion is

$$\dot{a} = I(a, \mathbf{z}, s, f) + ra - c_n - \tilde{p}_c c_c - \tilde{p}_p c_p - C^d(d, f) - C^r(m, f), \tag{9}$$

and the controlled forest drift is

$$\dot{f} = m - d, \qquad f \in [0, s],$$

with the Poisson forest shocks described above. Let $V(a, \mathbf{z}, s, f)$ denote the stationary value function. The Hamilton-Jacobi-Bellman equation is

$$\begin{aligned} \rho V(a, \mathbf{z}, s, f) = \max_{c_c, c_p, c_n, d, m} \Big\{ & u(c_c, c_p, c_n) + V_a(a, \mathbf{z}, s, f)\dot{a} + V_f(a, \mathbf{z}, s, f)(m - d) \\ & + \gamma_z \left[\int V(a, \mathbf{z}', s, f)\, \Gamma(d\mathbf{z}') - V(a, \mathbf{z}, s, f) \right] \\ & + \gamma_f \left[\mathbb{E}_\varepsilon V\Big(a, \mathbf{z}, s, \mathbf{f}_{[0,s]}(f + \varepsilon s)\Big) - V(a, \mathbf{z}, s, f) \right] \Big\}, \end{aligned} \tag{10}$$

subject to $c_c, c_p, c_n > 0$, $d \geq 0$, $m \geq 0$, and the state constraints $a \geq 0$ and $f \in [0, s]$. At the state boundaries, admissible choices satisfy

$$\dot{a} \geq 0 \quad \text{if } a = 0, \qquad m - d \geq 0 \quad \text{if } f = 0, \qquad m - d \leq 0 \quad \text{if } f = s.$$

We assume $w > 0$, $q^C, q^{NC} \geq 0$, and

$$w + q^{NC}s - \zeta_e \bar{\beta} s > 0$$

for every plot size in the population. These conditions ensure that working provides strictly positive income at every forest state.

The first-order conditions associated with the HJB are reported in Appendix D.3.

Proposition 4 (Forest adjustment in continuous time)**.** *Suppose V is differentiable in a and f, and suppose the state constraints on a and f are locally non-binding. Then optimal deforestation d and reforestation m satisfy*

$$V_a \left[\zeta_{d,0} + \zeta_{d,1} \left(1 - \frac{f}{s} \right) + \zeta_{d,2} \frac{d}{s} \right] + V_f \geq 0,$$

with equality if $d > 0$, and

$$V_a \left[\zeta_{r,0} + \zeta_{r,1} \left(1 - \frac{f}{s} \right) + \zeta_{r,2} \frac{m}{s} \right] - V_f \geq 0,$$

with equality if $m > 0$.

Deforestation is attractive when the asset value of the converted land exceeds the marginal cost of clearing. Reforestation is attractive when the marginal value of forest cover exceeds the marginal resource cost of restoring land.

Stationary Equilibrium. At each instant, individuals differ in their assets a, productivity vector $\mathbf{z} = (z_c, z_p)$, plot size s, and forest cover f. Let $G(a, \mathbf{z}, s, f)$ denote the stationary distribution of these states, and let $(\tilde{p}_c, \tilde{p}_p, r, w, q^C, q^{NC})$ denote the equilibrium prices. The marginal distribution of plot sizes in G is the exogenous distribution of land endowments. We normalize

$$\int G(da, d\mathbf{z}, ds, df) = 1,$$

and restrict attention to stationary equilibria with finite aggregate assets, production, and input demands.

Given prices, firms in the non-agricultural sector maximize profits, and individuals solve the static farm problem, the occupational choice problem, and the dynamic problem summarized by the HJB in (10). The resulting policy functions determine production, input demands, occupational choices, consumption, savings, deforestation, and reforestation. Market clearing conditions are standard and are reported in Appendix E.

In equilibrium, aggregate forest cover is consistent with individual forest holdings:

$$F = \int f \, G(da, d\mathbf{z}, ds, df).$$

Thus the HJB depends on the stationary distribution through equilibrium prices. In stationarity, the distribution G is invariant under the optimal policies and the Poisson transition processes for productivity and forest cover. Let $g(a, \mathbf{z}, s, f)$ denote the generalized density representing G, allowing for point masses at state boundaries and at the compliance threshold $f = \bar{\beta} s$. The stationary

Kolmogorov forward equation is interpreted in the distributional sense, with κ_f including the point masses induced by clipping at $f = 0$ and $f = s$:

$$\begin{aligned} 0 = & -\frac{\partial}{\partial a}\left[\dot{a}(a,\mathbf{z},s,f)g(a,\mathbf{z},s,f)\right] \\ & -\frac{\partial}{\partial f}\left[\big(m(a,\mathbf{z},s,f)-d(a,\mathbf{z},s,f)\big)g(a,\mathbf{z},s,f)\right] \\ & -\gamma_z g(a,\mathbf{z},s,f)+\gamma_z\Gamma(\mathbf{z})\int g(a,\tilde{\mathbf{z}},s,f)\,d\tilde{\mathbf{z}} \\ & -\gamma_f g(a,\mathbf{z},s,f)+\gamma_f\int \kappa_f(f\mid\tilde{f},s)g(a,\mathbf{z},s,\tilde{f})\,d\tilde{f}. \end{aligned} \tag{11}$$

The first two terms capture the deterministic drift in assets and forest cover induced by optimal savings, deforestation, and reforestation. The next two terms capture productivity redraws. The last two terms capture idiosyncratic forest shocks, where $\kappa_f(f \mid \tilde{f}, s)$ is the transition kernel induced by

$$f = \mathbf{f}_{[0,s]}(\tilde{f} + \varepsilon s), \qquad \varepsilon \sim U[\underline{\varepsilon}, \bar{\varepsilon}].$$

If $\gamma_f = 0$, the forest-shock terms drop out.

5 Calibration

We calibrate the model to the Brazilian Legal Amazon in 2017, combining granular data from CAR, MapBiomas, and the Agricultural Census with aggregate statistics from official household surveys and regional accounts. Specifically, we discipline the parameter space through external and internal calibration, choosing internally calibrated parameters jointly such that model-implied moments match their empirical counterparts. Importantly, we interpret CAR property boundaries as reflecting the equilibrium allocation of land after rental decisions, so we treat the model counterpart of observed property area as forest plus operated agricultural land ($f + l$). For the equilibrium prices, we take r, $\tilde{p}_c$, and $\tilde{p}_p$ as given, while land prices q^C and q^{NC} clear the compliant and noncompliant land markets, respectively. The nonagricultural firm's first order conditions then determines the equilibrium wage w. Tables A.5 and A.6 summarize the externally and internally calibrated parameters.

Preferences and the nonagricultural sector. With logarithmic utility, σ_c and σ_p correspond to expenditure shares. We therefore use the Brazilian Household Budget Survey (POF) for 2017–18 to measure spending on food from crops and animal products as shares of total household expenditure. We calculate both shares from mean monthly monetary and nonmonetary expenditure for Brazil across all income classes. Specifically, crop expenditure includes cereals, legumes and oilseeds, flours and pasta, roots and tubers, sugars, vegetables, fruits, breads, and oils and fats, while animal expenditure includes meat, offal and fish, poultry and eggs, and milk and dairy. The resulting shares are $\sigma_c = 0.034$ and $\sigma_p = 0.037$.

To discipline nonagricultural productivity A_n, we target the agricultural employment share in the Legal Amazon using the 2017 Continuous National Household Sample Survey (PNAD Contínua).[3]

[3] Agricultural employment covers agriculture, livestock, forestry, fishing, and aquaculture among persons aged 14 or older employed in the reference week. The model counterpart includes farmers and hired agricultural workers.

Similarly, we discipline $\tilde{p}_c$ using total agricultural gross value added as a share of total GDP in the Legal Amazon, aggregating both measures across municipalities from the 2017 municipal GDP accounts (PIB dos Municípios). Finally, we set $r = 0.02$, $\alpha_n = 0.40$, and $\delta = 0.08$, following Cavalcanti, Kaboski, Martins and Santos (2021), Gomes, Pessoa and Veloso (2003), and Restuccia and Rogerson (2008), respectively and choose the discount rate ρ to target an aggregate capital to output ratio of 2.25.

Agricultural technology. We use the 2017 Agricultural Census to discipline the production parameters α_c, α_p, ψ_c, and ψ_p, the mechanization cost parameters ξ_c and ξ_p, and the pasture output price $\tilde{p}_p$. The Census reports production and expenditure by state and main economic activity. Here, we classify establishments whose main activity is temporary or permanent crop production as crop farms and establishments primarily engaged in livestock and other animal production as pasture farms. For each group, we measure value added as production net of intermediate expenditure, capital expenditure (purchases of machinery and vehicles), and labor expenditure (wages paid).[4] First, we set $\alpha_c = 0.434$ and $\alpha_p = 0.229$ to the respective shares of capital expenditure in total expenditure on capital and labor.

Second, to discipline ψ_c, ψ_p, ξ_c, ξ_p, and $\tilde{p}_p$, we target the share of agricultural value added generated by crop farms and total expenditure on capital and labor relative to value added, separately for crop and pasture farms. We also target capital expenditure per hectare on crop farms relative to pasture farms and expenditure on rented land as a share of agricultural value added.[5]

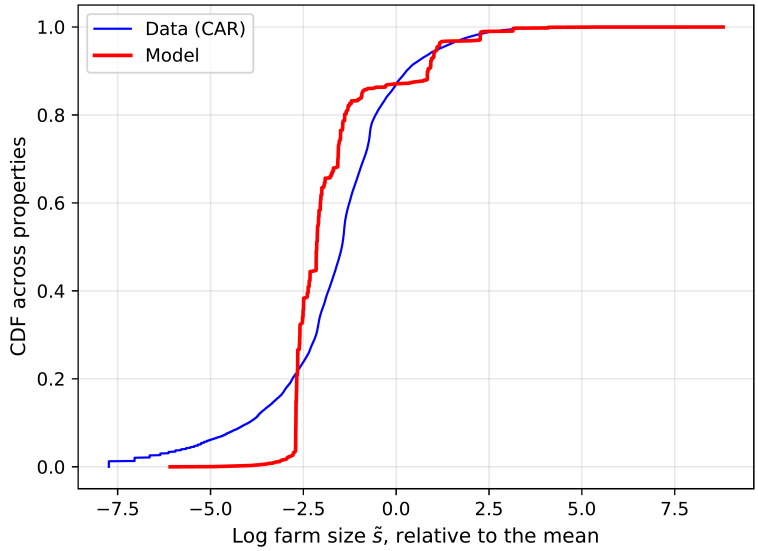
Lastly, we discipline the land efficiency parameters θ_c and θ_p by targeting the share of total property area allocated to crops and pasture, respectively. We measure both shares using MapBiomas Collection 10 land cover maps for 2017 within CAR property boundaries.[6] Here, we weight properties by area in both the data and the model, such that each property contributes to the targeted shares in proportion to its land area.

[4] Intermediate expenditure includes fertilisers and soil correctives, pesticides, seeds and seedlings, salt, feed and supplements, fuel, veterinary medicine, contracted services, transport of production, and electricity.

[5] We measure crop area as land allocated to permanent and temporary crops and flowers, and pasture area as land allocated to natural and planted pasture. Expenditure on rented land corresponds to reported payments for land leases, aggregated across all agricultural establishments, with value added measured across the same establishments.

[6] Crop area includes land classified as soybean, sugarcane, rice, cotton, coffee, citrus, palm oil, other temporary crops, and other perennial crops. Pasture area corresponds to the pasture class. We measure total property area from all pixels within the CAR boundary and use forest plus operated agricultural land, $f + l$, as the model counterpart.

Figure 3: Distribution of Property Area, Model and Data



Notes: The figure plots the cumulative distribution of property area $\tilde{s} = f + l$ across properties, in the data and in the model. The horizontal axis is the logarithm of property area relative to its mean, and the vertical axis is the cumulative share of properties. The data are 941,476 Legal Amazon properties in 2017 with at least 5% of their area in crops or pasture, each counted once.

Plot size and productivity. We assume a lognormal distribution of initial plot size endowments, $\log s \sim \mathcal{N}(-\frac{1}{2}\nu_s^2, \nu_s^2)$, and normalize $\mathbb{E}[s] = 1$. To discipline the dispersion parameter ν_s, we target the ratio of the 90th to the 50th percentile of observed CAR property area in 2017 (again weighted by area) In Figure 3, we compare the cumulative distribution of property area $f + l$ in the model with the CAR counterpart, each expressed relative to its mean.

Next, we assume that farmers' crop productivity z_c and pasture productivity z_p follow independent Pareto distributions, with shape parameters η_c and η_p and lower bounds $\underline{z}_i = (\eta_i - 1)/\eta_i$, normalizing $\mathbb{E}[z_i] = 1$. We discipline η_c and η_p by targeting the Gini coefficients of operated agricultural area across crop and pasture properties, respectively, weighting properties by area.[7] Finally, we discipline the productivity redraw rate γ_z using the share of pasture area in 2016 converted to crops in 2017 in the Legal Amazon, measured from MapBiomas land cover transition matrices.

Forest dynamics. We discipline the deforestation cost parameters $\zeta_{d,0}$, $\zeta_{d,1}$, and $\zeta_{d,2}$ and the reforestation cost parameters $\zeta_{r,0}$, $\zeta_{r,1}$, and $\zeta_{r,2}$ using changes in forest cover within CAR properties between 2016 and 2017, measured from MapBiomas. We define forest cover as native vegetation and measure deforestation and reforestation as decreases and increases in the share of property area under forest, respectively.[8] To capture how forest adjustment varies with initial forest cover, we group properties

[7] In the CAR data, we classify a property as a crop property when crop area exceeds pasture area and as a pasture property otherwise.

[8] Native vegetation includes the MapBiomas classes forest, savanna, mangrove, flooded forest, wooded sandbank vegetation, wetland, grassland, hypersaline tidal flat, rocky outcrop, and other natural formations. We link the same properties across 2016 and 2017 and measure forest shares relative to property area in each year.

into quintiles of their 2016 forest share, weighting properties by area.[9]

For deforestation, we target mean rates in the bottom and top quintiles, together with total deforested area as a share of forest area in 2016. Similarly, for reforestation, we target mean rates in the bottom and third quintiles and total reforested area as a share of nonforest area in 2016. The conditional rates capture differences in forest adjustment across initial forest shares, while the aggregate rates discipline the overall extent of land conversion.

Additionally, we discipline the forest shock parameters γ_f, $\underline{\varepsilon}$, and $\bar{\varepsilon}$ using the mean absolute change in the forest share relative to its standard deviation and the 5th and 95th percentiles of the change. Forest shocks capture fires, regrowth, and other changes outside the owner's control. We therefore construct the model moments from annual changes in the forest share $f/(f+l)$, incorporating both endogenous adjustment and forest shocks.

The Forest Code. Brazil's 2012 Forest Code requires landowners to maintain a minimum share of their property under native vegetation as a Legal Reserve. Within the Legal Amazon, the baseline requirement is 80 percent in the Amazon biome, 35 percent in the Cerrado, and 20 percent in other biomes. Our model abstracts from regional variation, so we set the common requirement $\bar{\rho} = 0.658$ to the mean requirement across properties in 2017, weighted by property area. In the data, we assess compliance against the requirement for the biome where the property is located. We then discipline the penalty parameters ζ_e and ζ_e^y using the share of total deforestation between 2016 and 2017 occurring on properties classified as noncompliant in 2016 and the share of properties complying in 2017, weighted by area.[10]

Credit. We normalize borrowing spreads to zero, $\tau^C = \tau^{NC} = 0$, and impose a common borrowing limit, $\lambda^C = \lambda^{NC} = \lambda$. To discipline λ, we target the share of agricultural establishments that obtained financing in 2017, using the Agricultural Census. We calculate the share for the Legal Amazon from the total number of establishments obtaining financing relative to the total number of establishments. The model counterpart is the share of farmers whose expenditure on capital and mechanization exceeds their assets, $k_i + \Phi_i(v_i) > a$.

6 Stationary Equilibrium

Next, we examine the stationary equilibrium to understand how productivity and assets shape farmers' production and financing decisions. Specifically, we study occupational choices, identify which farms borrow and face binding credit constraints, and examine compliance patterns across crop and pasture farms. We use the resulting patterns to explain how credit constraints and differences in agricultural technology influence the allocation of land between compliant and noncompliant production.

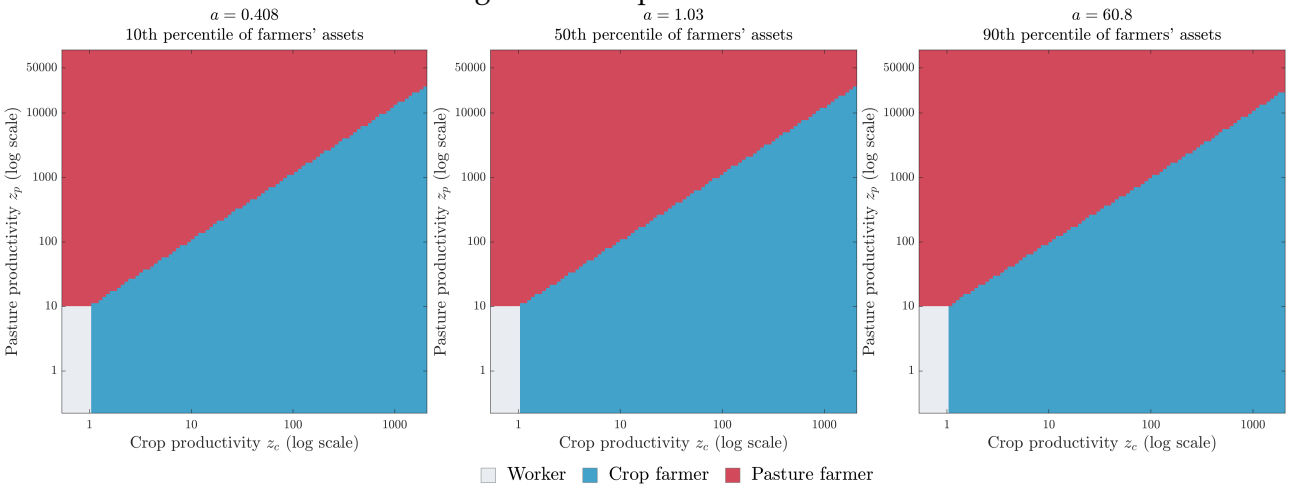
[9] We construct quintile boundaries from the area weighted distribution of forest shares in 2016 and weight all subsequent means, percentiles, and standard deviations by property area in 2017. We apply the corresponding weights $f + l$ across farmers in the model.

[10] We construct the model moments using farmers' forest shares $f/(f+l)$ relative to the common requirement $\bar{\rho}$, weighting farms by $f + l$.

Occupational choice. Figure 4 shows how households choose between working, producing crops, and operating pasture across crop productivity z_c and pasture productivity z_p, evaluated at the 10th, 50th, and 90th percentiles of farmers' assets. Households work when productivity in both sectors is low, as wage income exceeds the return from farming. Crop production becomes more profitable than working at approximately $z_c = 1$, while pasture production requires approximately $z_p = 10$. Above both thresholds, households choose between crops and pasture according to relative profitability, with an approximately linear boundary of slope one in logarithms. Thus, a proportional increase in crop productivity requires a similar increase in pasture productivity to leave a household indifferent between the two activities.

Despite the differences in financing capacity, occupational choices vary little across asset levels. Greater assets allow households to finance more capital and mechanization, yet the calibrated output elasticities of capital and effective land, $\alpha_i \psi_i$, are only 0.008 for crops and 0.039 for pasture. A binding borrowing constraint therefore has a limited effect on output, helping explain why the occupational boundaries remain similar across the asset distribution.

Figure 4: Occupational Choice



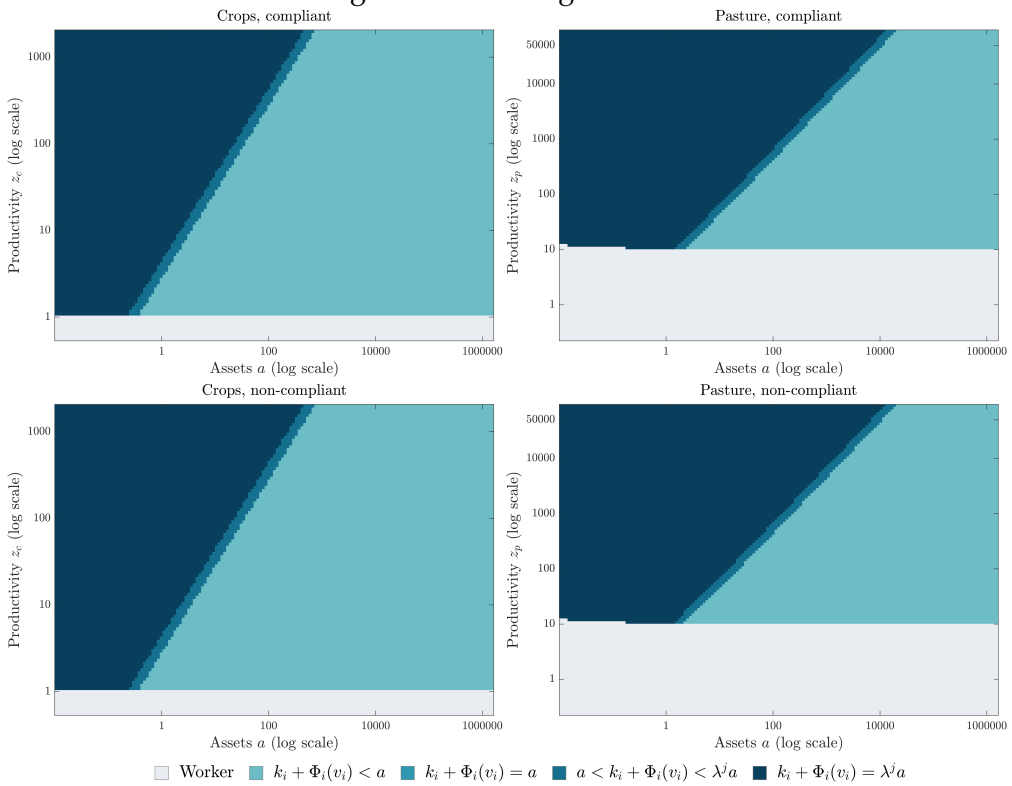
Notes: The figure plots the optimal occupation of a household whose plot satisfies $f/s \geq \bar{\rho}$, as worker, crop farmer or pasture farmer. The horizontal axis is crop productivity z_c and the vertical axis is pasture productivity z_p, both on a log scale. The three panels hold assets a fixed at the 10th, 50th and 90th percentile of farmers' assets.

Financing of farms. In Figure (5) we illustrate how productivity and assets determine a farm's reliance on credit. Higher productivity raises expenditure on capital and mechanization ($k_i + \Phi_i(v_i)$), while greater assets provide more internal funds and expand borrowing capacity. Consequently, farms with high productivity relative to their assets reach the borrowing limit. At a given productivity, farms with more assets can finance production while borrowing less than the limit permits, and farms with sufficient assets finance production entirely from their own funds. Figure (5) shows that borrowing below the limit occurs only within a narrow interval between the asset levels at which farms exhaust their borrowing capacity and finance production entirely themselves.

Importantly, farmers have no incentive to keep expenditure exactly equal to their assets, as borrowing and internal funds carry the same opportunity cost (r) when spreads are zero. Farmers can

therefore supplement their own funds with credit without facing an increase in the marginal financing cost, until the borrowing limit binds. The financing boundaries coincide across compliant and noncompliant farms in the baseline, where both regimes face the same borrowing limit and zero spreads.

Figure 5: Financing of farms



Notes: The figure plots a farm's spending on capital and mechanization, $k_i + \Phi_i(v_i)$, relative to its assets a and its borrowing limit $\lambda^j a$. The horizontal axis is assets a and the vertical axis is productivity z_i of the farm's sector, both on a log scale. The colours indicate spending below a, equal to a, between a and $\lambda^j a$, and equal to $\lambda^j a$, and grey indicates states in which the household works. The four panels are crop and pasture farms in the compliant and in the non-compliant regime.

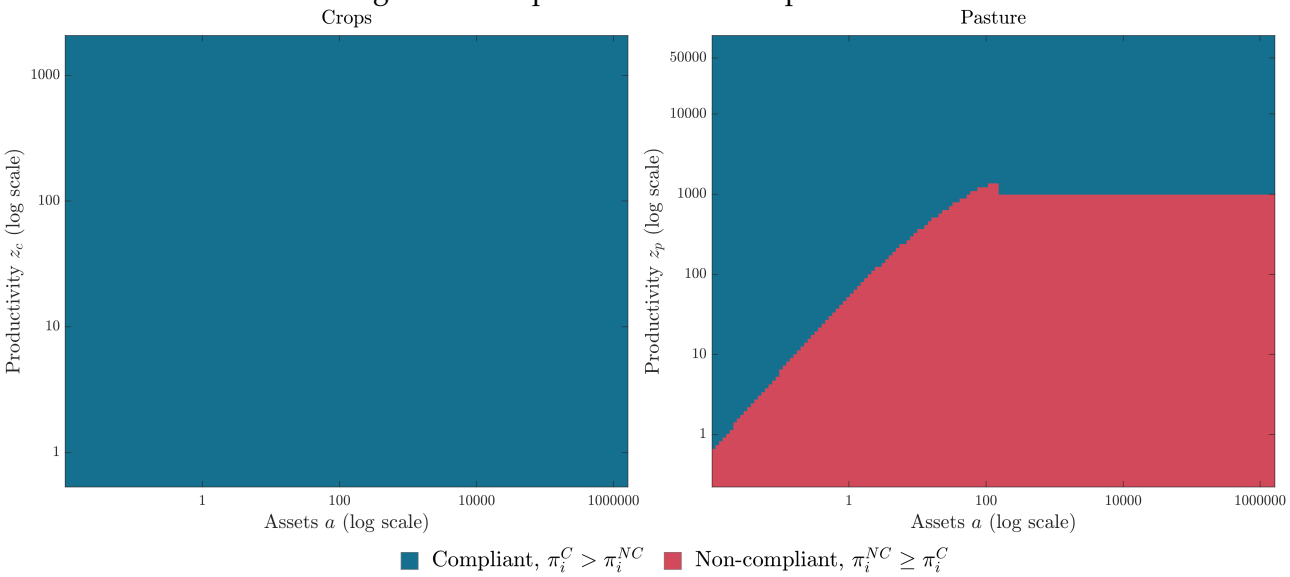
Compliance choice. In Figure 6, we show the profit maximizing compliance choice across assets a and productivity z_i, separately for crops and pasture, conditional on the farmer's own plot satisfying $f/s \geq \bar{\rho}$. Crop farms choose compliant production at every plotted combination of a and z_c. Pasture farms instead choose noncompliant production when productivity z_p is low and assets a are high, and compliant production when productivity rises relative to assets.

The difference reflects the greater land efficiency of crop production in our calibration, $\theta_c > \theta_p$. Given capital and mechanization, a higher θ_i reduces land requirements through $l_i = k_i/(\theta_i v_i)$. Crop farms therefore incur a smaller additional rental cost from using compliant land at $q^C > q^{NC}$, making compliance profitable in exchange for avoiding the revenue penalty ζ_e^y. We illustrate the role of θ_c in Appendix Figure A.21, where we lower θ_c to θ_p and recompute the stationary equilibrium, holding all other parameters at their baseline values. Crop farms then choose noncompliant production

across most of the asset and productivity grid, displaying a pattern similar to pasture farms.

For pasture farms, compliance becomes profitable where borrowing constraints or mechanization reduce land requirements. When productivity is high relative to assets, the borrowing limit restricts capital and operated land. At sufficiently high productivity, unconstrained farms also reduce land requirements through greater mechanization v_p. Both channels reduce the rental cost of compliance relative to the benefit of avoiding the revenue penalty.

Figure 6: Compliant and non-compliant farms



Notes: The figure plots the regime with the higher profit for a farm on a plot that satisfies $f/s \geq \bar{\rho}$, compliant where $\pi_i^C > \pi_i^{NC}$ and non-compliant where $\pi_i^{NC} \geq \pi_i^C$. The horizontal axis is assets a and the vertical axis is productivity z_i of the farm's sector, both on a log scale. The two panels are crop farms and pasture farms.

7 Policy Experiments

A key question in our paper is how Brazil's rural credit programme can be redesigned to promote forest conservation while sustaining agricultural production. We use the calibrated model to compare credit conditions linked to compliance with the Forest Code with stricter Legal Reserve requirements and higher penalties for noncompliance. Our analysis addresses two questions: (i) How much forest can credit reform preserve, and at what cost in agricultural output relative to alternative conservation policies? (ii) How do adjustments in land rents change the effectiveness of credit reform and forest regulation? We examine both questions through counterfactual experiments that account for landowners' conservation decisions, farmers' production choices, and equilibrium responses in land markets.

Policy Design. We consider four reforms that change the financial incentives and legal requirements for forest conservation.

I. **Higher borrowing costs for noncompliant farms.** We raise the borrowing spread to $\tau^{NC} = 0.22$.

II. **Credit restricted to compliant farms.** We set $\lambda^{NC} = 1$, requiring noncompliant farms to finance capital and mechanization entirely from their own assets.

III. **A higher Legal Reserve requirement.** We increase the required forest share $\bar{\rho}$ by 10 percentage points.

IV. **Higher fines for forest shortfalls.** We raise ζ_e, the fine per hectare below the Legal Reserve requirement, by 10 percent.

We evaluate the reforms by comparing counterfactual stationary equilibria with our baseline economy. In general equilibrium, we allow rents q^C and q^{NC} to adjust until both land markets clear. We also compute the response at baseline rents in partial equilibrium, allowing households to adjust their decisions while holding q^C and q^{NC} fixed. Comparing the two exercises reveals how land rent adjustments change the forest and production effects of the reforms. Land market clearing links aggregate forest cover to the area operated by farmers,

$$F = \int s \, dG - \sum_{i,j} \int o_i^j l_i^j \, dG.$$

Given the fixed aggregate land endowment, an increase in forest cover therefore requires a reduction in agricultural land use. In Table 2, we report the general and partial equilibrium results for Policies I to IV. In Appendix Table A.7, we combine the higher Legal Reserve requirement under Policy III separately with higher borrowing costs under Policy I, credit restrictions under Policy II, and higher fines under Policy IV.

Policy effectiveness. We find that conditioning rural credit on compliance with the Forest Code can increase forest cover while leaving agricultural output almost unchanged. Raising borrowing costs for noncompliant farms under Policy I and restricting credit to compliant farms under Policy II increase the forest share by approximately one percentage point, with an output loss of only 0.01 percent.

Both policies increase the value of maintaining a plot that meets the Legal Reserve requirement. Under Policy I, compliance provides access to cheaper borrowing, while under Policy II, compliance determines access to credit. The incentive to retain forest therefore extends beyond current borrowers to landowners who may enter farming after a productivity change or asset accumulation. As landowners preserve more forest, the supply of cleared land falls and equilibrium rents q^C and q^{NC} rise. Farmers consequently face a higher cost of using land and respond by increasing mechanization and reducing the area they operate.

Greater mechanization allows farmers to maintain production on less land, while the small calibrated output elasticities of capital and effective land, $\alpha_i \psi_i$, limit the output loss from lower input use. Additionally, the direct restrictions on borrowing apply to a small group of noncompliant farmers. Credit conditionality thus creates conservation incentives beyond the farms directly affected by

tighter borrowing conditions, while adjustments in agricultural production accommodate the reduction in available land with little to no loss of output.

Table 2: Counterfactuals: individual policies

		General equilibrium				Partial equilibrium			
	Baseline	I	II	III	IV	I	II	III	IV
		$\tau^{NC} = 0.22$	$\lambda^{NC} = 1$	$\bar{\rho} + 0.10$	$\zeta_e \uparrow$	$\tau^{NC} = 0.22$	$\lambda^{NC} = 1$	$\bar{\rho} + 0.10$	$\zeta_e \uparrow$
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. Shares and ratios	*Level (%)*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*
Share of land under forest ($F / \int s\, dG$)	56.39	1.04	1.05	0.77	0.07	7.21	9.35	−12.87	5.39
Share of plots that comply ($f/s \geq \bar{\rho}$)	94.09	0.62	0.67	0.07	−0.02	1.40	1.86	−2.33	0.93
Share of land deforested per year	32.10	0.43	0.42	−0.70	0.02	−0.50	−0.67	−0.86	−0.34
of which: on compliant plots	17.22	2.10	2.11	−0.92	0.02	3.74	4.88	−9.66	2.73
of which: on non-compliant plots	14.88	−1.67	−1.69	0.22	0.00	−4.25	−5.55	8.80	−3.07
Share of land reforested per year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Share of individuals who are farmers	20.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
of which: compliant farms	19.71	0.07	0.07	−0.05	0.00	0.14	0.15	−0.13	0.03
of which: non-compliant farms	0.85	−0.07	−0.07	0.05	0.00	−0.14	−0.15	0.13	−0.03
Share of total farmland used for crops	14.14	0.23	0.24	−0.08	0.02	0.13	0.13	0.00	0.00
Share of farms that borrow	20.27	−1.09	−1.18	−4.91	0.00	−0.86	−0.87	−0.03	0.01
Farm borrowing / agricultural output	0.28	−0.07	−0.07	0.00	0.00	−0.05	−0.05	0.00	0.00
Panel B. Levels	*Level*	Δ %	Δ %	Δ %	Δ %	Δ %	Δ %	Δ %	Δ %
Total farm borrowing	0.0066	−24.63	−24.81	−0.23	0.03	−18.98	−18.82	−0.08	0.02
Average mechanization	3.9856	0.99	1.01	1.19	0.11	0.19	0.20	−0.01	0.00
Agricultural output	2.3434	−0.01	−0.01	−0.01	0.00	0.00	0.00	0.00	0.00
Rent on compliant land (q^C)	0.0051	10.17	10.00	33.07	0.19	0.00	0.00	0.00	0.00
Rent on non-compliant land (q^{NC})	0.0035	4.05	4.19	5.34	0.51	0.00	0.00	0.00	0.00

Notes: Policy I sets $\tau^{NC} = 0.22$; Policy II sets $\lambda^{NC} = 1$; Policy III raises $\bar{\rho}$ by 10 percentage points, from 0.658 to 0.758; Policy IV raises ζ_e by 10 percent. In columns (2) to (5) q^C and q^{NC} clear both land markets; in columns (6) to (9) both rents are held at their baseline values. All aggregates integrate over G, with o_i^j the occupational indicator and sums running over $i \in \{c, p\}$ and $j \in \{C, NC\}$. Forest cover is $F = \int f\, dG$ and total land is $\int s\, dG$; total land deforested and reforested per year is $\int d\, dG$ and $\int m\, dG$, and land deforested on compliant and on non-compliant plots is $\int d\, \mathbf{1}\{f/s \geq \bar{\rho}\}\, dG$ and $\int d\, \mathbf{1}\{f/s < \bar{\rho}\}\, dG$. The mass of farmers is $\sum_{i,j} \int o_i^j\, dG$. Total farmland is $\sum_{i,j} \int o_i^j l_i^j\, dG$, of which $\sum_j \int o_c^j l_c^j\, dG$ is used for crops. A farm borrows if $k_i^j + \Phi_i(v_i^j) > a$, and total farm borrowing is $\sum_{i,j} \int o_i^j \max\{k_i^j + \Phi_i(v_i^j) - a, 0\}\, dG$. Total agricultural output is $\sum_{i,j} \int o_i^j\, \tilde{p}_i\, y_i^j\, dG$. Average mechanization is $\sum_{i,j} \int o_i^j v_i^j l_i^j\, dG$ divided by total farmland.

General equilibrium effects. We find that adjustments in land rents substantially reduce the forest gains from credit conditionality and higher fines, and reverse the response to a stricter Legal Reserve requirement. At baseline rents, Policies I and II increase the forest share by approximately 7 and 9 percentage points, respectively. Allowing q^C and q^{NC} to adjust reduces both gains to approximately one percentage point. Landowners initially respond to stronger conservation incentives by supplying less cleared land. However, farmers continue to demand land for production, bidding up rents and increasing the income landowners forgo by retaining forest. Higher rents therefore offset part of the incentive to conserve, while encouraging farmers to reduce their land requirements. With agricultural output almost unchanged, the equilibrium forest gain depends primarily on how much less land farmers use per unit of output. The same interaction explains why higher fines under Policy IV produce little additional forest in general equilibrium.

A stricter Legal Reserve requirement under Policy III shows that land rent adjustments can even change the direction of the forest response. Raising the requirement makes previously compliant

plots noncompliant. At baseline rents, some owners respond by clearing forest, as the additional conservation needed to regain compliance is insufficiently attractive. For owners remaining noncompliant, retaining another hectare reduces the fine by ζ_e but sacrifices rental income q^{NC}, which is more than ten times larger. The forest share consequently falls by 12.9 percentage points when rents remain fixed.

8 Conclusions

We study how rural credit affects agricultural land use and forest conservation in Brazil, and how credit policy can promote conservation while sustaining agricultural production. Using administrative credit records linked to satellite imagery, we find that farmers respond to credit by reallocating land from pasture toward crops, increasing spending on machinery and fertilizer, and retaining more forest on their properties. Land use effects persist for up to eighteen years after the first receipt of rural credit, suggesting that access to finance can support lasting changes in agricultural production and forest conservation.

We then develop a dynamic general equilibrium model with heterogeneous farmers to evaluate how Brazil's rural credit programme can be redesigned to promote forest conservation while sustaining agricultural output. Raising borrowing costs for farms that fail to meet the Forest Code's Legal Reserve requirement or restricting credit to compliant farms increases total forest cover in the Legal Amazon by approximately 2 percent with negligible effects on agricultural output. Linking borrowing terms to compliance raises the value of retaining forest, including for owners who may enter farming in the future. As owners supply less cleared land, higher rents encourage farmers to increase mechanization and reduce the land they operate.

However, we find that equilibrium adjustments in land rents limit the conservation gains from credit reform. Retaining more forest reduces the land available for agricultural production, raising rents and the income landowners forgo by conserving forest. Accounting for rent adjustment reduces the predicted increase in total forest cover from approximately 13 to 17 percent to approximately 2 percent. Linking rural credit to environmental compliance can therefore preserve more forest with negligible effects on agricultural output, although evaluations at fixed rents substantially overstate the conservation gains.

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A Appendix

Table A.1: Descriptive Statistics by Farm Size Quintiles — Full Sample (All Brazil)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Freq.	Forest	Pasture	Crops	P(Credit)	Credit	Credit/ha	P(Payment)	Expend.	Expend./ha	Fertilizer	Capital
Q1 (Smallest)	0.20	0.06	0.58	0.27	0.04	22,790	26,325	0.23	4,453	3,215	597	128
		(0.17)	(0.42)	(0.37)	(0.20)	(1,564,750)	(1,100,166)	(0.42)	(815,790)	(442,353)	(139,309)	(35,016)
Q2	0.20	0.12	0.44	0.34	0.09	44,779	9,029	0.29	17,283	3,354	1,924	622
		(0.21)	(0.39)	(0.35)	(0.29)	(2,582,297)	(516,752)	(0.46)	(1,962,044)	(366,956)	(273,162)	(96,594)
Q3	0.20	0.15	0.39	0.34	0.14	43,047	3,923	0.36	20,038	1,917	1,815	799
		(0.22)	(0.37)	(0.34)	(0.35)	(2,503,665)	(247,178)	(0.48)	(2,322,404)	(229,031)	(268,534)	(118,629)
Q4	0.20	0.16	0.41	0.28	0.14	53,396	1,974	0.37	22,176	812	1,906	919
		(0.23)	(0.35)	(0.32)	(0.35)	(2,207,607)	(87,789)	(0.48)	(2,197,248)	(85,514)	(245,392)	(111,969)
Q5 (Largest)	0.20	0.19	0.42	0.22	0.14	227,542	1,126	0.37	159,771	579	20,289	7,202
		(0.25)	(0.33)	(0.29)	(0.35)	(2,240,933)	(17,244)	(0.48)	(4,634,885)	(25,289)	(625,871)	(320,056)
Observations		118,581,733				13,083,050				38,417,058		
Farms		6,939,393				1,852,258				2,217,035		

Notes: All statistics computed at the farm-year observation level (2003–2020). Standard deviations in parentheses. Quintiles based on registered farm size (hectares). Land use shares computed as fraction of total property area (Crops exclude Aquaculture). P(Credit) is the share of farm-year observations with positive credit. Credit and Credit/ha are means over farm-year observations where credit was received (real 2003 USD). P(Payment) is the share of farm-year observations where the farm has a link in the payment system. Expenditure, *Fertilizer*, and *Capital* are outgoing farm payments classified by creditor CNAE sector (real 2003 USD); means are taken over farm-year observations with a payment system link (independent of credit receipt).

Table A.2: Descriptive Statistics by Farm Size Quintiles — Amazon Biome

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Freq.	Forest	Pasture	Crops	P(Credit)	Credit	Credit/ha	P(Payment)	Expend.	Expend./ha	Fertilizer	Capital
Q1 (Smallest)	0.19	0.18	0.75	0.01	0.03	28,289	24,390	0.20	5,271	2,932	805	106
		(0.28)	(0.32)	(0.09)	(0.16)	(354,734)	(1,083,569)	(0.40)	(391,666)	(469,595)	(48,810)	(8,291)
Q2	0.20	0.27	0.67	0.01	0.04	26,906	1,271	0.27	2,786	149	614	59
		(0.30)	(0.32)	(0.10)	(0.21)	(134,940)	(6,482)	(0.44)	(177,388)	(12,605)	(49,673)	(3,012)
Q3	0.21	0.32	0.64	0.01	0.05	39,978	909	0.30	2,661	60	415	80
		(0.30)	(0.31)	(0.09)	(0.22)	(168,477)	(3,969)	(0.46)	(89,119)	(1,886)	(11,743)	(3,578)
Q4	0.20	0.38	0.57	0.02	0.05	62,493	791	0.28	6,158	76	1,042	193
		(0.30)	(0.31)	(0.12)	(0.23)	(199,440)	(2,669)	(0.45)	(257,032)	(2,839)	(32,121)	(6,520)
Q5 (Largest)	0.20	0.39	0.53	0.04	0.09	280,150	657	0.31	110,321	140	18,743	4,442
		(0.29)	(0.31)	(0.15)	(0.28)	(1,030,166)	(2,098)	(0.46)	(5,837,289)	(3,201)	(379,552)	(452,242)
Observations		12,324,977				653,952				3,348,250		
Farms		767,636				142,700				199,178		

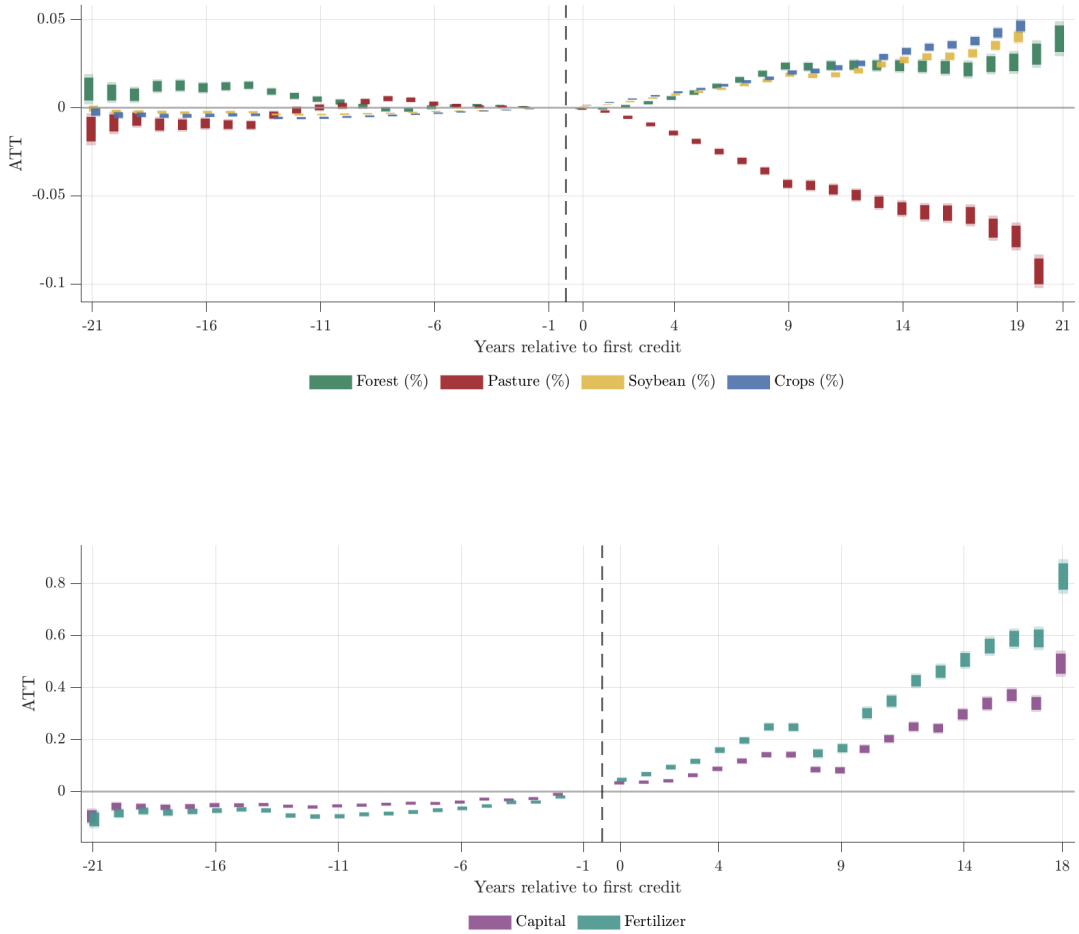
Notes: All statistics computed at the farm-year observation level (2003–2020). Standard deviations in parentheses. Quintiles based on registered farm size (hectares). Land use shares computed as fraction of total property area (Crops exclude Aquaculture). P(Credit) is the share of farm-year observations with positive credit. Credit and Credit/ha are means over farm-year observations where credit was received (real 2003 USD). P(Payment) is the share of farm-year observations where the farm has a link in the payment system. Expenditure, *Fertilizer*, and *Capital* are outgoing farm payments classified by creditor CNAE sector (real 2003 USD); means are taken over farm-year observations with a payment system link (independent of credit receipt).

Table A.3: Descriptive Statistics by Farm Size Quintiles — Cerrado

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Freq.	Forest	Pasture	Crops	P(Credit)	Credit	Credit/ha	P(Payment)	Expend.	Expend./ha	Fertilizer	Capital
Q1 (Smallest)	0.19	0.06	0.56	0.24	0.04	35,656	60,901	0.22	7,497	5,793	792	241
		(0.17)	(0.40)	(0.33)	(0.19)	(2,283,859)	(1,722,804)	(0.42)	(1,260,322)	(460,954)	(139,707)	(66,742)
Q2	0.20	0.08	0.50	0.25	0.06	67,454	8,484	0.25	29,136	3,546	3,155	897
		(0.17)	(0.36)	(0.30)	(0.24)	(3,092,455)	(400,190)	(0.43)	(2,616,829)	(322,354)	(312,883)	(125,120)
Q3	0.20	0.10	0.46	0.25	0.08	88,559	4,437	0.29	30,633	1,529	3,280	1,209
		(0.18)	(0.34)	(0.29)	(0.27)	(3,182,015)	(175,584)	(0.46)	(2,694,751)	(136,200)	(319,901)	(141,519)
Q4	0.20	0.12	0.45	0.24	0.11	116,435	2,185	0.33	46,914	902	3,959	1,919
		(0.19)	(0.33)	(0.29)	(0.31)	(2,492,050)	(58,571)	(0.47)	(2,675,447)	(59,470)	(232,920)	(130,312)
Q5 (Largest)	0.20	0.13	0.38	0.27	0.18	432,604	1,121	0.42	321,279	635	56,679	13,848
		(0.17)	(0.31)	(0.30)	(0.38)	(3,130,357)	(6,569)	(0.49)	(5,437,450)	(14,980)	(1,105,615)	(379,440)
Observations		28,075,171				2,641,593				8,530,617		
Farms		1,659,433				414,177				502,392		

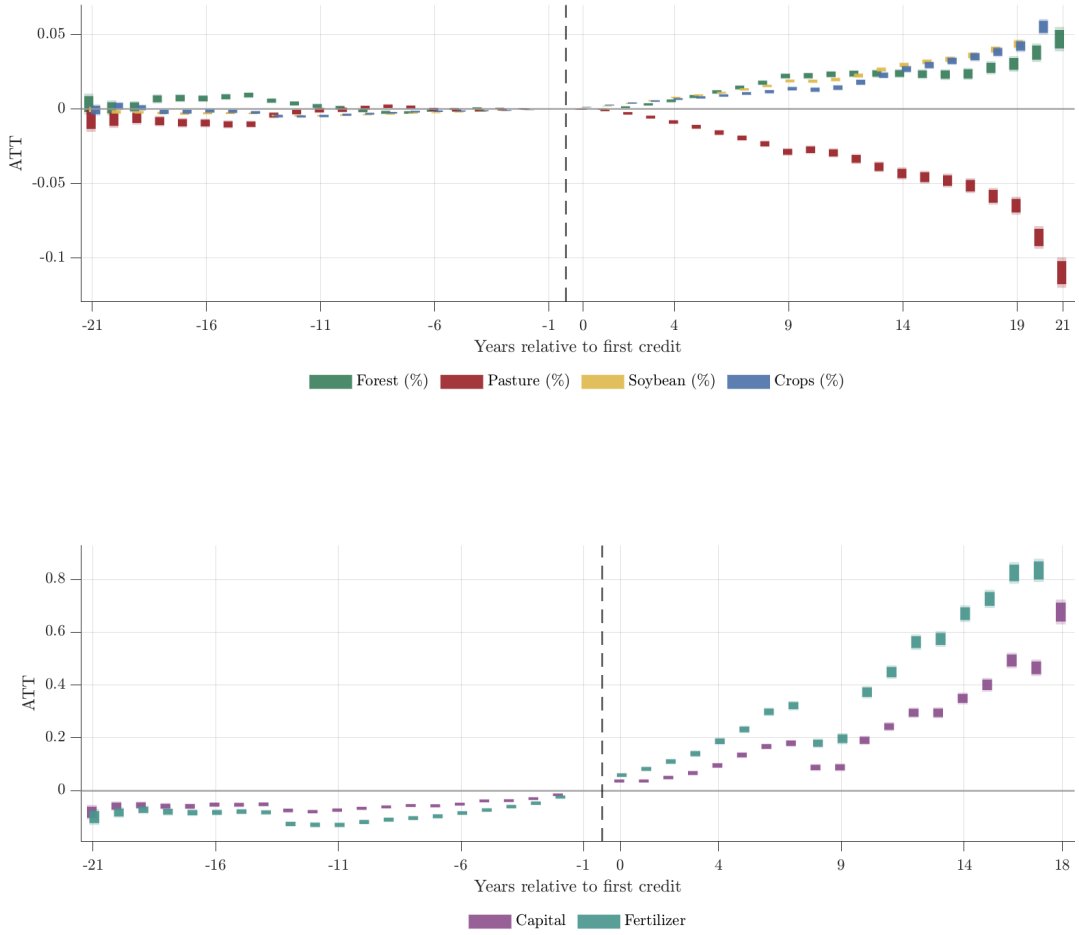
Notes: All statistics computed at the farm-year observation level (2003–2020). Standard deviations in parentheses. Quintiles based on registered farm size (hectares). Land use shares computed as fraction of total property area (Crops exclude Aquaculture). P(Credit) is the share of farm-year observations with positive credit. Credit and Credit/ha are means over farm-year observations where credit was received (real 2003 USD). P(Payment) is the share of farm-year observations where the farm has a link in the payment system. Expenditure, *Fertilizer*, and *Capital* are outgoing farm payments classified by creditor CNAE sector (real 2003 USD); means are taken over farm-year observations with a payment system link (independent of credit receipt).

Figure A.1: Baseline — Amazon Biome



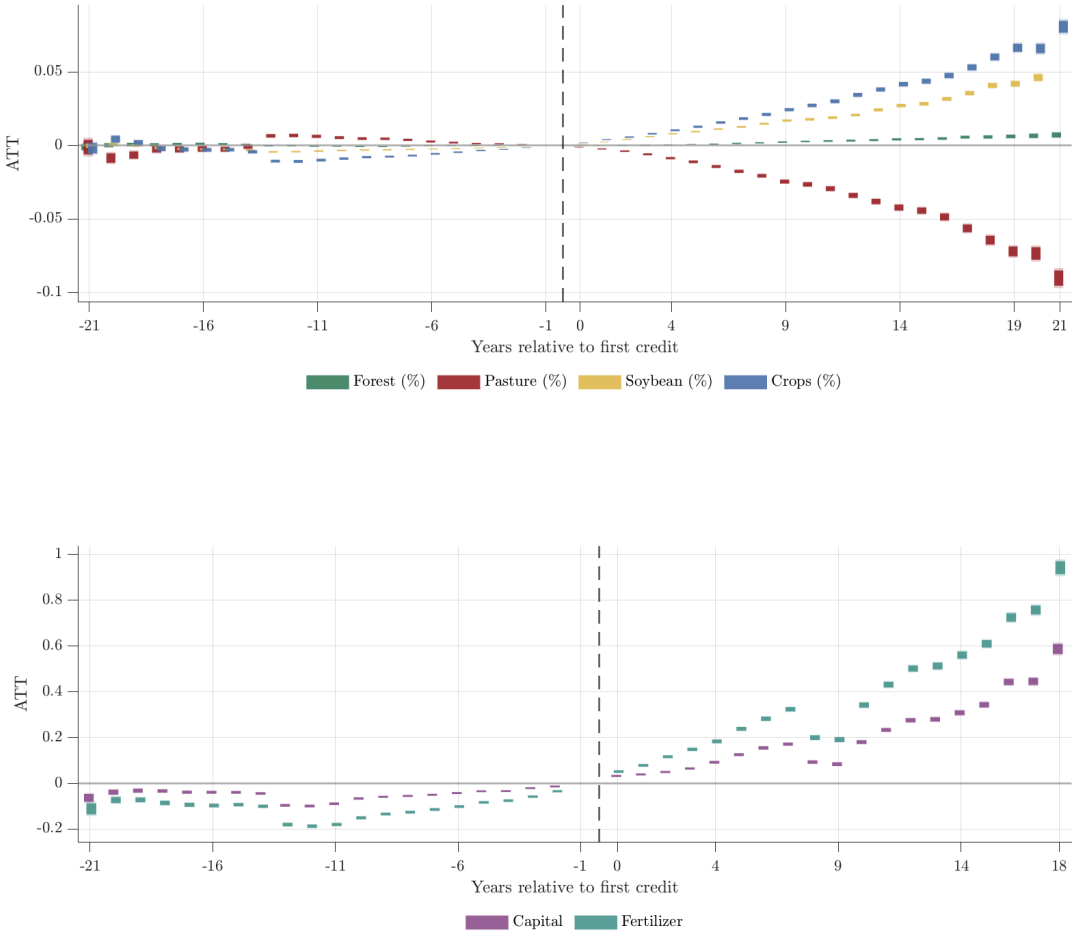
Notes: Amazon Biome farms with at least 5% farming share. Visual representation of the group-time average treatment effects on the treated $\text{ATT}(g,t)$ of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1+\text{Capital})$ and $\log(1+\text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.2: Baseline — Legal Amazon (with $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$ payments)



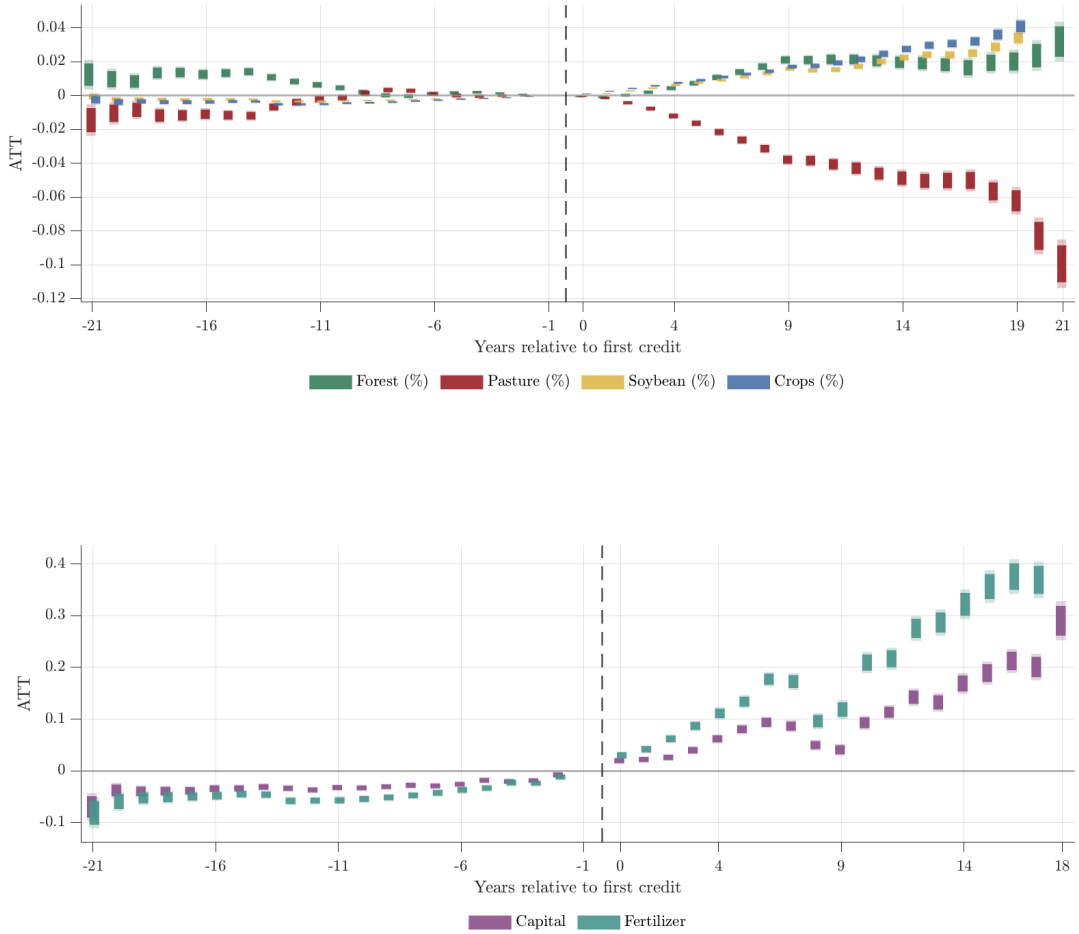
Notes: Legal Amazon farms with at least 5% farming share. Visual representation of the group-time average treatment effects on the treated $\text{ATT}(g, t)$ of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.3: Baseline — Cerrado



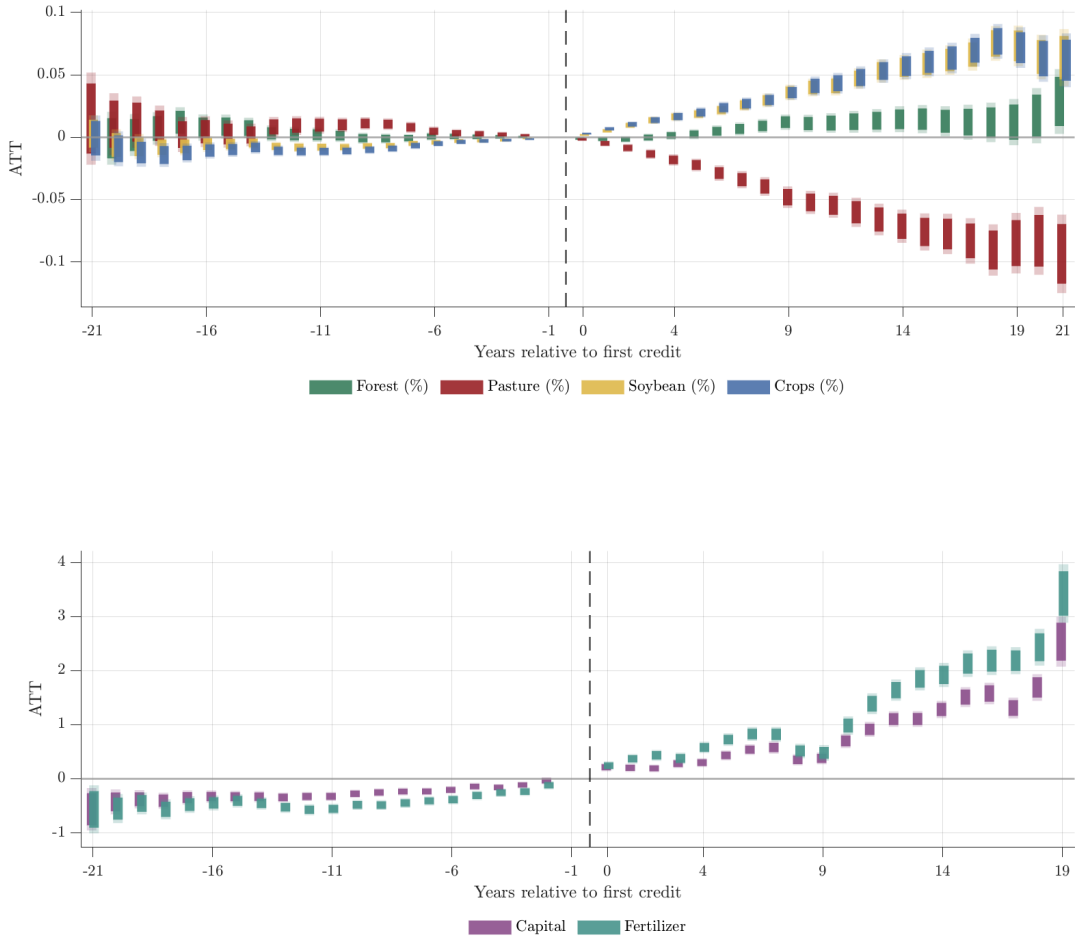
Notes: Cerrado farms with at least 5% farming share. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.4: Heterogeneity by Farm Size — Amazon Biome, Below 4 Fiscal Modules



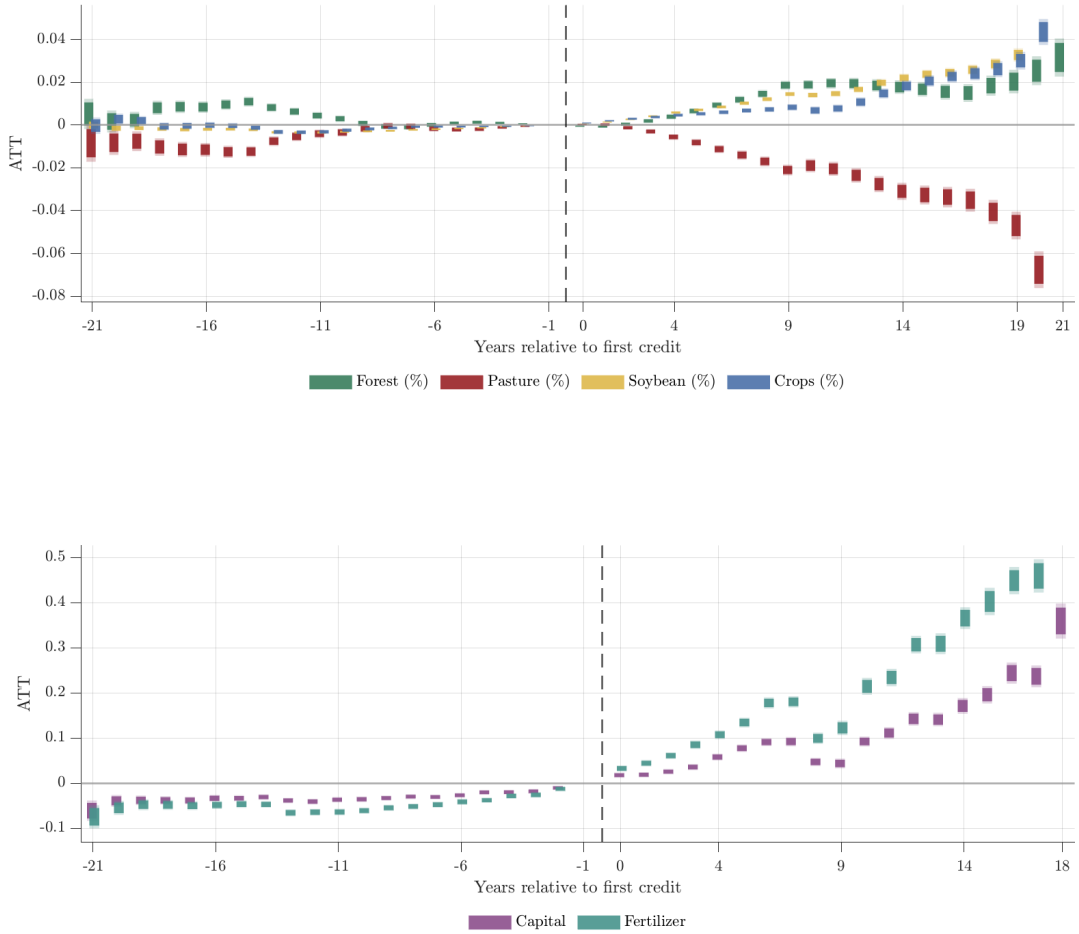
Notes: Amazon Biome farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g, t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.5: Heterogeneity by Farm Size — Amazon Biome, Above 4 Fiscal Modules



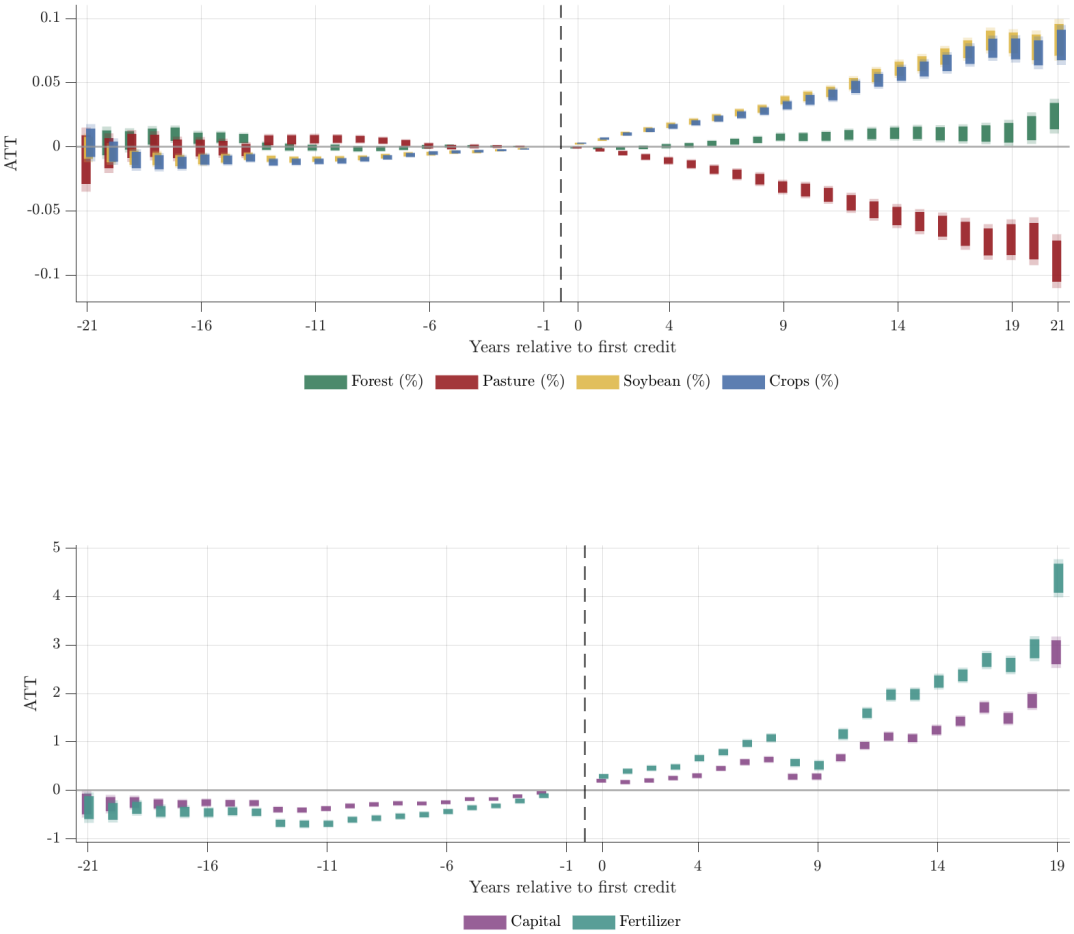
Notes: Amazon Biome farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1+\text{Capital})$ and $\log(1+\text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.6: Heterogeneity by Farm Size — Legal Amazon, Below 4 Fiscal Modules



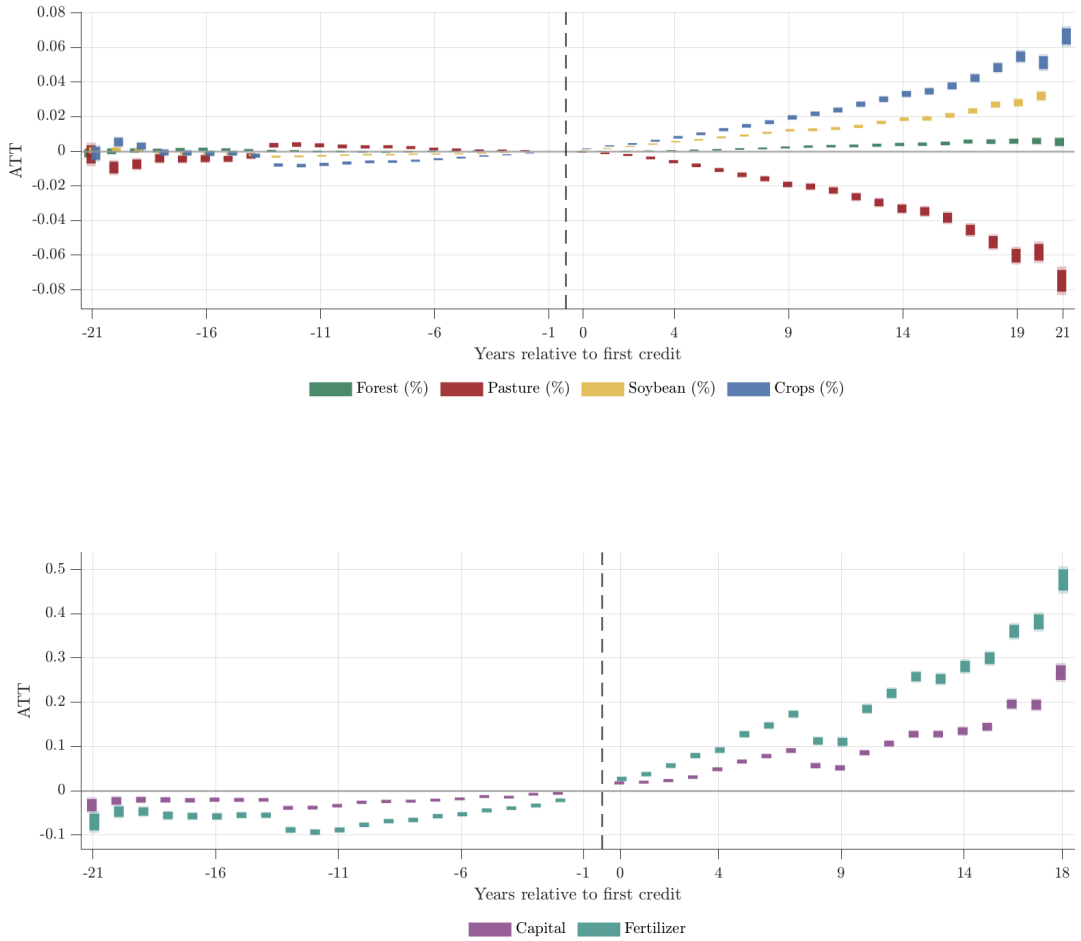
Notes: Legal Amazon farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g, t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.7: Heterogeneity by Farm Size — Legal Amazon, Above 4 Fiscal Modules



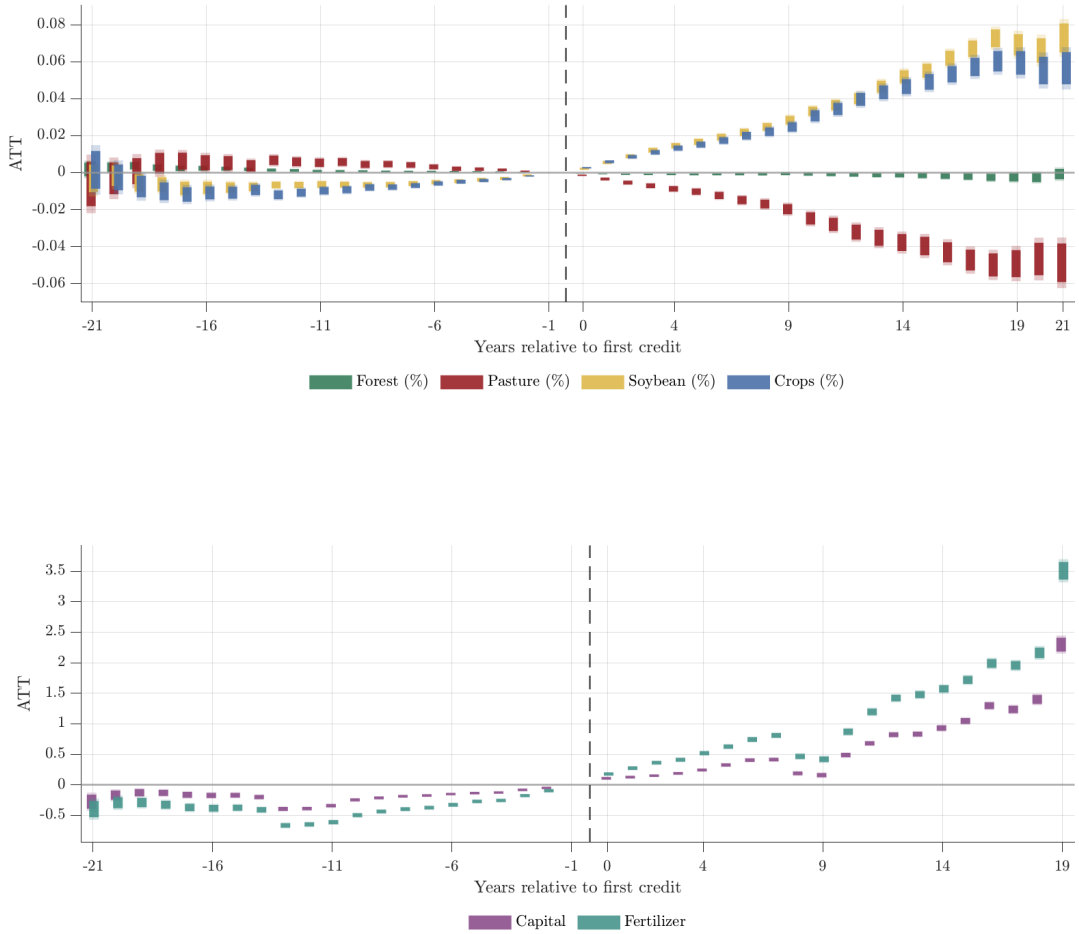
Notes: Legal Amazon farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated $\text{ATT}(g,t)$ of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1+\text{Capital})$ and $\log(1+\text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.8: Heterogeneity by Farm Size — Cerrado, Below 4 Fiscal Modules



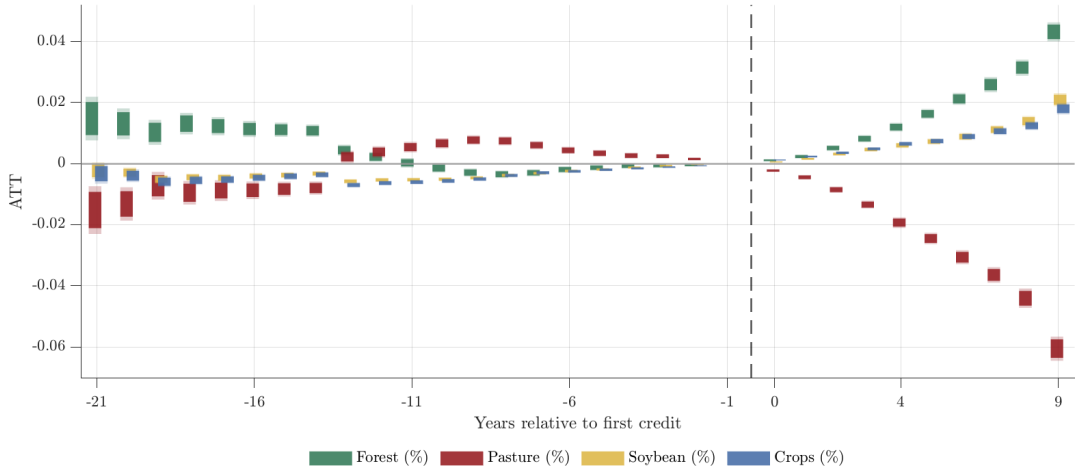
Notes: Cerrado farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.9: Heterogeneity by Farm Size — Cerrado, Above 4 Fiscal Modules



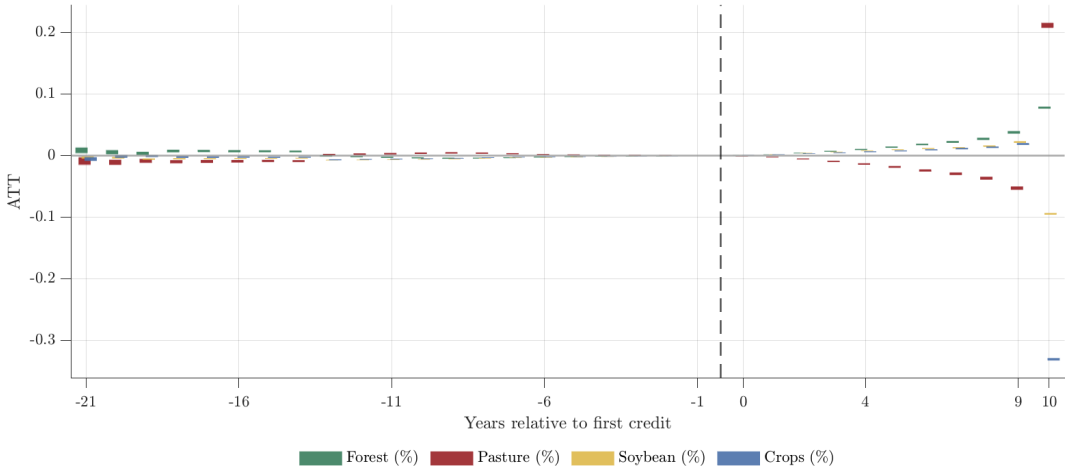
Notes: Cerrado farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Land use outcomes (Forest, Pasture, Soybean, Crops) are shares of total registered property area from MapBiomas satellite data. Payment outcomes are $\log(1 + \text{Capital})$ and $\log(1 + \text{Fertilizer})$, where *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.10: Land Use by Owner Type — Amazon Biome



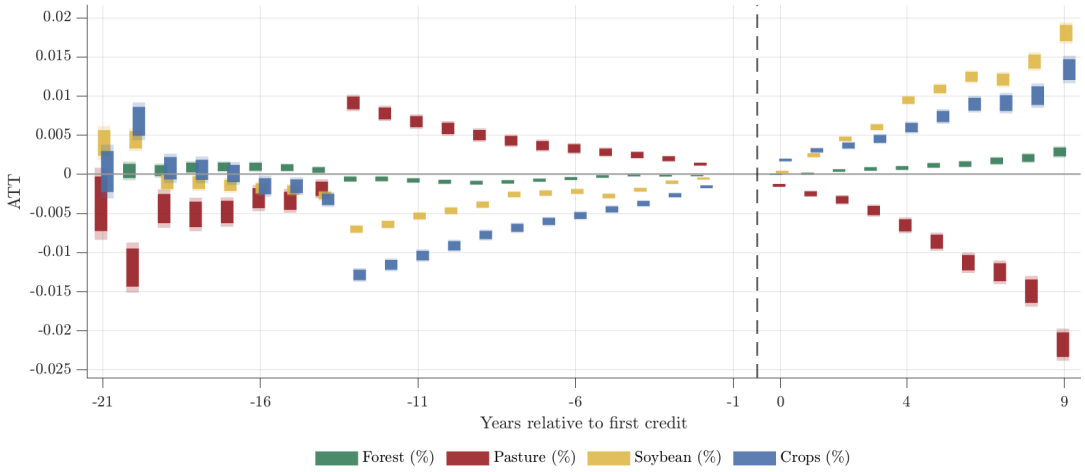
Notes: Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Outcomes are land use shares split by borrower ownership type (individual vs. firm). Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.11: Land Use by Owner Type — Legal Amazon



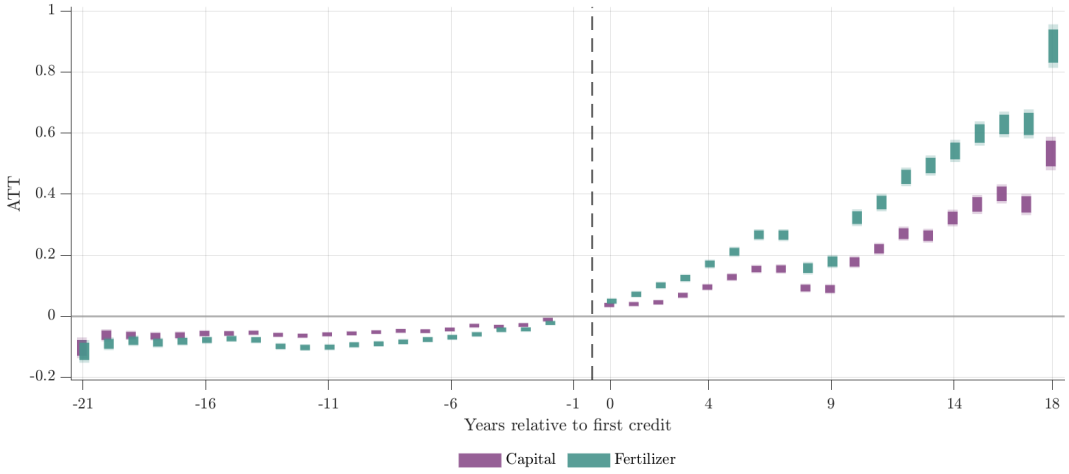
Notes: Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Outcomes are land use shares split by borrower ownership type (individual vs. firm). Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.12: Land Use by Owner Type — Cerrado



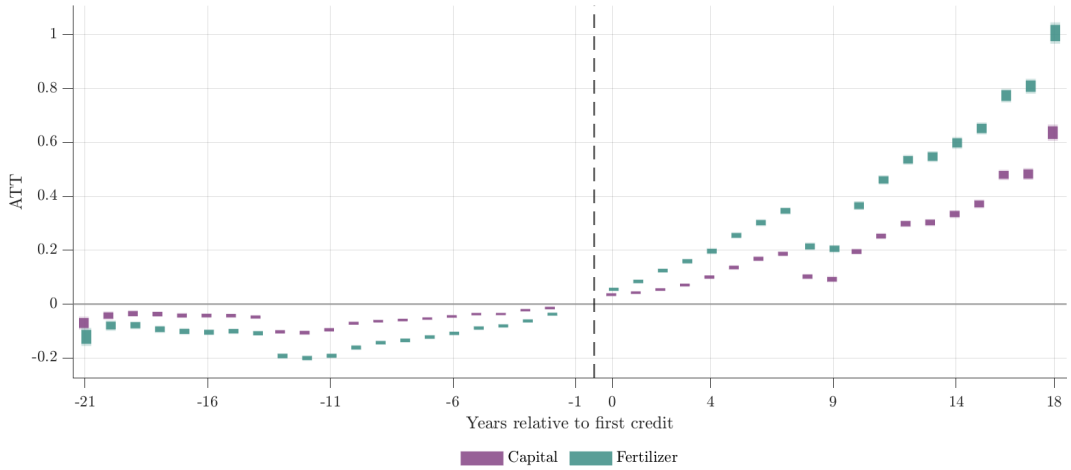
Notes: Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Outcomes are land use shares split by borrower ownership type (individual vs. firm). Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.13: Robustness — Amazon Biome



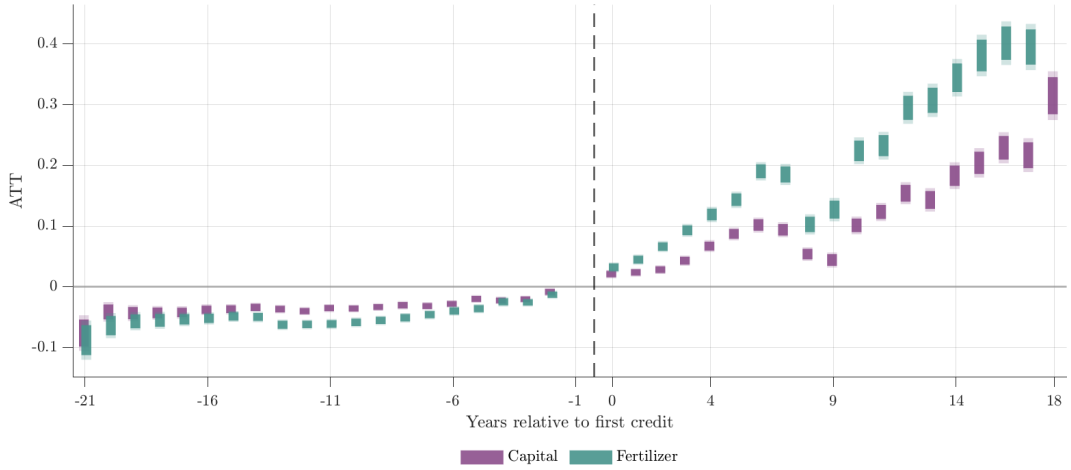
Notes: Amazon Biome farms with at least 5% farming share. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.14: Robustness — Cerrado



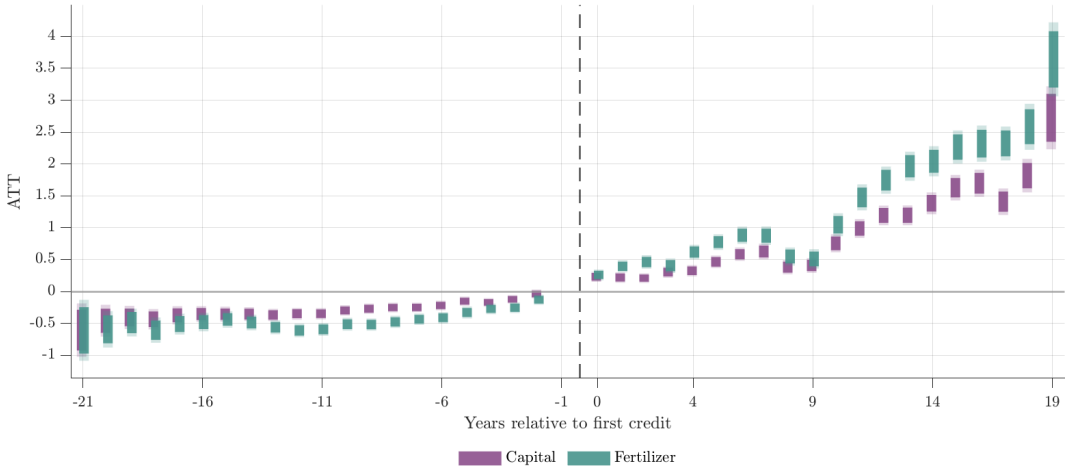
Notes: Cerrado farms with at least 5% farming share. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.15: Robustness — Amazon Biome, Below 4 Fiscal Modules



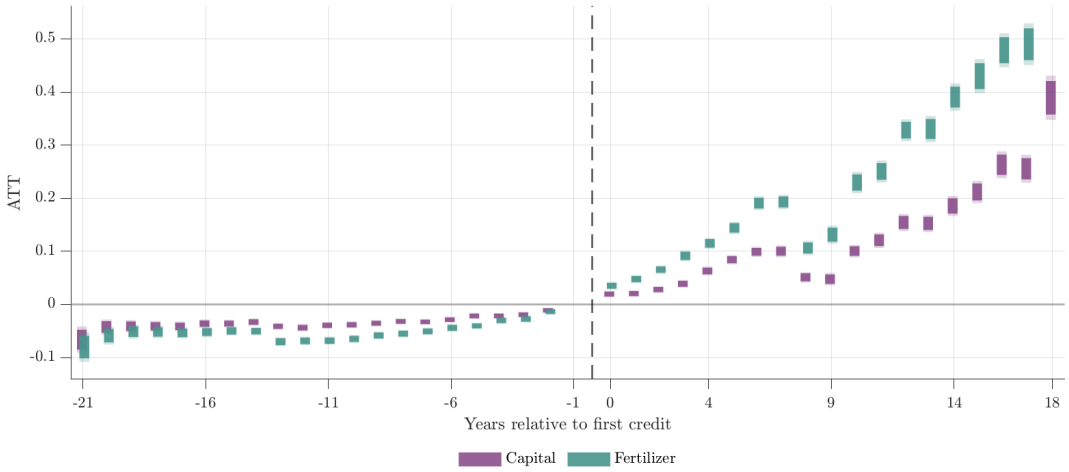
Notes: Amazon Biome farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.16: Robustness — Amazon Biome, Above 4 Fiscal Modules



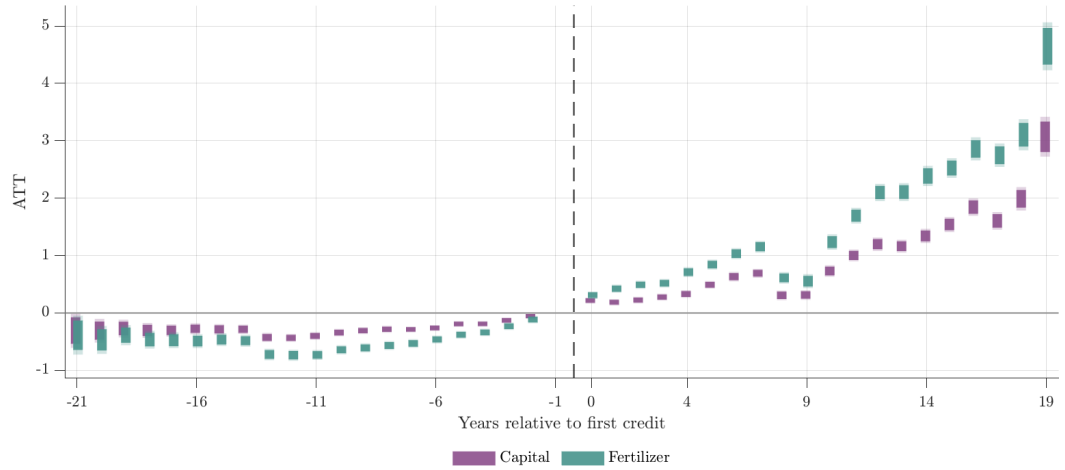
Notes: Amazon Biome farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.17: Robustness — Legal Amazon, Below 4 Fiscal Modules



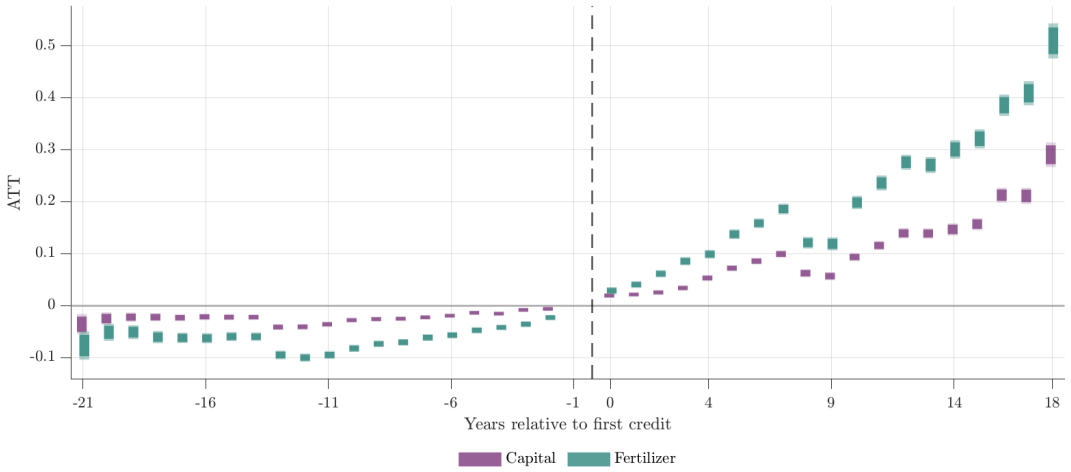
Notes: Legal Amazon farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.18: Robustness — Legal Amazon, Above 4 Fiscal Modules



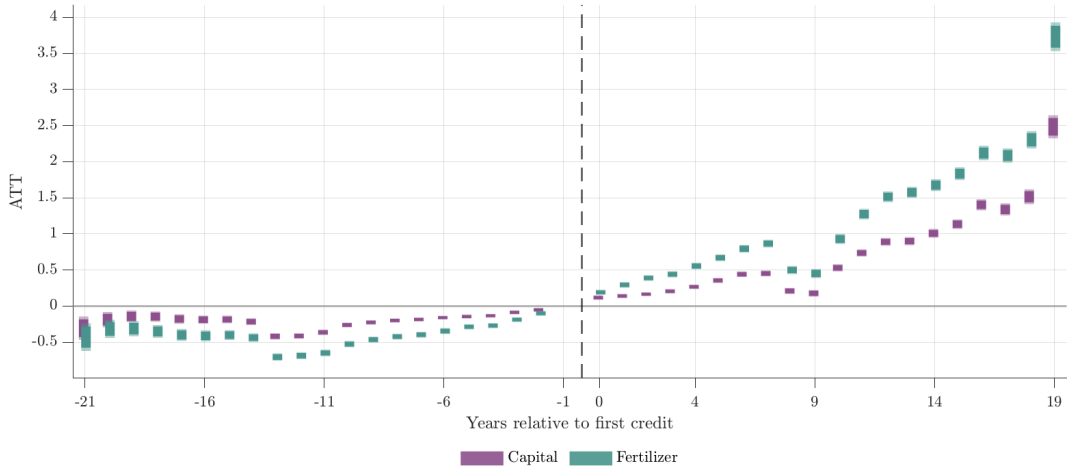
Notes: Legal Amazon farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.19: Robustness — Cerrado, Below 4 Fiscal Modules



Notes: Cerrado farms with at most 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Figure A.20: Robustness — Cerrado, Above 4 Fiscal Modules



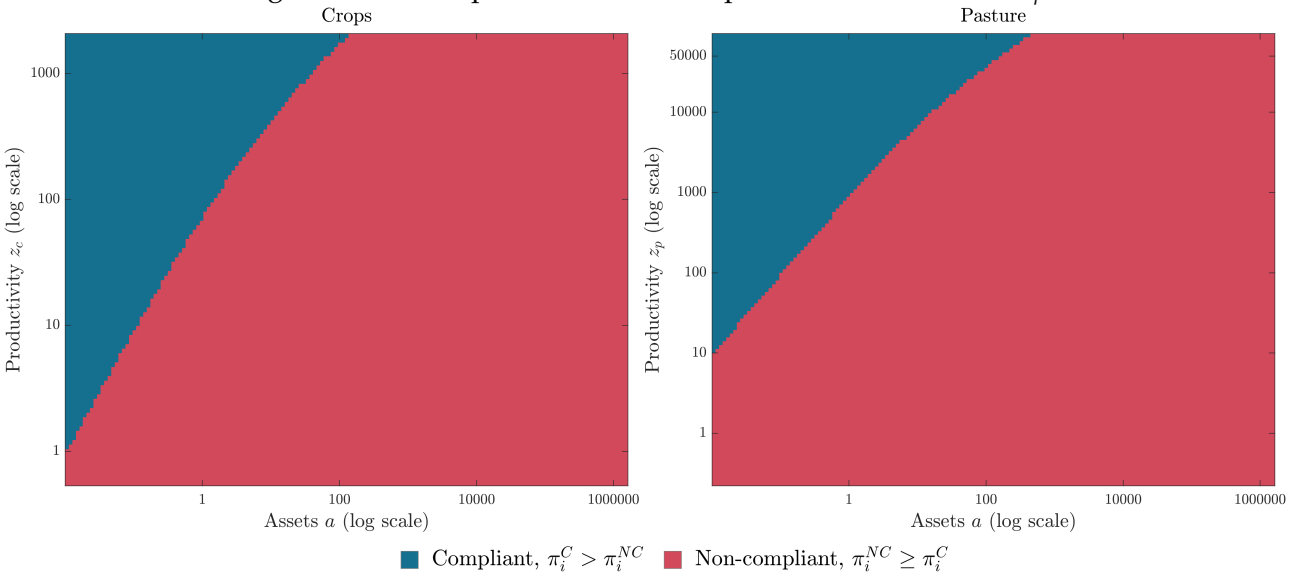
Notes: Cerrado farms with more than 4 fiscal modules. Visual representation of the group-time average treatment effects on the treated ATT(g,t) of Callaway & Sant'Anna (2021), aggregated to event-time coefficients with not-yet-treated farms as the comparison group. Point estimates represent dynamic effects relative to the reference period (long differences). Treatment is the first year a farm receives rural credit. Payment outcomes are $\sinh^{-1}(\text{Capital})$ and $\sinh^{-1}(\text{Fertilizer})$, where $\sinh^{-1}(z) = \ln\left(z + \sqrt{z^2+1}\right)$ is the inverse hyperbolic sine transformation, and *Capital* and *Fertilizer* are outgoing farm payments (real 2003 USD) classified by receiving-counterparty CNAE sector. Bars show 95% confidence intervals (solid) and 99% confidence intervals (shaded).

Table A.4: CNAE Classification of Outgoing Payments

CNAE Code	Level	Description
Panel A: Capital		
2831-3	Subclass	Mfg. of agricultural tractors, parts and accessories
2833-0	Subclass	Mfg. of agricultural and livestock machinery and equipment (excl. irrigation)
2853-4	Subclass	Mfg. of tractors (excl. agricultural), parts and accessories
2854-2	Subclass	Mfg. of earthmoving, paving and construction machinery
2910-7/01	Subclass	Mfg. of automobiles, vans and utility vehicles
2920-4/01	Subclass	Mfg. of trucks and buses
2930-1/01	Subclass	Mfg. of cabins, bodies and trailers for trucks
3314-7/11	Subclass	Maintenance and repair of agricultural machinery
3314-7/12	Subclass	Maintenance and repair of agricultural tractors
Div. 27	Division	Mfg. of electrical machinery, apparatus and materials
Div. 28 rem.	Division	Mfg. of machinery and equipment (remainder)
Div. 29 rem.	Division	Mfg. of motor vehicles, trailers and bodies (remainder)
Div. 30	Division	Mfg. of other transport equipment
Panel B: Fertilizer / Chemicals		
Class 2012	Class	Mfg. of fertilizer intermediates
Class 2013	Class	Mfg. of fertilizers (organic-mineral and others)
Class 2051	Class	Mfg. of agricultural defensives (crop protection)
Class 2122	Class	Mfg. of veterinary medicines
Class 4683	Class	Wholesale of defensives, fertilizers and soil correctives

B Calibration Tables and Combined Policies

Figure A.21: Compliant and non-compliant farms with $\theta_c = \theta_p$



Notes: The figure plots the same objects as Figure 6 in the stationary equilibrium with $\theta_c = \theta_p$ and all other parameters at their baseline values. The horizontal axis is assets a and the vertical axis is productivity z_i of the farm's sector, both on a log scale. The two panels are crop farms and pasture farms.

Table A.5: Externally Calibrated Parameters

Parameter	Description	Param. Val.	Source
Preferences			
σ_c	Crop expenditure share	0.034	POF 2017–18
σ_p	Livestock expenditure share	0.037	POF 2017–18
Non-agricultural sector			
r	Risk-free rate	0.02	Cavalcanti, Kaboski, Martins and Santos (2021), p. 24
α_n	Capital share, non-ag	0.40	Gomes, Pessoa and Veloso (2003)
δ	Depreciation rate	0.08	Restuccia and Rogerson (2008)
Agricultural technology			
α_c	Capital elasticity, crops	0.434	Census 2017 (Legal Amazon)
α_p	Capital elasticity, pasture	0.229	Census 2017 (Legal Amazon)
μ_c	Forest externality, crops	0.00	—
μ_p	Forest externality, pasture	0.00	—
Forest Code			
$\bar{\rho}$	Legal reserve requirement	0.658	Property-area-weighted avg; Law 12,651/2012
Credit market			
τ^C	Compliant borrowing spread	0.000	Normalization
τ^{NC}	Non-compliant borrowing spread	0.000	Normalization
Normalizations			
$\mathbb{E}[s]$	Mean plot size	1	Normalization
Other			
$\underline{a}$	Asset lower bound	0	Natural borrowing limit

Notes: Crop and pasture farms are census establishments whose main economic activity is crop production (temporary and permanent) and livestock, respectively. σ_c and σ_p are expenditure on crop-based food (cereals, legumes and oilseeds, flours and pasta, roots, sugars, vegetables, fruits, breads, oils and fats) and on animal-based food (meats and fish, poultry and eggs, dairy), each relative to total household expenditure. α_i is purchases of machinery and vehicles relative to the sum of these purchases and the wage bill paid to hired workers. $\bar{\rho}$ averages the biome-specific Legal Reserve requirements: 80% in the Amazon biome, 35% in the Cerrado and 20% elsewhere.

Table A.6: Internally Calibrated Parameters and Targeted Moments (Legal Amazon)

Parameter	Param. Val.	Model Moment	Data Moment	Model Val.	Target	Source
A_n	1.868	$1 - \int o^W \, dG + \sum_{i,j} \int o_i^j n_i^j \, dG$	Agricultural share of employment	0.218	0.171 (0.030)	PNAD Contínua, 2017
$\tilde{p}_c$	4.616	$\sum_{i,j} \int o_i^j \tilde{p}_i y_i^j \, dG \,/\, (Y_n + \sum_{i,j} \int o_i^j \tilde{p}_i y_i^j \, dG)$	Agricultural gross value / total GDP	0.296	0.111 (0.15)	PIB Municípios, 2017
$\tilde{p}_p$	0.990	$\sum_j \int o_c^j \tilde{p}_c y_c^j \, dG \,/\, \sum_{i,j} \int o_i^j \tilde{p}_i y_i^j \, dG$	Crop value added / (crop + pasture) value added	0.903	0.595 (0.35)	Census 2017
ψ_c	0.0188	$\sum_j \int o_c^j (\delta k_c^j + w n_c^j) \, dG \,/ \sum_j \int o_c^j \tilde{p}_c y_c^j \, dG$	(Capital + labor cost) / value added, crop farms	0.017	0.161 (0.12)	Census 2017
ψ_p	0.171	$\sum_j \int o_p^j (\delta k_p^j + w n_p^j) \, dG \,/ \sum_j \int o_p^j \tilde{p}_p y_p^j \, dG$	(Capital + labor cost) / value added, pasture farms	0.157	0.180 (0.12)	Census 2017
θ_c	2.429	$\sum_j \int o_c^j l_c^j \, dG \,/ \int \tilde{s} \, dG$	Crop area, share of total property area (weighted)	0.103	0.087 (0.20)	CAR+MapBiomas
θ_p	0.0437	$\sum_j \int o_p^j l_p^j \, dG \,/ \int \tilde{s} \, dG$	Pasture area, share of total property area (weighted)	0.628	0.407 (0.30)	CAR+MapBiomas
ξ_c	2.282	$(\sum_j \int o_c^j k_c^j dG / \sum_j \int o_c^j l_c^j dG) \,/\, (\sum_j \int o_p^j k_p^j dG / \sum_j \int o_p^j l_p^j dG)$	Capital per hectare, crop relative to pasture farms	13.90	10.26	Census 2017
ξ_p	2.252	$\sum_j \int o_i^j q^j l_i^{j,\text{rented}} \, dG \,/\, \sum_j \int o_i^j \tilde{p}_i y_i^j \, dG$	Land rental expenditure / value added	0.001	0.045 (0.041)	Census 2017
$\zeta_{d,0}$	0.00059	$\mathbb{E}\left[d / \tilde{s} \mid f/\tilde{s} \in Q_5\right]$	Deforestation, share of property area, 5th quintile of forest share (weighted)	0.0032	0.0124 (0.037)	CAR+MapBiomas
$\zeta_{d,1}$	0.0071	$\mathbb{E}\left[d / \tilde{s} \mid f/\tilde{s} \in Q_1\right]$	Deforestation, share of property area, 1st quintile of forest share (weighted)	0.0000	0.0033 (0.011)	CAR+MapBiomas
$\zeta_{d,2}$	0.0031	$\int d \, dG \,/\, F$	Deforestation, share of forest area	0.0074	0.0187 (0.052)	CAR+MapBiomas
$\zeta_{r,0}$	0.0371	$\mathbb{E}\left[m / \tilde{s} \mid f/\tilde{s} \in Q_3\right]$	Reforestation, share of property area, 3rd quintile of forest share (weighted)	0.0006	0.0042 (0.014)	CAR+MapBiomas
$\zeta_{r,1}$	0.0877	$\mathbb{E}\left[m / \tilde{s} \mid f/\tilde{s} \in Q_1\right]$	Reforestation, share of property area, 1st quintile of forest share (weighted)	0.0015	0.0029 (0.011)	CAR+MapBiomas
$\zeta_{r,2}$	63.89	$\int m \, dG \,/ \int (\tilde{s} - f) \, dG$	Reforestation, share of non-forest area (weighted)	0.0038	0.0066 (0.024)	CAR+MapBiomas
ζ_e	0.00027	$\int \mathbf{1}\{f_{-1}/\tilde{s}_{-1} < \bar{\rho}\} \max\{-\Delta f, 0\} \, dG \,/ \int \max\{-\Delta f, 0\} \, dG$	Share of deforestation from non-compliant plots (weighted)	0.528	0.585	CAR+MapBiomas
ζ_e^y	0.0019	$\int \mathbf{1}\{f \geq \bar{\rho}\tilde{s}\} \, dG$	Share of farms meeting the Legal Reserve requirement (weighted)	0.261	0.349	CAR+MapBiomas
ρ	0.0435	$(K_n + \sum_{i,j} \int o_i^j k_i^j \, dG) \,/\, (Y_n + \sum_{i,j} \int o_i^j \tilde{p}_i y_i^j \, dG)$	Capital / output	2.85	2.25	—
$\lambda^{NC} = \lambda^C = \lambda$	1.599	$\Pr\left[k_i^j + \Phi_i(v_i^j) > a \mid o^W{=}0\right]$	Share of farms obtaining financing	0.203	0.104 (0.075)	Census 2017
ν_s	2.617	$P_{90}/P_{50}(\tilde{s})$	P_{90}/P_{50} of total property area (weighted)	19.59	19.41	CAR+MapBiomas
η_c	1.809	$\text{Gini}(\{l\}_{o_c=1})$	Gini of operated area, crop farms (weighted)	0.544	0.730	CAR+MapBiomas
η_p	1.205	$\text{Gini}\left(\{l\}_{o_p=1}\right)$	Gini of operated area, pasture farms (weighted)	0.870	0.866	CAR+MapBiomas
γ_z	0.136	$\gamma_z \sum_j \int o_p^j \, \Pr[o_c'{=}1] \, l_p^j \, dG \,/ \sum_j \int o_p^j l_p^j \, dG$	Annual pasture-to-crop conversion, share of pasture area	0.0271	0.0102 (0.014)	MapBiomas
γ_f	46.90	$\mathbb{E}\left\lvert\Delta(f/\tilde{s})\right\rvert \,/\, \text{sd}\left(\Delta(f/\tilde{s})\right)$	Mean absolute change in forest share, relative to the standard deviation of the change (weighted)	0.369	0.411	CAR+MapBiomas
$\underline{\varepsilon}$	-0.0040	$P_5(\Delta(f/\tilde{s}))$	5th percentile of the change in forest share (weighted)	-0.011	-0.041	CAR+MapBiomas
$\bar{\varepsilon}$	0.0185	$P_{95}(\Delta(f/\tilde{s}))$	95th percentile of the change in forest share (weighted)	0.0135	0.0163	CAR+MapBiomas

Notes: All moments are for 2017; annual changes are 2016–2017. Property area is $\tilde{s} \equiv f + l$. In the census, value added is gross production value net of intermediate consumption (fertiliser, pesticide, seed, feed, fuel, veterinary products, contracted services, freight, electricity), capital is machinery and vehicle purchases and labour is the wage bill paid to hired workers. Every CAR+MapBiomas moment is conditioned on land operated by a farmer and weighted by total property area, with the registry sample restricted to properties having at least 5% of their area in crops or pasture. Forest is native vegetation, the forest share is forest area relative to property area, the deforestation rate is the annual decrease in the forest share and the reforestation rate the annual increase. The Legal Reserve requirement is biome-specific (80% Amazon, 35% Cerrado, 20% elsewhere); a plot is non-compliant if its forest share falls below that requirement. The ATT is a staggered difference-in-differences estimate of the effect of rural credit access. Standard deviations are in parentheses and calculated across the units each moment aggregates (properties for CAR+MapBiomas, municipalities for Census, PIB Municípios, SICOR and MapBiomas, and states for PNAD Contínua), with the same weights.

Table A.7: Counterfactuals: policies combined with the Forest Code

		General equilibrium			Partial equilibrium		
	Baseline	I & III	II & III	IV & III	I & III	II & III	IV & III
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Shares and ratios	*Level (%)*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*	Δ *pp*
Share of land under forest ($F/\int s\,dG$)	56.39	1.82	1.85	0.82	−11.38	−10.85	−11.13
Share of plots that comply ($f/s \geq \bar{\rho}$)	94.09	0.48	0.55	0.07	−2.09	−1.99	−2.16
Share of land deforested per year	32.10	−0.28	−0.28	−0.68	−1.04	−1.12	−1.01
of which: on compliant plots	17.22	0.75	0.78	−0.88	−9.21	−9.04	−9.18
of which: on non-compliant plots	14.88	−1.03	−1.06	0.20	8.17	7.93	8.16
Share of land reforested per year	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Share of individuals who are farmers	20.56	0.00	0.00	0.00	0.00	0.00	0.00
of which: compliant farms	19.71	0.00	0.00	−0.05	−0.03	−0.03	−0.11
of which: non-compliant farms	0.85	0.00	0.00	0.05	0.03	0.03	0.11
Share of total farmland used for crops	14.14	0.13	0.14	−0.06	0.12	0.12	0.00
Share of farms that borrow	20.27	−6.25	−6.34	−4.90	−1.47	−1.62	−0.02
Farm borrowing / agricultural output	0.28	−0.09	−0.09	0.00	−0.06	−0.06	0.00
Panel B. Levels	*Level*	Δ %	Δ %	Δ %	Δ %	Δ %	Δ %
Total farm borrowing	0.0066	−32.77	−32.95	−0.20	−22.40	−22.68	−0.07
Average mechanization	3.9856	2.00	2.05	1.33	0.13	0.15	−0.01
Agricultural output	2.3434	−0.02	−0.02	−0.01	−0.01	−0.01	0.00
Rent on compliant land (q^C)	0.0051	48.21	48.37	33.58	0.00	0.00	0.00
Rent on non-compliant land (q^{NC})	0.0035	9.82	10.04	6.01	0.00	0.00	0.00

Notes: Policy III combined with Policies I, II and IV, defined in Table 2. In columns (2) to (4) q^C and q^{NC} clear both land markets; in columns (5) to (7) both rents are held at their baseline values. Definitions as in Table 2.

C Proof of Analytical Results

D Intensification choice

This appendix derives Proposition 1. Consider first farmers with positive production for whom the expenditure constraint is slack and borrowing status is locally fixed. Let

$$R^j_{b,i} \equiv r + \delta + \tau \mathbf{1}_{b,i}, \qquad B^j_{b,i} \equiv 1 + r + \tau \mathbf{1}_{b,i},$$

with $R^j_{b,i} > 0$ and $B^j_{b,i} > 0$, and define

$$\tilde{\alpha}_i \equiv \frac{1 - (1-\alpha_i)\psi_i}{1-\psi_i} = 1 + \frac{\alpha_i \psi_i}{1-\psi_i}.$$

Using (8), the interior first-order condition for intensification, conditional on $v_i > 1$, can be written as

$$L^j_i(v_i) = R^j_i(v_i),$$

where

$$L^j_i(v) \equiv \frac{q^j}{\theta_i v^2} z_i \left[\psi_i p^j_i \left(\frac{1-\alpha_i}{w} \right)^{(1-\alpha_i)\psi_i} \left(\frac{\alpha_i \theta_i v}{R^j_{b,i} \theta_i v + q^j} \right)^{1-(1-\alpha_i)\psi_i} \right]^{\frac{1}{1-\psi_i}},$$

and

$$R^j_i(v) \equiv B^j_{b,i} \Phi'_i(v), \qquad v > 1.$$

Since

$$\Phi_i(v) = \phi_i + (v-1)^{\xi_i}, \qquad v > 1, \quad \xi_i > 1,$$

we have

$$R^j_i(v) = B^j_{b,i} \xi_i (v-1)^{\xi_i - 1}.$$

Both $L^j_i(v)$ and $R^j_i(v)$ are continuous for $v > 1$. Moreover,

$$\lim_{v \downarrow 1} L^j_i(v) > 0, \qquad \lim_{v \downarrow 1} R^j_i(v) = 0.$$

As $v \to \infty$,

$$L^j_i(v) = C^j_i v^{\tilde{\alpha}_i - 2} (R^j_{b,i} \theta_i v + q^j)^{-\tilde{\alpha}_i} \sim \tilde{C}^j_i v^{-2} \to 0,$$

for positive constants C^j_i and $\tilde{C}^j_i$, while

$$R^j_i(v) = B^j_{b,i} \xi_i (v-1)^{\xi_i - 1} \to \infty.$$

Therefore,

$$\lim_{v \downarrow 1} \left(L^j_i(v) - R^j_i(v) \right) > 0, \qquad \lim_{v \to \infty} \left(L^j_i(v) - R^j_i(v) \right) = -\infty.$$

By continuity, there exists at least one $v_i > 1$ satisfying $L^j_i(v_i) = R^j_i(v_i)$. Such a solution is an interior candidate only if its input choices satisfy the slack expenditure constraint and the assumed borrowing status.

For uniqueness on the smooth adopting branch, note that

$$L_i^j(v) = \bar{C}_i^j v^{\tilde{\alpha}_i - 2}(R_{b,i}^j \theta_i v + q^j)^{-\tilde{\alpha}_i}$$

for some $\bar{C}_i^j > 0$. Hence

$$\frac{d \ln L_i^j(v)}{dv} = \frac{\tilde{\alpha}_i - 2}{v} - \frac{\tilde{\alpha}_i R_{b,i}^j \theta_i}{R_{b,i}^j \theta_i v + q^j} = \frac{(\tilde{\alpha}_i - 2) q^j - 2 R_{b,i}^j \theta_i v}{v(R_{b,i}^j \theta_i v + q^j)}.$$

If

$$(\tilde{\alpha}_i - 2) q^j \leq 2 R_{b,i}^j \theta_i,$$

then $L_i^j(v)$ is weakly decreasing for $v > 1$. Since $R_i^j(v)$ is strictly increasing for $v > 1$, the equation $L_i^j(v) = R_i^j(v)$ has at most one solution on this branch. Using

$$\tilde{\alpha}_i - 2 = \frac{\alpha_i \psi_i}{1 - \psi_i} - 1,$$

the uniqueness condition is

$$\left(\frac{\alpha_i \psi_i}{1 - \psi_i} - 1 \right) q^j \leq 2(r + \delta + \tau \mathbf{1}_{b,i}) \theta_i.$$

A sufficient condition is $\tilde{\alpha}_i \leq 2$, which is equivalent to

$$\psi_i (1 + \alpha_i) \leq 1.$$

The fixed flow cost does not enter the interior first-order condition, but affects profits and financing requirements. The baseline $v_i = 1$ must therefore be evaluated separately, under its applicable financing regime, and compared with feasible adopting choices. Uniqueness of an interior adopting candidate does not exclude indifference between adoption and the baseline.

Now consider the binding-expenditure case. Define

$$\widehat{\alpha}_i := (1 - \alpha_i) \psi_i, \qquad \widehat{\psi}_i := \frac{\alpha_i \psi_i}{1 - \widehat{\alpha}_i}.$$

The binding constraint implies

$$k_i^{\chi,j}(v_i) = \chi a - \Phi_i(v_i), \qquad l_i^{\chi,j}(v_i) = \frac{\chi a - \Phi_i(v_i)}{\theta_i v_i}.$$

Feasibility requires $v_i \geq 1$ and $\Phi_i(v_i) \leq \chi a$. Since

$$\Phi_i(v_i) = \phi_i \mathbf{1}\{v_i > 1\} + (v_i - 1)^{\xi_i},$$

the feasible set is

$$\mathcal{V}_i(\chi a) = \begin{cases} \{1\}, & 0 \leq \chi a \leq \phi_i, \\ \left[1,\ 1 + (\chi a - \phi_i)^{1/\xi_i}\right], & \chi a > \phi_i. \end{cases}$$

This set is nonempty, closed, and bounded whenever $\chi a \geq 0$. In particular, adoption is feasible only if $\chi a > \phi_i$.

For a given v_i, optimal labor demand is

$$n_i^{\chi,j}(v_i) = \left[(1-\alpha_i)\psi_i p_i^j z_i^{1-\psi_i} \left(\chi a - \Phi_i(v_i)\right)^{\alpha_i\psi_i} \frac{1}{w}\right]^{\frac{1}{1-\widehat{\alpha}_i}}.$$

Hence there exists $A_i^j(p_i^j, w, z_i) > 0$ such that revenue net of labor costs can be written as

$$p_i^j y_i^{\chi,j}(v_i) - w n_i^{\chi,j}(v_i) = (1-\psi_i) A_i^j(p_i^j, w, z_i) \left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i}.$$

Substituting into profits yields the reduced problem

$$\max_{v_i \in \mathcal{V}_i(\chi a)} \Pi_i^{\chi,j}(v_i),$$

where

$$\begin{aligned}\Pi_i^{\chi,j}(v_i) = {} & (1-\psi_i) A_i^j(p_i^j, w, z_i) \left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i} - (r+\delta)\big(\chi a - \Phi_i(v_i)\big) \\ & - \frac{q^j}{\theta_i v_i}\big(\chi a - \Phi_i(v_i)\big) - (1+r)\Phi_i(v_i) - \tau(\chi - 1)a \\ & + \Big[q^C \mathbf{1}\{\beta \geq \bar{\beta}\} + q^{NC}\mathbf{1}\{\beta < \bar{\beta}\}\Big]\tilde{l}.\end{aligned}$$

If $\chi a \leq \phi_i$, the feasible set contains only $v_i = 1$, so an optimum exists. Suppose instead that $\chi a > \phi_i$. The reduced profit function need not be continuous at $v_i = 1$, because the fixed flow cost reduces capital from χa at the baseline to $\chi a - \phi_i$ in the limit along the adopting branch.

For $v_i > 1$, the adopting branch is continuous and has a finite right-hand limit at $v_i = 1$. Extending this branch to $v_i = 1$ using that limit gives a continuous function on the compact interval

$$\left[1,\ 1 + (\chi a - \phi_i)^{1/\xi_i}\right].$$

The Weierstrass theorem therefore guarantees a maximum of this extended branch.

For $v_i > 1$ with positive capital, differentiating reduced profits gives

$$\begin{aligned}\frac{\partial \Pi_i^{\chi,j}}{\partial v_i} = {} & \left[\delta - 1 + \frac{q^j}{\theta_i v_i} - (1-\psi_i)\widehat{\psi}_i A_i^j(p_i^j, w, z_i)\left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i - 1}\right]\Phi_i'(v_i) \\ & + \frac{q^j}{\theta_i v_i^2}\big(\chi a - \Phi_i(v_i)\big).\end{aligned}$$

For

$$1 < v_i < 1 + (\chi a - \phi_i)^{1/\xi_i},$$

we have $\Phi_i'(v_i) > 0$, and therefore

$$\begin{aligned}\frac{1}{\Phi_i'(v_i)}\frac{\partial \Pi_i^{\chi,j}}{\partial v_i} = {} & \delta - 1 + \frac{q^j}{\theta_i v_i} - (1-\psi_i)\widehat{\psi}_i A_i^j(p_i^j, w, z_i)\left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i - 1} \\ & + \frac{q^j\left(\chi a - \Phi_i(v_i)\right)}{\theta_i v_i^2 \Phi_i'(v_i)}.\end{aligned}$$

The right-hand side is strictly decreasing throughout this interval. Indeed, $\chi a - \Phi_i(v_i)$ is strictly decreasing, $\Phi_i'(v_i)$ is positive and strictly increasing, and $\widehat{\psi}_i \in (0,1)$. Moreover,

$$\lim_{v_i \downarrow 1} \frac{1}{\Phi_i'(v_i)} \frac{\partial \Pi_i^{\chi,j}}{\partial v_i} = +\infty,$$
$$\lim_{v_i \uparrow 1+(\chi a - \phi_i)^{1/\xi_i}} \frac{1}{\Phi_i'(v_i)} \frac{\partial \Pi_i^{\chi,j}}{\partial v_i} = -\infty.$$

Thus there is exactly one interior adopting choice satisfying the first-order condition. Reduced profits increase before this choice and decrease after it, so it is the unique maximizer conditional on adoption and has positive capital. The strict second-order condition holds at this maximizer.

Comparing its profit with the actual baseline profit $\Pi_i^{\chi,j}(1)$ establishes existence of an optimal intensification choice. The baseline can be optimal because adoption requires paying the fixed flow cost. The overall choice is unique unless the baseline and the adopting maximizer yield the same profit.

For positive capital, candidates must also satisfy the corresponding financing-regime conditions. If $\lambda > 1$,

$$\alpha_i \psi_i \frac{p_i^j y_i}{k_i} - (r+\delta) - \frac{q^j}{\theta_i v_i} \begin{cases} = 0, & k_i + \Phi_i(v_i) < a, \\ = \tau, & a < k_i + \Phi_i(v_i) < \lambda a, \\ \in [0,\tau], & k_i + \Phi_i(v_i) = a < \lambda a, \\ \geq \tau, & a < k_i + \Phi_i(v_i) = \lambda a. \end{cases}$$

The inequalities at the self-financing kink reflect the difference between the marginal costs of internal and external finance. At the collateral boundary, the marginal return can exceed the borrowing cost because further borrowing is infeasible.

If $\lambda = 1$, borrowing is infeasible. At the coincident self-financing and collateral boundary $k_i + \Phi_i(v_i) = a$, the condition is

$$\alpha_i \psi_i \frac{p_i^j y_i}{k_i} - (r+\delta) - \frac{q^j}{\theta_i v_i} \geq 0.$$

These conditions apply together with optimal intensification within the relevant financing regime. All feasible candidates, including the baseline $v_i = 1$, are compared in the full static problem.

D.1 Comparative statics of intensification

This appendix derives Proposition 2. All derivatives are evaluated at an interior adopting choice $v_i > 1$ with positive capital, under the maintained strict second-order condition and an unchanged financing regime.

Consider first the slack-expenditure case, with borrowing status $\mathbf{1}_{b,i}$ locally fixed. Using

$$R_{b,i}^j \equiv r + \delta + \tau \mathbf{1}_{b,i}, \qquad B_{b,i}^j \equiv 1 + r + \tau \mathbf{1}_{b,i},$$

the interior first-order condition for intensification is

$$\frac{q^j}{\theta_i v_i^2} k_i^j(v_i; R_{b,i}^j, q^j, w, p_i^j) = B_{b,i}^j \Phi_i'(v_i). \tag{12}$$

On the adopting branch, the fixed flow cost has zero derivative, so this condition retains its previous form. For a given v_i,

$$k_i^j(v_i) = z_i \left[\psi_i p_i^j \left(\frac{1-\alpha_i}{w} \right)^{(1-\alpha_i)\psi_i} \left(\frac{\alpha_i}{R_{b,i}^j + q^j/(\theta_i v_i)} \right)^{1-(1-\alpha_i)\psi_i} \right]^{\frac{1}{1-\psi_i}}.$$

Hence $k_i^j(v_i)$ is decreasing in $R_{b,i}^j$, decreasing in w, and increasing in p_i^j. Under the strict second-order condition, the left-hand side of (12) is locally decreasing in v_i relative to the right-hand side. Therefore a rise in $R_{b,i}^j$ shifts the left-hand side down, and a rise in $B_{b,i}^j$ shifts the right-hand side up. Since both $R_{b,i}^j$ and $B_{b,i}^j$ increase with r, and both increase with τ when $\mathbf{1}_{b,i} = 1$,

$$\frac{\partial v_i^j}{\partial r} < 0, \qquad \frac{\partial v_i^j}{\partial \tau} < 0 \quad \text{if } \mathbf{1}_{b,i} = 1.$$

When $\mathbf{1}_{b,i} = 0$, τ does not enter the slack-expenditure first-order condition. A rise in w lowers $k_i^j(v_i)$, so

$$\frac{\partial v_i^j}{\partial w} < 0.$$

A rise in p_i^j raises $k_i^j(v_i)$, so

$$\frac{\partial v_i^j}{\partial p_i^j} > 0.$$

Assets a and borrowing capacity λ do not enter (12) when the expenditure constraint is slack and borrowing status is fixed. Thus

$$\frac{\partial v_i^j}{\partial a} = 0, \qquad \frac{\partial v_i^j}{\partial \lambda} = 0.$$

The sign of the response to q^j is ambiguous because a higher q^j raises the direct land-saving return, $q^j/(\theta_i v_i^2)$, but lowers $k_i^j(v_i)$ through the effective unit cost $R_{b,i}^j + q^j/(\theta_i v_i)$.

Now consider the binding-expenditure case. Using the definitions in Appendix D, the interior first-order condition can be written as

$$\left[(1-\psi_i)\widehat{\psi}_i A_i^j(p_i^j, w, z_i) \left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i - 1} + 1 - \delta - \frac{q^j}{\theta_i v_i} \right] \Phi_i'(v_i) = \frac{q^j}{\theta_i v_i^2} \left(\chi a - \Phi_i(v_i)\right). \tag{13}$$

The terms r and τ enter reduced profits only through terms that are constant in v_i, conditional on χa. Hence

$$\frac{\partial v_i^{\chi,j}}{\partial r} = 0, \qquad \frac{\partial v_i^{\chi,j}}{\partial \tau} = 0 \quad \text{conditional on } \chi a.$$

Under the maintained strict second-order condition, the implicit-function theorem determines the signs of the local comparative statics from shifts in (13). An increase in q^j raises the right-hand side and lowers the bracketed marginal-value term through $-q^j/(\theta_i v_i)$. Therefore

$$\frac{\partial v_i^{\chi,j}}{\partial q^j} > 0.$$

An increase in w lowers $A_i^j(p_i^j, w, z_i)$, reducing the opportunity cost of the capital services crowded out by intensification. Thus

$$\frac{\partial v_i^{\chi,j}}{\partial w} > 0.$$

An increase in p_i^j raises $A_i^j(p_i^j, w, z_i)$, increasing the opportunity cost of reducing capital services, and therefore

$$\frac{\partial v_i^{\chi,j}}{\partial p_i^j} < 0.$$

Finally, differentiating with respect to assets gives

$$\frac{\partial^2 \Pi_i^{\chi,j}}{\partial v_i \, \partial a} = \chi \Bigg[(1-\psi_i)\widehat{\psi}_i(1-\widehat{\psi}_i) A_i^j(p_i^j, w, z_i) \times \left(\chi a - \Phi_i(v_i)\right)^{\widehat{\psi}_i - 2} \Phi_i'(v_i) + \frac{q^j}{\theta_i v_i^2} \Bigg] > 0.$$

Similarly,

$$\frac{\partial^2 \Pi_i^{\chi,j}}{\partial v_i \, \partial \chi} = \frac{a}{\chi} \frac{\partial^2 \Pi_i^{\chi,j}}{\partial v_i \, \partial a} > 0.$$

These inequalities use $\widehat{\psi}_i \in (0,1)$, $q^j > 0$, positive capital, $v_i > 1$, and $a, \chi > 0$.

By the maintained strict second-order condition, $\partial^2 \Pi_i^{\chi,j} / \partial v_i^2 < 0$. Therefore,

$$\frac{\partial v_i^{\chi,j}}{\partial a} = -\frac{\partial^2 \Pi_i^{\chi,j} / \partial v_i \, \partial a}{\partial^2 \Pi_i^{\chi,j} / \partial v_i^2} > 0,$$

$$\frac{\partial v_i^{\chi,j}}{\partial \chi} = -\frac{\partial^2 \Pi_i^{\chi,j} / \partial v_i \, \partial \chi}{\partial^2 \Pi_i^{\chi,j} / \partial v_i^2} > 0.$$

The response to χ describes the response to borrowing capacity when $\chi = \lambda$. At the self-financing kink, $\chi = 1$ remains fixed.

D.2 Intensification adoption and operated land

This appendix proves Proposition 3.

For the first part, the binding expenditure boundary and $\Phi_i(1) = 0$ imply

$$k_i^{\chi,j}(1) = \chi a, \qquad l_i^{\chi,j}(1) = \frac{\chi a}{\theta_i}.$$

For any feasible choice $v_i > 1$,

$$l_i^{\chi,j}(v_i) = \frac{\chi a - \Phi_i(v_i)}{\theta_i v_i}.$$

Consequently,

$$\frac{l_i^{\chi,j}(v_i)}{l_i^{\chi,j}(1)} = \frac{1 - \Phi_i(v_i)/(\chi a)}{v_i} < 1,$$

because $\Phi_i(v_i) > 0$ and $v_i > 1$. This establishes the first part.

For the second part, the baseline choice $v_i = 1$ at the self-financing boundary has capital a and operated land a/θ_i. After adoption, the binding collateral constraint implies

$$k_i = \lambda a - \Phi_i(v_i), \qquad l_i^j = \frac{\lambda a - \Phi_i(v_i)}{\theta_i v_i}.$$

Thus operated land falls precisely when

$$\frac{\lambda a - \Phi_i(v_i)}{\theta_i v_i} < \frac{a}{\theta_i}.$$

Since $\theta_i > 0$ and $v_i > 1$, this is equivalent to

$$\lambda a - \Phi_i(v_i) < v_i a,$$

or

$$(\lambda - 1)a < \Phi_i(v_i) + (v_i - 1)a.$$

This establishes the second part. Unlike the fixed-budget comparison, a finite increase in credit capacity need not reduce operated land: the larger expenditure budget can offset the land-saving effect of adoption.

D.3 First-order conditions of the HJB

The following first-order conditions apply where the relevant state constraints are locally non-binding. At state boundaries, choices must also satisfy the admissibility conditions stated in the main text.

The consumption terms in the HJB are

$$u(c_c, c_p, c_n) - V_a(c_n + \tilde{p}_c c_c + \tilde{p}_p c_p).$$

Thus

$$u_{c_n} = V_a, \qquad u_{c_c} = V_a \tilde{p}_c, \qquad u_{c_p} = V_a \tilde{p}_p.$$

With log preferences,

$$c_n = \frac{1 - \sigma_c - \sigma_p}{V_a}, \qquad c_c = \frac{\sigma_c}{V_a \tilde{p}_c}, \qquad c_p = \frac{\sigma_p}{V_a \tilde{p}_p}.$$

For forest adjustment, the relevant HJB terms are

$$-V_a C^d(d, f) - V_f d, \qquad -V_a C^r(m, f) + V_f m.$$

With $d \geq 0$ and $m \geq 0$, the Kuhn–Tucker conditions are

$$V_a C_d^d(d, f) + V_f \geq 0, \qquad d\left[V_a C_d^d(d, f) + V_f\right] = 0,$$

and

$$V_a C_m^r(m, f) - V_f \geq 0, \qquad m\left[V_a C_m^r(m, f) - V_f\right] = 0.$$

D.4 Forest adjustment

The HJB terms involving deforestation d are

$$-V_a C^d(d,f) - V_f d.$$

For an interior $d > 0$,

$$-V_a C^d_d(d,f) - V_f = 0,$$

or

$$V_a \left[\zeta_{d,0} + \zeta_{d,1}\left(1 - \frac{f}{s}\right) + \zeta_{d,2}\frac{d}{s}\right] + V_f = 0.$$

With the non-negativity constraint $d \geq 0$, this becomes the Kuhn–Tucker condition in Proposition 4.

The HJB terms involving reforestation m are

$$-V_a C^r(m,f) + V_f m.$$

For an interior $m > 0$,

$$-V_a C^r_m(m,f) + V_f = 0,$$

or

$$V_a \left[\zeta_{r,0} + \zeta_{r,1}\left(1 - \frac{f}{s}\right) + \zeta_{r,2}\frac{m}{s}\right] - V_f = 0.$$

The corresponding Kuhn–Tucker condition follows from $m \geq 0$.

E Market Clearing Conditions

Let G denote the stationary distribution. Capital-market clearing, including working capital, is

$$\sum_{j\in\{C,NC\}} \sum_{i\in\{c,p\}} \int o_i^j(a,\mathbf{z},s,f)\left[k_i^j(a,\mathbf{z},s,f) + \Phi_i\left(v_i^j(a,\mathbf{z},s,f)\right)\right] G(da,d\mathbf{z},ds,df)$$
$$+ K_n = \int a\, G(da,d\mathbf{z},ds,df).$$

Labor-market clearing is

$$\sum_{j\in\{C,NC\}} \sum_{i\in\{c,p\}} \int o_i^j(a,\mathbf{z},s,f) n_i^j(a,\mathbf{z},s,f)\; G(da,d\mathbf{z},ds,df)$$
$$+N_n = \int o^W(a,\mathbf{z},s,f)\, G(da,d\mathbf{z},ds,df).$$

Compliant land clears when

$$\sum_{i\in\{c,p\}} \int o_i^C(a,\mathbf{z},s,f) l_i^C(a,\mathbf{z},s,f)\, G(da,d\mathbf{z},ds,df)$$
$$= \int \mathbf{1}\{\beta \geq \bar{\beta}\}(s-f)\, G(da,d\mathbf{z},ds,df).$$

Non-compliant land clears when

$$\sum_{i\in\{c,p\}} \int o_i^{NC}(a,\mathbf{z},s,f) l_i^{NC}(a,\mathbf{z},s,f)\, G(da,d\mathbf{z},ds,df)$$
$$= \int \mathbf{1}\{\beta < \bar{\beta}\}(s-f)\, G(da,d\mathbf{z},ds,df).$$

These conditions equate operated land with agricultural land available from plots of each compliance status, including land used by its owner as well as rented land. For each agricultural good $i \in \{c, p\}$, equilibrium requires

$$\int c_i(a, \mathbf{z}, s, f)\, G(da, d\mathbf{z}, ds, df) = \sum_{j \in \{C,NC\}} \int o_i^j(a, \mathbf{z}, s, f) y_i^j(a, \mathbf{z}, s, f)\, G(da, d\mathbf{z}, ds, df).$$

Let $x = (a, \mathbf{z}, s, f)$. The non-agricultural good clears when

$$\begin{aligned}
&\int c_n(x)\, G(dx) + \delta K_n + \sum_{j \in \{C,NC\}} \sum_{i \in \{c,p\}} \int o_i^j(x) \left[\delta k_i^j(x) + \Phi_i\left(v_i^j(x)\right)\right] G(dx) \\
&\quad + \sum_{j \in \{C,NC\}} \sum_{i \in \{c,p\}} \int o_i^j(x) \tau \max\left\{k_i^j(x) + \Phi_i\left(v_i^j(x)\right) - a, 0\right\} G(dx) \\
&\quad + \int C^d(d(x), f)\, G(dx) + \int C^r(m(x), f)\, G(dx) \\
&\quad + \int \mathbf{1}\{f/s < \bar{\beta}\} \zeta_e(\bar{\beta} s - f)\, G(dx) \\
&\quad + \sum_{i \in \{c,p\}} \int o_i^{NC}(x) \zeta_e^y \tilde{p}_i y_i^{NC}(x)\, G(dx) = Y_n.
\end{aligned}$$