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A Macroeconomic Perspective of Structural Deforestation in Brazil's Legal Amazon

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Abstract

Despite policy efforts in recent decades, deforestation remains a pervasive phenomenon in Brazil. Yet deforestation is not only affected by forest governance. It is also driven by global demand for commodities and the relative competitiveness of agriculture, which in turn depends on macroeconomic factors impacting product and factor prices. These macroeconomic mechanisms remain largely unexplored. This paper explores the role of economic productivity in shaping deforestation. It uses an economic model with an empirically founded land use extension to study the macro-structural drivers of land use patterns in Brazil's Legal Amazon. It demonstrates that productivity gains in the Legal Amazon's agriculture sector increase deforestation, while such gains in non-land intensive sectors (such as manufacturing) reduce deforestation by attenuating the relative competitiveness of agriculture. Higher productivity in other parts of Brazil also reduces incentives for forest conversion in the Legal Amazon. The paper points to the economic forces that forest protection efforts need to counter, while calling for complementary structural reforms to overcome "Brazilian disease" in the longer-term: addressing the legacy of import substitution industrialization and moving up the value chain will shift economic drivers beyond commodities, thus also reconciling development with standing forests.

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A Macroeconomic Perspective of Structural Deforestation in Brazil's Legal Amazon

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1. Introduction

Deforestation and land use change are among the largest source of net CO2 emissions for Brazil and a major threat to biodiversity. Most deforestation in Brazil occurs in the nine states of the Legal Amazon (Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins, and some municipalities in the state of Maranhão). Among those states, deforestation tends to be concentrated in the southeast, also known as the "Arc of Deforestation", which keeps shifting north from the Cerrado savannah into the Amazon rainforest. The Amazon is at risk of vast irreversible destruction if a tipping point is triggered (Nepstad et al. 2008; Golding and Betts 2008; Vergara and Scholz, 2010; Franklin and Pindyck, 2018). Accordingly, one of Brazil's central commitments in the Nationally Determined Contribution under the Paris Climate Accord, most recently renewed at COP26, is to halt illegal deforestation.

Deforestation in the Legal Amazon fell significantly in the 2000s, mostly attributed to Brazil's Plan for Deforestation Prevention and Control for the Amazon of 2004 which focused on 1) land tenure and territorial planning, 2) environmental monitoring and control, and 3) fostering sustainable production. According to the Brazilian *Instituto Nacional de Pesquisas Espaciais (INPE)*, deforestation in the Legal Amazon fell from 27,772 km^2 per year in 2004 to 4,571 km^2 per year in 2012.[1] Since then, deforestation slowly picked up again. In 2021, deforestation reached 13,235 km^2. There is evidence that Command and Control policies can reduce deforestation (Assunção et al. 2019) and the recent increase in deforestation has generally been associated with weaker environmental law enforcement (e.g. Blackman 2020). Indeed, environmental law enforcement has weakened over the last two years, as declining fines for environmental crimes relative to accelerating deforestation illustrate (OECD, 2021), pinpointing the role of weakening law enforcement in the recent surge in deforestation in the Legal Amazon.

One angle less discussed in the literature is the macroeconomic drivers of deforestation. Wunder and Sunderlin (2004) show for a number of tropical countries that oil exporting economies tend to experience lower deforestation levels. This is consistent with the 'Dutch Disease' effect, where commodity sectors crowd out other tradable sectors like manufacturing or, indeed, agriculture or forestry. More recently, Richards (2021) also argues that macroeconomic forces related to the economy's rate of economic growth have important effects on deforestation. This paper falls into a similar tradition, focusing on productivity.

The paper proposes that, from a macro-structural perspective, given a certain effectiveness of forest governance, deforestation in the Legal Amazon is the result of the inability of the Brazilian economy to overcome its legacy of import substitution industrialization. It entails a relatively weak manufacturing sector, protected by high trade tariffs juxtaposed with a highly competitive agriculture sector. Given the growing demand for agricultural products, competitive agriculture is land-hungry, sustaining strong demand for agricultural land—which drives deforestation. In this sense, a structural imbalance in Brazil's economy causes a structural deforestation problem, which, leaning on the "Dutch Disease" concept, could be termed "Brazilian Disease".

Overcoming "Brazilian Disease" would require advancing the Brazilian economy in its structural transformation toward productivity gains in more urban, less land-intensive traded sectors (like manufacturing) which would mitigate economic pressures on natural lands. This would not only reduce pressure on deforestation but also reinvigorate economic growth in Brazil, which in the

[1] http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/rates

longer-term depends on productivity gains. A second point developed in this paper is that an increase in agricultural productivity in already consolidated land markets, notably in the south and southeast of Brazil rather than the frontier of the Legal Amazon markets, could also help raise national agricultural output while reducing overall deforestation pressures.

Structural economic change takes time and effective forest governance remains critical to counter the economic forces that drive deforestation in the shorter-term. In this light, structural policies to overcome "Brazilian Disease" and governance measures to protect forests are complementary.

2. Related literature

As many other countries in Latin America and the developing world more generally, Brazil aimed to diversify from its externally competitive agricultural model into higher value-added activities by adopting a model of import substitution industrialization in the early 20th century (Vidal Luna and Klein 2014). This model has helped Brazil become a higher middle-income country with a gross domestic product (GDP) per capita of US$ 6,797 in 2020. Much of the growth to reach this level of development was driven by factor accumulation, notably demographics and growth in labor supply, accompanied by higher school enrollment, with lower savings rates limiting capital accumulation. Dutz (2018) shows that this was not, however, accompanied by significant progress in the quality of human capital or productivity. In fact, total factor productivity in Brazil has disappointed, remaining flat or even being negative.

At the heart of this lies a poorly performing manufacturing sector. Vasconcelos (2017), following the methodology proposed by Hsieh and Klenow (2009), found significant misallocation of resources in Brazil's formal manufacturing sector, explaining low productivity of manufacturing. As another source of low manufacturing productivity, Lisboa et al. (2010) identify Brazil's high tariff structures which limit the ability to import technologically sophisticated products and components. This contrasts with an agriculture sector that has always been export-oriented, from sugarcane and coffee in the early years to other crops like soybeans in more recent years. At the same time, Brazil's agricultural research and development system[2] has helped make Brazilian agriculture highly productive (IFPRI, 2016). This helps explain the large gap in the productivity performance of agriculture and manufacturing in Brazil: data from the *Fundação Getúlio Vargas's* (FGV) *Observatório da Produtividade* show that between 1996 and 2020 labor productivity grew by 5.8% in agriculture and -0.9% in manufacturing on average.

In principle, higher productivity in agriculture should reduce the required inputs to produce a certain amount of output, given the higher implied efficiency. However, while this tends to hold at the global level, it does not necessarily hold at the local level. This is known in the literature as the Jevons effect where higher productivity results in more intensive resource use (Jevons, 1866). Hertel (2012) provides a framework under which the Jevons effect emerges in agriculture. It emerges when the land supply is relatively elastic, as expanding land will only result in a small increase in its price, facilitating more extensive farming. For as long as native forests are not properly protected, the vast forests of the Legal Amazon imply an elastic land supply. Secondly, deforestation is more likely to occur when demand is elastic as farmers can expand outputs without

[2] The Brazilian Agricultural Research Corporation (Embrapa) and many other institutions, like research centers and universities.

causing large price drops. As the infrastructure in the Legal Amazon strengthens market access, demand becomes increasingly elastic, and export-oriented commodities (which tend to have relatively elastic demand) like soy and beef become attractive, causing deforestation from agricultural expansion.

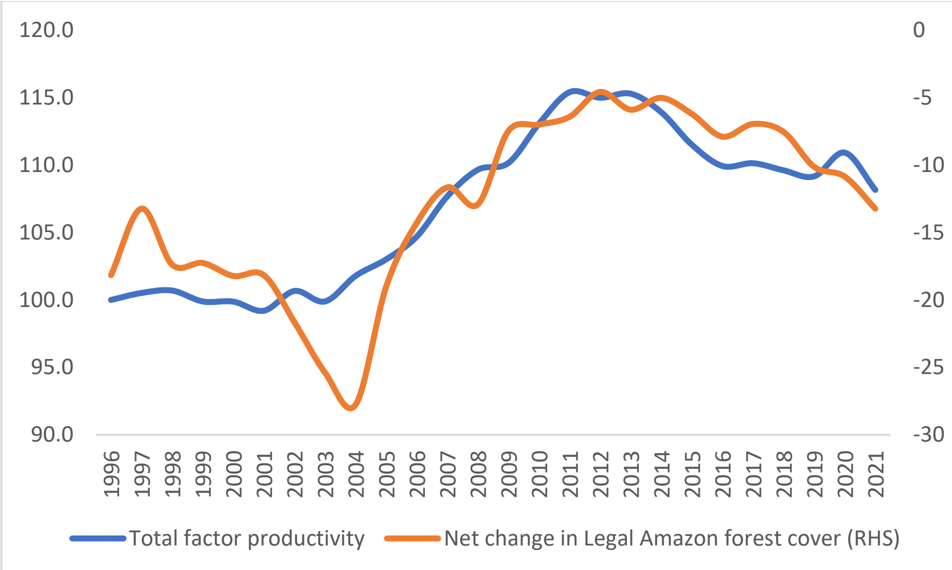
Policy in Brazil has aimed at restricting the land supply through environmental policies, including designating vast lands as protected or indigenous areas, a strong Forest Code, and sophisticated law enforcement (Command and Control). In principle, this would provide incentives to intensify agricultural production. However, as shown in Instituto Escolhas (2017) and Ferreira Filho et al. (2018), restricting the land supply results in significant welfare losses, due to higher food prices and lower agricultural employment, relative to the baseline. This is one reason why compliance with environmental protection laws tends to be relatively low in the Amazon states (Schons et al. 2019), allowing structural economic forces to continue shaping deforestation in the Legal Amazon.

Conversely, lower agricultural competitiveness or raising the cost of land relative to other production factors would reduce conversion of forest to productive land. These variables are affected by general equilibrium effects across the economy. The Balassa-Samuelson effect (Balassa, 1964 and Samuelson, 1964) entails that productivity increases in one sector do not only raise wages and prices in this sector but rather in the entire economy. This means that in order to remain competitive, all sectors need to raise their productivity so as not to be crowded out by the most productive sectors. This means that a productivity gain across the economy will also impact the relative competitiveness of agriculture and the cost of its factors of production. This impacts deforestation.

Figure 1 provides some illustration of those effects in Brazil. The graph focuses on the period 1996 to 2021 owing to data availability and to exclude the period of Brazil's macroeconomic stabilization under the Plano Real of 1994. As can be seen, there is a strong correlation[3] between national total factor productivity and deforestation in the Legal Amazon. Since the productivity gain of the 2000s was largely caused by past structural reforms and the last commodity price supercycle (Dutz 2018), Figure 1 suggests that both domestic structural policies and the commodity boom were sizeable contributors to lower deforestation in the Legal Amazon. As the effects of structural reforms dissipated and the commodity boom ended, deforestation accelerated again.

[3] The R2 of regressing one variable on the other is 77%.

Figure 1. Total factor productivity (index, LHS) and year net change in Legal Amazon forest cover ('000km2, RHS)



Source: FGV, INPE PRODES and authors' representation

Agriculture only accounts for about 5 percent of GDP in Brazil,[4] therefore what matters in the rest of the economy also matters for deforestation. The low productivity of manufacturing provides an artificial boost to agriculture: if Brazil were to advance in its structural transformation toward more urban, traded sectors (notably manufacturing), this would reduce the external competitiveness of agriculture and thus attenuate the structural drivers of deforestation, or the "Brazilian disease". This is further aided by a second channel. As machinery and inputs are produced by the manufacturing sector, productivity gains in manufacturing would reduce the cost of capital and inputs for agriculture, relative to the price of land—or, alternatively, higher Brazilian purchasing power associated with productivity gains would lower the cost of importing machines or inputs. Irrespective, higher productivity in urban sectors would then reduce the demand for land and thus deforestation.

In addition, this paper also suggests that there are differential effects across Brazilian regions. Agriculture is highly developed in Brazil's south, southeast and center-west, with much lower productivity in the Legal Amazon (Souza-Rodrigues, 2019). States outside the Legal Amazon have already gone through a process of deforestation. This also suggests that the land supply there is already relatively low since natural forest stocks are used up in those areas and land markets are more developed (Helfand and Taylor 2018). Therefore, agricultural productivity gains in these parts of Brazil would reduce deforestation pressures by shifting more production to those parts of the country and away from the forests of the Legal Amazon.

Finally, this paper draws attention to the fact that deforestation is not merely a problem of the Legal Amazon states. While it is well known that global agricultural demand is a driver of deforestation in Brazil (Assunção et al. 2015) and globally (WRI, 2019), the role of economic development and deforestation within the Brazilian federation is less well researched. Cattaneo (2005, 2008) analyzed the differential effects of productivity increases in agriculture, when

[4] According to Brazil's 2019 National Accounts.

occurring in different activities and locations inside the territory. Differently from our analysis, however, his focus is on agricultural productivity solely. In this paper we extend the idea to include a broader framework, where manufacturing productivity increases relative to agriculture play a key role to explain deforestation.

Yet the economies of the Legal Amazon are very small, at only about 9 percent of total Brazilian GDP. Embedded in the broader national economy, what happens elsewhere in the country also impacts land use dynamics in the Legal Amazon, including through macroeconomic variables like the exchange rate and other relative prices. This paper shows that raising productivity in other parts of Brazil, in agriculture (as mentioned earlier) but also in more urban sectors, slows deforestation in the Legal Amazon. In other words, raising productivity in São Paulo's manufacturing sector can reduce deforestation pressures in the Legal Amazon.

3. Methodology

The analysis was performed with the aid of the TERM-BR model, a computable general equilibrium (CGE) model of Brazil, tailored for land-use analysis, built on previous work by Ferreira Filho and Horridge (2012, 2014). The detailed core model structure is described in Horridge (2011), and a summary of the Brazilian version is provided here.

The TERM-BR model is a recursive, bottom-up, dynamic computable general equilibrium model that includes a detailed regional representation of Brazil, with 27 regions (26 states plus the Federal District), 110 products and 110 productive activities, 10 types of families (classified by family income bracket) and 10 types of work (classified by salary range).

From the point of view of its dynamic behavior, the model presents solutions for annual periods, evolving in time guided by a dynamic process that consists of four mechanisms:

- A stock-flow relationship between investment in a given period and capital stock in the following period;
- A positive relationship between sectoral investment and the respective rate of profit;
- A positive relationship between real wage variation and regional labor supply[5]; and
- A positive relationship between deforestation in a given period and the available land stock for agriculture and livestock in the following period.

Through these mechanisms it is possible, together with other hypotheses, to design a baseline for a given economy, that is, an inertial trajectory of growth in relation to which a second trajectory (policy trajectory), which differs from the first only in terms of the economic policy to be implemented, can be compared. The difference between the two trajectories is the effect of the policy under analysis. The policy scenarios in this study entail various alternative productivity evolution patterns.

The TERM-BR model has as particular characteristic a land use change (LUC) module and an associated GHG emissions module; as well as a second emissions matrix describing emissions on fuel use and on the activities' level of production.

[5] Inter-state labor migration is controlled by a source-destination pairwise matrix of migration elasticities, from Barbosa (2021).

The transition matrix concept gives support to the LUC module in the model. These matrices, elaborated by state and biome, make use of information obtained through satellite imagery for land use changes (LUC) observed between 2002 and 2010 (MCT, 2015). This information was processed to distinguish three major types of land use, Crops (CROP), Pastures (PASTURE) and Forestry (planted forests, FORESTRY), and a residual type identified in the model as UNUSED, which refers to native forests. These transition matrices are detailed by state and, within each state, by six distinct biomes: Amazon, Cerrado, Caatinga, Atlantic Forest, Pampa and Pantanal. An example can be seen in Table 1, which displays the observed original transitions for the Mato Grosso state.

Table 1. Transition matrix for the state of Mato Grosso, Cerrado biome. Millions of hectares.

	1 Crop	2 Pasture	3 PlantForest	4 Unused	Total 2002
1 Crop	8.32	0.82	0.02	0.05	9.20
2 Pasture	2.23	37.57	0.06	0.53	40.38
3 PlantForest	0.00	0.00	0.02	0.00	0.03
4 Unused	0.47	0.98	0.00	13.16	14.61
Total 2010	11.01	39.37	0.10	13.73	64.22

Source: model database.

The transition matrix in Table 1 shows, for example, that 0.53 million hectares (Mha) of physical units of land of the Cerrado biome in the state of Mato Grosso, which was natural vegetation in 2002, became Pasture in 2010, while 13.16 Mha remained as natural vegetation. In the same state and period, 0.82 Mha of Pasture was transformed into Crops. The model has, therefore, for each biome in every state, a complete transition matrix. The data observed in the period mentioned above was processed to show the Markov probability that each hectare under given use in a certain year will be in another use the following year.

These transitions are also price influenced. Transition from pastures or forests to crops, for example, accelerates with the growth of the relative prices of agricultural products. Moreover, the model is flexible enough to allow exogenous projections of the level of deforestation according to desired patterns. In this case, the Transition Matrix ensures information consistency, that is, the increase of pasture, crop and forestry area in a given year must respect the increase in the available area given by deforestation in the previous year.

The transition matrices, then, determine the total land available for each broad land use group (Crops, Pasture, Forestry and Natural Forests or Unused). Once the amount of each aggregate category is determined, the model will allocate land among the activities within each category. Crop area, for example, will be allocated among the eleven agricultural activities of the model, through a CES (Constant Substitution Elasticity) function, based on the relative prices of the products of these activities.

An emissions matrix in LUC is associated to the transition matrices described above. This matrix accounts for emissions in LUC, and has the same dimensionality. The GHG emissions matrix associated to the LUC module (MCT, 2015), then, shows observed emissions on LUC transitions, by state and biome. This allows a detailed accounting of emissions on land use transitions, and the computation of sinks on forest restoration.

As mentioned above, the model has two main emissions matrices, which track all emissions in the economy. The second emissions matrix tracks emissions in all economy activities (except deforestation, which is dealt with in the transition matrix described above), where emissions are associated to each productive sector and final demand, and can be of two broad types (sources): emissions associated to fuel use and emissions associated to the level of activity of each sector (like fugitive emissions in mining, or CH4 emissions in livestock for example). All emissions are accounted by the original GHG gases, and transformed to CO2 equivalents using the Global Potential Warming for 100 years (GPW-100) coefficients from the IPCC Fifth Assessment Report –SAR (IPCC, 2014). These emissions are in fixed coefficients in either fuel use or the level of sector activity.

4. Simulation strategy

The TERM-BR model was used to perform a series of stylized simulations aiming to illustrate the importance of sectoral technological changes for deforestation, under different scenarios. The first step is to build a baseline from 2015 to 2030, which was used as a reference for the policy shocks. The period 2015-2018 is the historical period, when the model reproduces the observed pattern of the Brazilian economy. The policy scenarios start in 2019, the results of interest being the difference between the baseline and the policy trajectory.

Three main regional broad scenarios were used: a total factor productivity shock (increase) in Brazil, in the Legal Amazon states, and in the South/Southeast Brazil. In the first two cases, the productivity shocks were applied to different broad sectors, one by one: agriculture, mining, services and manufacturing. All activities within those broad sectors received the same productivity shock. An annual 0.5% increase in productivity was considered in the simulations, for each region and sectoral scenario.

5. Results

Table 2 depicts the cumulative impact of a permanent 0.5 percentage point increase in the displayed variables between the years 2019 and 2030. The results show that an increase in productivity across Brazil's tradable sectors—agriculture, mining, manufacturing—reduces deforestation, both in the Legal Amazon and in Brazil overall. Only productivity gains in the services sector are shown to very modestly raise deforestation. Overall, the model shows that an increase in Brazilian productivity reduces deforestation. This is consistent with Figure 1, where higher national productivity is correlated with lower deforestation. In fact, Table 2 shows that raising productivity even in other parts of Brazil alone would reduce deforestation in the Legal Amazon, consistent with the relatively small size of the Legal Amazon's economy, which is consequently shaped by broader national developments.

For agriculture, the results in Table 2 tell a nuanced story. When agricultural productivity increases in the Legal Amazon, the Jevons effect emerges, where higher agricultural productivity increases deforestation. This effect as also observed by Cattaneo (2008).At the national level, higher agricultural productivity reduces deforestation. This is consistent with the notion that land markets outside the frontiers of the Legal Amazon are more consolidated—essentially most deforestation has already happened there, so higher productivity tends to result in higher intensification of agriculture.

Beyond agriculture, productivity gains in all sectors in the Legal Amazon reduce deforestation. Within this overall finding, two results are noteworthy, however. First, manufacturing productivity reduces deforestation in the Legal Amazon and in Brazil overall—however, the reduction in deforestation across the country is slightly lower compared to the Legal Amazon. This suggests small spillovers of deforestation from the Legal Amazon states that experience a relative productivity gain to other Brazilian biomes, like the Cerrado. The reason for this is that the relative loss of agricultural competitiveness in the Legal Amazon associated with higher manufacturing productivity there will partly be picked up by agriculture in other parts of the country resulting in a small increase in deforestation there. The overall net effect however remains lower deforestation across Brazil.

Second, the model results suggest that services productivity unequivocally reduces deforestation across Brazil if it occurs in the Legal Amazon (contrary to the more ambiguous finding for national-level services productivity). The reason is that services tend to be nontraded, so an increase in productivity raises local consumption and imports without increasing exports (except through indirect value chain effects not captured by the CGE model). When happening at the national level, this raises consumption more than it lowers the relative competitiveness of agriculture through relative price movements. This additional demand for agricultural goods thus causes some additional deforestation. This effect is, however, weaker in the Legal Amazon where the services sector value share in the local economy is somewhat smaller than in the rest of Brazil—thus in the Legal Amazon the model suggests that an increase in services productivity also lowers deforestation there.

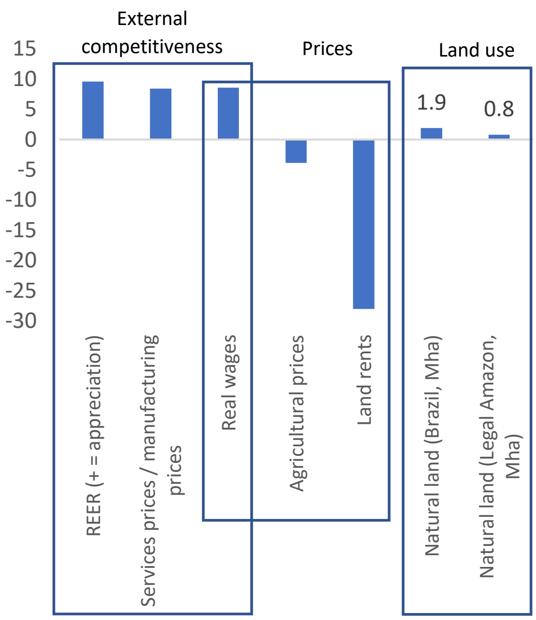
Table 2. Sectoral impacts productivity gains on growth, welfare, deforestation, and net emissions.

		Legal Amazon					All Brazil	
		GDP	**Land rents**	**Forested land (Mha)**	**CO2 (gG)**		**Forested land (Mha)**	**CO2 (gG)**
TFP Brazil	Agriculture	1.8	0.0	0.3	4,193		0.8	18,221
	Mining	0.3	-1.2	0.1	-2,834		0.2	-650
	Services	9.1	-10.5	-0.1	-6,637		-0.1	3,085
	Manufacturing	3.9	-24.9	0.8	-33,486		1.9	-67,833
TFP Amazônia	Agriculture	2.1	10.3	-0.5	32,282		-0.1	15,004
	Mining	0.2	0.9	0.0	-693		0.0	-708
	Services	9.8	-5.9	0.4	-14,211		0.2	-8,372
	Manufacturing	3.8	-8.1	0.6	-16,310		0.4	-14,350
TFP in Brazil South/Southeast		0.5	-40.6	0.8	-56605		1.9	-90,420

Source: Simulation results from CGE model.
Note: red (green) coloring implies higher (lower) deforestation and CO2 emissions relative to the baseline.

To unpack these macroeconomic effects, Figure 2 displays some of the mechanisms underlying Table 2 for the case of manufacturing. It shows that an increase in manufacturing productivity appreciates the real exchange rate, thus reducing the external competitiveness of sectors that do not experience a productivity shock in this simulation (like agriculture). The figure shows that the real effective exchange rate appreciates nationally. Another measure of a real appreciation is the ratio of nontraded to traded prices which here is proxied by comparing services to manufacturing prices—this measure too points to a real appreciation. Finally consistent with the Balassa-Samuelson effect, wages increase across the country, also reducing the external competitiveness of sectors that did not experience a productivity gain (like agriculture). The real appreciation reduces international agricultural prices in local currency units. Both the loss of competitiveness of agriculture and the lower prices in local currency terms reduce agricultural production, and accordingly land rents fall. Lower land rents reflect less demand for the conversion of natural land to production and hence deforestation declines (natural land remains higher than in the baseline in Figure 2).

Figure 2. Impacts from an increase in Brazilian manufacturing TFP. Deviation from the baseline. Percent changes for prices, Millions of hectares for land use



Source: Simulation results from CGE model.
Note: Assumes a 0.5pp permanent increase in Brazilian manufacturing TFP relative to the baseline.

This shows that raising the competitiveness of non-land intensive sectors like manufacturing can reduce deforestation. However, this does not mean that manufacturing productivity should be pursued at the expense of agricultural productivity. Table 3 confirms the results of Table 2 that show that an increase in agricultural productivity in the Legal Amazon results in higher local deforestation (while increasing cattle and soy production in the region) and higher manufacturing productivity in the Legal Amazon lowers local deforestation. Yet the table provides some additional information on the extensity of farming, land productivity (more closely related to the concept of agricultural yields and agricultural intensification). Although manufacturing productivity reduces deforestation, it makes agriculture less land-efficient: Table 3 shows that both agricultural output and land productivity fall when only manufacturing total factor productivity increases. This could simply displace the deforestation problem to other parts of the world. Agricultural productivity thus remains a critical complement to manufacturing productivity to raise productivity overall without causing deforestation. Table 3 shows that a scenario in which both agriculture and manufacturing raise productivity at the same rate both agricultural output and land productivity can be raised without causing deforestation. The reason is that the productivity gain in manufacturing lowers the cost of capital and inputs (whether produced by manufacturing in Brazil or whether imported, aided by the appreciated exchange rate). Thus, the price of capital and inputs falls relative to the price of land and labor. This results in higher mechanization of agriculture, with lower labor shares but also lower demand for natural land. In other words, these are macroeconomic drivers of the intensification of farming that raise agricultural output with less deforestation it promotes the structural transformation of agriculture (labor migrating into industry and services) while reducing deforestation.

Table 3. Productivity and deforestation in the Legal Amazon. Impact of a 0.5pp TFP increase by sector or combination of sectors. Percent change relative to the baseline for all variables except for natural land which is expressed in million hectares

Sector	Output		Land productivity		Land rents		Wages (rel. to Brazil)	Natural land (Amazon)
	Cattle	Soy	Pasture	Crops	Pasture	Crops		
Agriculture	8.87	9.73	8.15	8.07	11.62	12.56	1.70	-0.54
Manufacturing	-3.61	-3.06	-2.93	-2.59	-8.59	-9.29	5.11	0.54
Agriculture & manufacturing	4.95	6.53	5.00	5.35	1.89	2.30	6.89	0.02

Source: Simulation results from CGE model.
Note: Cumulative impacts 2020 to 2030.

Finally, inferences can be drawn about the overall impacts of emissions from these different growth models. Revisiting Table 2 once more shows that among the scenarios displayed the largest positive impacts on lowering CO2 emissions can be achieved by increasing productivity outside the Legal Amazon, notably Brazil's economic centers in the south and southeast. This is followed by raising productivity in manufacturing across Brazil, further followed by raising manufacturing productivity in the Legal Amazon itself. This takes into account both the emissions associated with manufacturing, land use change and deforestation. The former is relatively small in Brazil, not least due to a relatively clean energy mix (largely hydropower). Thus, the emissions associated with industrial expansion from a manufacturing productivity gain are outweighed by the saved emissions from lower deforestation. Notably, this is not the case for agriculture: even though raising agricultural productivity across Brazil can help reduce deforestation, agricultural emissions are sizeable and therefore not offset by emissions savings from lower deforestation.[6]

6. Conclusions and policy implications

Protecting Brazil's vast natural forest wealth is of utmost importance. In the shorter-term, effective governance, including land regularization and command and control policies to enforce

[6] Notice that livestock production is included in the broad agriculture sector. Emissions associated with the level of livestock activity is the highest single sector emissions in Brazil.

Brazil's existing forest protection framework, needs to contain the structural economic drivers of deforestation. In the longer-term, it will be critical to address the structural drivers themselves that put pressure on natural lands and constrain economic development. This requires a stronger focus on productivity and moving up the value chain, meaning a shift beyond primary sectors like agriculture toward more urban sectors like manufacturing and certain services. In other words, overcoming the legacy of import substitution industrialization to make Brazil a competitive country in non-commodity sectors will raise economic growth while simultaneously making it more sustainable, as it would be a growth model that places less pressure on natural forests. This approach can also help reduce Brazil's CO2 emissions, needed to meet the country's Nationally Determined Contribution.

The paper highlights implications for both the Legal Amazon itself and for the whole country. Brazil is a large country, where economic activity is highly concentrated in the South-Southeast region. The analysis suggests that looking at the deforestation region (the "Arch of Deforestation") in an isolated way misses the broader economic dynamics in the whole country within which it is nested. In this respect, the simulations highlight many regional effects which should be taken into account. First, fostering manufacturing productivity across the country and within the Legal Amazon specifically reduces deforestation. Second, supporting productivity across sectors in the south and southeast of Brazil reduces deforestation. Third, supporting agricultural productivity *across the country* reduces deforestation. Fourth, if coupled with manufacturing productivity, agricultural productivity in the Legal Amazon may be net neutral on deforestation. Agricultural productivity without accompanying manufacturing productivity in the Legal Amazon, however, is likely to accelerate deforestation due to the Jevons effect.

Deforestation, then, is more than a circumstantial phenomenon. It can be seen as a development model in Brazil, one that emerges due to the country´s failure to foster productivity growth in manufacturing. Exploiting the abundant natural resource, land, is a solution for growth, one that creates further difficulties for manufacturing development, a kind of natural resource curse style problem: one could call it the "Brazilian disease", inspired by the related, well-known "Dutch disease" effect. Breaking this vicious circle is a challenge for economic policy in Brazil for the coming years, especially when faced with the new challenges posed by climate change pressures upon agriculture.

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