Meat Exports and Pasture Degradation in Brazil[1]

Filipe Lage
Fluminense Federal University – fl_sousa@id.uff.br

Erik Lavoie
University of Maryland, USA – elavoie1@umd.edu

Eve Devens
University of Maryland, USA – edevens@umd.edu

Abstract Confirmation Number: 4114

Abstract

Global greenhouse gas emissions are a major concern in the 21st century. While the United States, Japan, the European Union, Brazil, Russia, India, and China account for two-thirds of global emissions, Brazil stands out: unlike the others, where energy and manufacturing dominate, its emissions are largely driven by land use, especially pasture degradation. 18 percent of Brazil's territory—152 million hectares—consists of pasture, and nearly two-thirds of it is degraded, an area larger than any European country. Using municipality-level export and pasture data, we build a panel of 5,000+ municipalities (2000–2023) to identify the causal impact of cattle exports on pasture degradation, using either shift-share analysis or pork and chicken exports as instruments. We also assess whether crop expansion reduces degradation. The findings inform whether international demand drives land degradation, implying a role for importer regulation as suggested in Oliveira et al (2025), or whether domestic policy is the key lever.

Keywords: Pasture Degradation, International Trade, Climate Change, Environmental Policy.

1. Introduction

Global emissions of greenhouse gases (GHG) are a significant humanitarian concern in the 21st century. In 1970, GHG emissions were 24 tons of CO2 Equivalent[2]; however, emissions have more than doubled in half a century, reaching 53 tons of CO2 Equivalent in 2023 (Crippa et al,

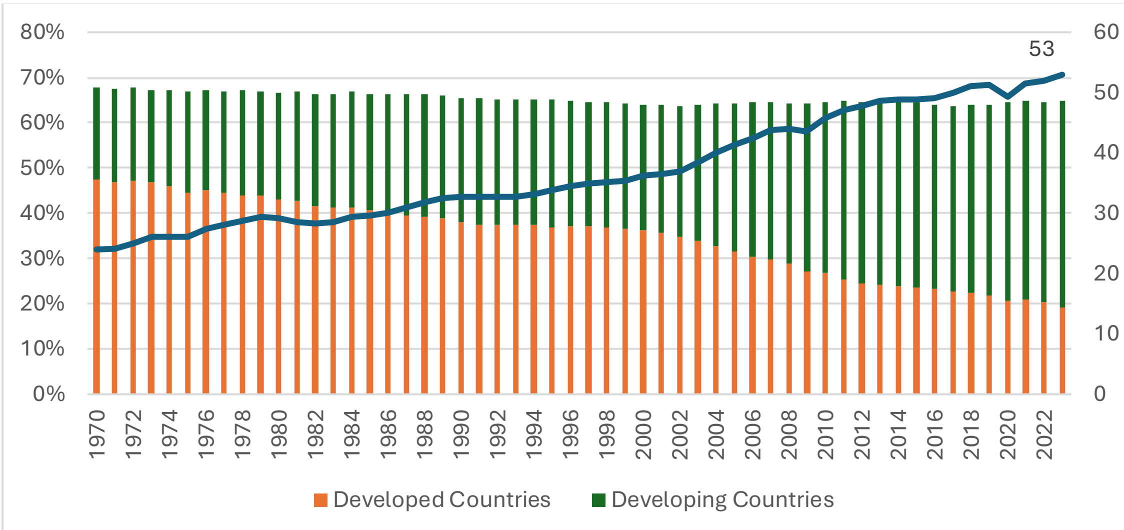
---

[1] The authors declare that this manuscript and all accompanying materials are original and do not violate any copyright or intellectual property rights.

[2] CO2 equivalent is a metric used to compare the climate impact of different greenhouse gases, like methane and nitrous oxide, by converting them into the equivalent amount of carbon dioxide (CO2) that would have the same warming effect.

2024). Although emissions by country have changed over time, especially from developed countries towards developing countries, 2/3 of all emissions are concentrated in seven regions of the globe over the entire period: the USA, European Union (27 countries), Japan, China, India, Russia, and Brazil, see Graph 1.

Graph 1: Total GHG Emissions and share of some developed countries (Japan, USA, and European Union) versus some developing countries (BRIC)



Source: Crippa et al (2024)

Although developing countries increased their contribution to total Greenhouse Gas (GHG) emissions, Brazil differs in terms of the main sectors contributing to it. While most of the contributions from developed and developing countries reside in energy generation (Power Industry) and manufacturing operations (Industry Combustion)[3], the main sector—contributing to around half of 2023 GHG emissions in Brazil—is agriculture: nearly half in 2023, see Table 1.

Table 1: Percentage of GHG emissions in each country/region

Sector	Brazil	China	India	Russia	USA	EU	Japan
Agriculture	49%	6%	19%	4%	7%	12%	5%
Buildings	4%	4%	7%	10%	10%	14%	11%
Fuel Exploitation	5%	9%	6%	19%	12%	6%	4%
Industrial Combustion	7%	18%	15%	12%	8%	10%	15%
Power Industry	4%	41%	34%	33%	25%	20%	39%
Processes	5%	12%	8%	7%	7%	9%	9%
Transport	17%	7%	8%	10%	29%	24%	17%
Waste	10%	2%	3%	5%	2%	4%	1%

Source: Crippa et al (2024)

Using a slightly different methodology that is more relevant to the national context of the Brazilian GHG emissions profile because it includes Land Use, Land-Use Change and Forestry (LULUCF), Tsai et al (2024) demonstrated that LULUCF represented 46% of Brazilian GHG

---

[3] The contribution of those two sectors accounted for 30% (EU) to 59% (China), which are far higher than the 11% share of those two sectors in the Brazilian emission profile.

Emissions, while agriculture represented 28%; combined, they represent nearly three-quarters of total Brazilian GHG emissions. Among LULUCF subdivisions, degraded pastures are a main element. Therefore, Brazilian policies addressing climate change should differ from those of the other six regions previously mentioned: developed and developing countries.

What distinguishes the Brazilian emissions pattern from the other main GHG emissaries is the increasing world demand for food, despite the productivity growth of the Brazilian agricultural sector to attend to this demand; an extensive literature has been corroborated on this front (Arias et al, 2017; Bustos et al, 2016; Contini and Geraldo, 2010; Rada et al, 2019). The environmental effects of agricultural expansion have already been investigated in the economic literature (Assunção et al, 2017; Carreira et al, 2024; Oliveira et al, 2025). However, recent literature focuses on deforestation and crops rather than degraded pastures and livestock. These two aspects remain underexplored in the economic literature and deserve closer attention due to their economic and environmental importance. First, higher income per capita has led to improvement in global living standards, consequently increasing the demand for protein. Second, transforming degraded pastures into other agricultural uses can capture GHG emissions, alleviating the environmental impacts of other economic activities.

In terms of size, Brazil's 152 million hectares of pasture is equivalent to the 18th largest country in the world, Mongolia, and is 2.5 times larger than the largest European country by area, Ukraine. Nearly two-thirds of Brazilian pastures—about 96 million hectares—exhibit some degree of degradation, an area roughly the size of Venezuela. Given this background, it is important to measure what was the contribution of the Brazilian meat exports to this scenario of pasture degradation.

Using Brazilian exports and pasture conditions at a very detailed regional disaggregation over the last 20 years, it is possible to construct a panel data set with reasonable information for such an investigation. This dataset will enable us to investigate the causality between meat exports and pasture degradation, as we will have access not only to cattle meat export data but also to other types of meat unrelated to pasture degradation, such as pork and chicken. Moreover, we can evaluate whether the expansion of other agricultural products may reduce the percentage of pasture degradation at the municipality level. The results of this research project might shed some needed light on policy implications on key relevant topics, such as climate change, food supply, and environmental impacts, in one of the most relevant countries for those issues: Brazil.

Considering this objective, this paper is structured as follows. Section 1 will describe the data set for this investigation. The following section will provide descriptive statistics and present the methodology. The main outcomes of the econometric exercise are shown in Section 4. The final concluding remarks are presented in the last section.

2. Data Description

We explored three different main datasets in this investigation. Two provide Brazilian export data, COMEX STATS (COMEX)[4] and Trase[5], and one presents pasture degradation, Atlas das Pastagens[6]. All these datasets have data at the municipality level, but their time spans differ.

---

[4] https://comexstat.mdic.gov.br/pt/home
[5] https://trase.earth/
[6] https://atlasdaspastagens.ufg.br/

While COMEX spans from 2000 to 2023, Trase spans from 2011 to 2017 and 2019 to 2023, and Atlas das Pastagens contains data from 1985 to 2023. These two export datasets have advantages and disadvantages. A strength of COMEX's municipality-level data is that it has a time dimension of 24 years of observations, while Trase has only a maximum of 7 years of continuous observations (12 years if considering the data following the break in 2018). However, COMEX registers the municipality of the exporter's tax domicile (headquarters of the declaring firm), not where it was produced. On this front, Trase excels: it provides detailed information on the supply chain of bovine products and where the cows are sourced from (produced), making it possible to link products and supply chain actors with specific areas of production[7]. Instead of discarding one, we used both sources, yet at different geographical scales. As Trase uses supply chain information that directly attaches a municipality to kilograms of bovine carcasses, it is safe to use it at the municipality level. On the other hand, COMEX requires more aggregated regional data, as COMEX likely registers kilograms of cattle reported from a slaughterhouse, which is generally close to the pastures it is sourced from, yet not necessarily from the same municipality as the slaughterhouse. Brazil has multiple classifications that consider the socioeconomic and physical characteristics to define them: states (27 geographical units), mesoregions (137 geographical units), microregions (558 geographical units), and municipalities (5,570 geographical units), all of which are nested geographical classifications. To increase the probability that the COMEX data represents meat exported that is linked to a pasture of production/source in the same geographical region, we used the mesoregion, which leads to a sample size of more than 3 thousand observations[8].

The Trase Brazil beef dataset includes flows with an unknown municipality of production, but some of these records also contain other identifying information, such as municipality of slaughter, product type, exporter group, port of export, and importer group. We implemented a Bayesian hierarchical evidence-weight-based imputation that allocates unknown production kilograms across municipalities using the empirical distribution of observed production shares within coarser profiles, starting with the most detailed profile level, containing all possible categories (slaughter × product type × exporter × port × importer), and then backing off level by level, from right to left in order, when evidence is sparse. For each flow combination within a profile level with unknown production, a score is assigned, determining how confident we are in assigning the unknown shares to the distribution of its known production counterpart for that profile-level flow. The score, which will ultimately serve as the proportion allocated to its known counterpart, is determined along 3 dimensions: strength of evidence (N kg of known profile counterpart), completeness of data (ratio of percent known to total known + unknown), and its informativeness (HHI-based metric). Any unallocated mass, according to a flow's score, was backed off to a coarser level to be scored again. When profile-specific evidence was unavailable, the remaining mass was allocated using the within-year national distribution. For post-2018 years—where missingness for cattle and beef offal types approached 100 percent—allocations were determined by blending current-year information with a 2015–2017 reference distribution for those product types. For the main analysis in this paper, we restrict attention to the pre-2018 Trase period; post-2018 data and the imputation-based extensions are reserved for future work.

Regarding pasture degradation, Atlas das Pastagens calculates the total area of pasture in each Brazilian municipality, as well as their level of degradation, into three classifications: Severe,

[7] See TRASE (2025) for further information.

[8] Specifically, there are 3,288 observations (137 mesoregions times 24 years)

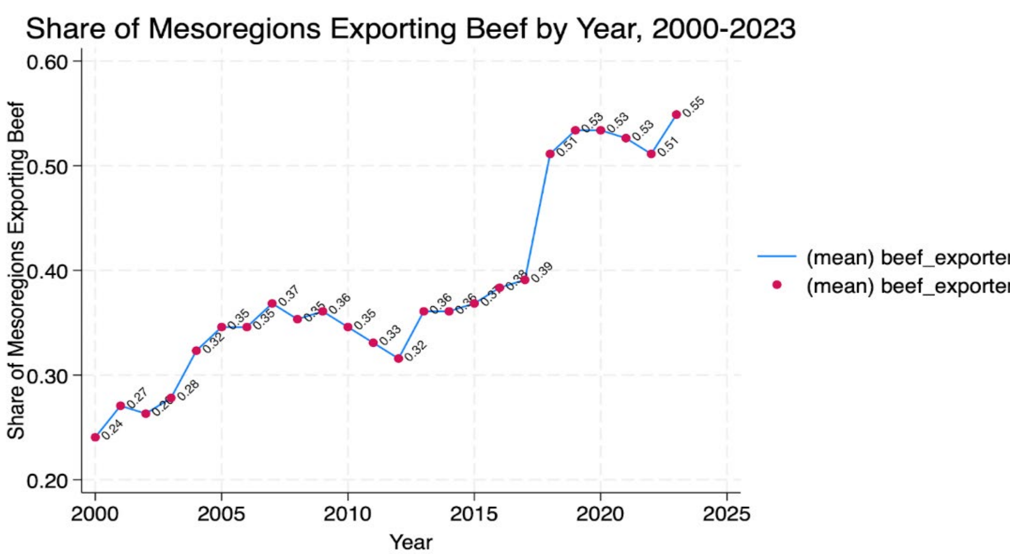
Moderate, or no sign of degradation[9]. Therefore, it is possible to observe the evolution of pasture over time and merge it with other datasets, as both have matching municipality IDs. This allows us to investigate correlation and causality between various variables.

We also utilized IBGE's Table 3939, which contains a headcount of cows across Brazil's municipalities from 2000 to 2023. According to Atlas das Pastagens, some municipalities only have hundreds of acres of pasture, despite IBGE indicating the presence of many cows in those same municipalities. This necessitated the creation of a mechanism to filter out municipalities via a data-quality screen, as pasture-sensing error is more consequential in municipalities with very small pasture areas. Therefore, we excluded geographical observations with implausible pasture measurements and stocking intensity (for municipalities >10 head/ha, < 1000 ha, plus other rules).

3. Descriptive Statistics and Methodology

On average, mesoregions exported 10 tons of meat per year, with a standard deviation greater than 30 tons of meat, implying a coefficient of variation of 3. Consequently, meat exports are concentrated in a few mesoregions, as evidenced in Graph 2, whereas the maximum share of mesoregions exporting meat was in the last year of observation. Yet we see that nearly half of the mesoregions do not contain any municipality within them that has reported any sort of export for this product. Nevertheless, the percentage of mesoregions recording exports increased substantially over time; in 2000, only 24 percent of Brazilian mesoregions were exporting meat, but after China joined the WTO, the percentage increased to 37 percent in 2007. After the Global Financial Crisis of 2008, the share of exporting mesoregions oscillated between 32 and 39 percent. Afterwards, the percentage of reporting mesoregions jumped to more than 50 percent in 2018, and it remained over that threshold until 2023.

Graph 2: Share of Mesoregions Exporting Beef by Year, 2000-2023



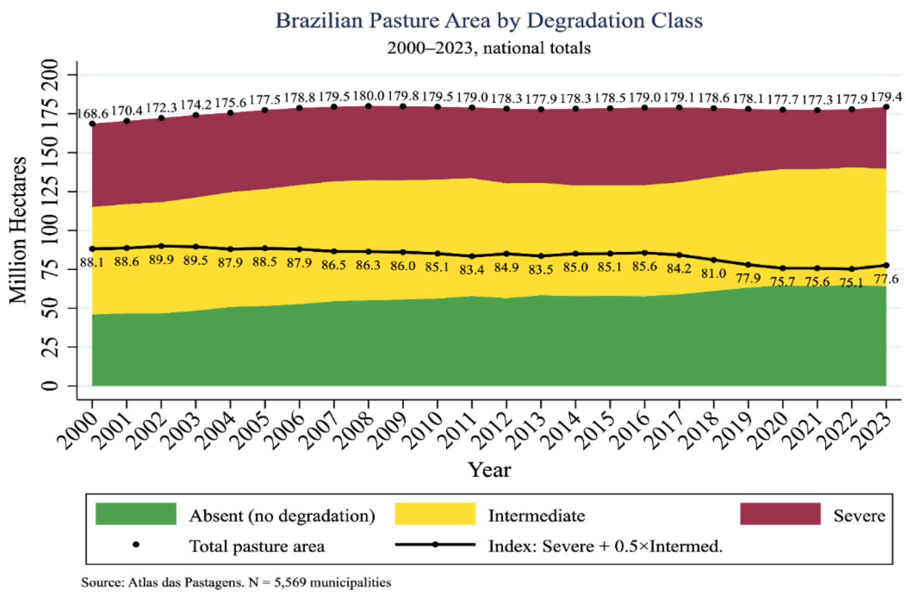
Source: Authors' Elaboration using COMEX STATS

---

[9] For more information, see ATLAS DAS PASTAGENS (2022)

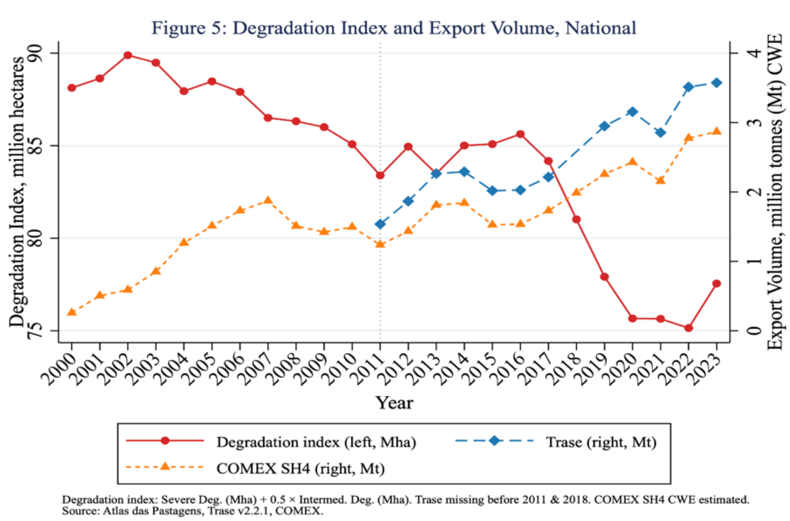
Graph 3 shows that the share of Brazilian land containing pasture has slightly increased between 2000 and 2023; however, it nonetheless indicates a slight shift in land use. The total share of pasture that is degraded—defined as severely degraded plus half of intermediate from here on—has declined over time, peaking at 89.9 in 2002, and reaching 77.6 in 2022. Moreover, pasture area has held relatively steady over the same period, indicating evidence of pasture rehabilitation or other reasons for declining degradation over time.

Graph 3: Brazilian Pasture and Degraded Pasture Area, 2000-2023



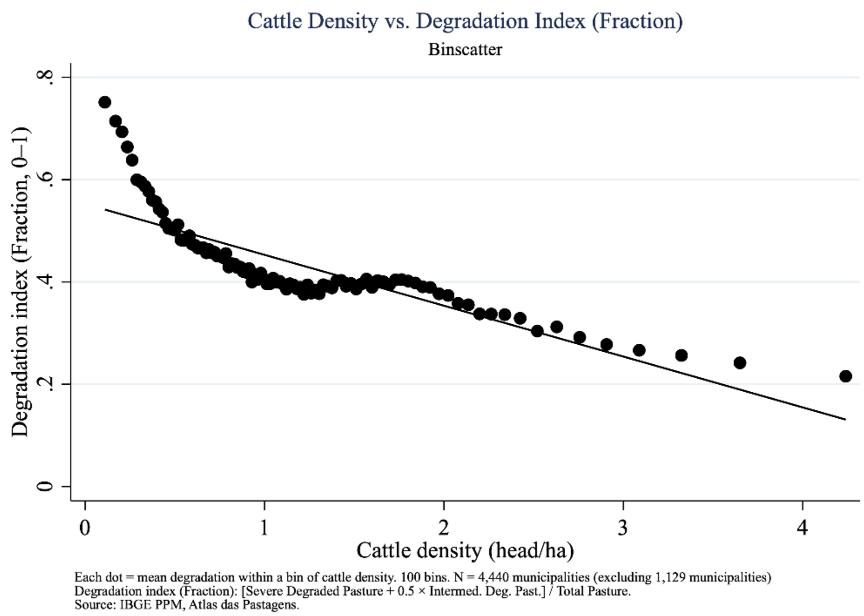
Combining information on exports and a constructed degradation index, Graph 4 shows their evolution over time. Given the expansion of regions reporting beef exports and declining pasture degradation, it can be reasonably inferred that the increase in productivity of meat production over the period might explain this pattern, as evidenced by Martins et al. (2022).

Graph 4: Degradation Index and Export Volume, National



One measure of productivity in the livestock industry is cattle stocking, also known as cattle density. A way to see whether pasture degradation is correlated with cattle density is to graphically plot them against each other. As indicated by Graph 5, lower contemporaneous degradation is associated with higher cattle density, a pattern consistent with robust pasture management systems and generally strong agricultural productivity. Therefore, it is imperative to account for productivity differences when estimating the relationship between export exposure and pasture degradation, as productivity presents itself as a serious confounder.

Graph 5: Cattle Density vs. Degradation Index (Fraction)



To move beyond descriptive patterns, we investigate the relationship between meat exports and pasture degradation as part of an estimated econometric specification:

$$DPindex_{it} = \alpha_0 + \alpha_1 BeefExport_{it} + \sum_{j=1}^{k} \alpha_j X_{jit} + u_{it}$$

In this specification, i is for the regional unit, and t is for the year of observation. $DPindex_{it}$ is the degradation index in each region at the specific year, and $BeefExport_{it}$ is the total volume of beef exports measured in millions of kilos. Therefore, α_1 is the parameter that will inform whether the volume of exports is correlated with the intensity of pasture degradation at a regional level in Brazil. X_{jit} & u_{it} are respectively the control j in the econometric specification (including region, time, and some of their interaction fixed effects) and the error term. All other terms are parameters to be estimated.

4. Empirical Results

For the moment, we will be presenting outcomes using only the Trase dataset, but further results will be presented in latter versions of this research project. Table 2 shows our first municipality-level results from our econometric specification. We consider four different approaches depending on what is considered as fixed effects: in the first column, outcomes are presented without any fixed effects; the second column includes year fixed effects, which might control for any time characteristic that might have affected the pasture degradation, such as the occurrence of droughts becoming more frequent due to climate change; the third column controls for municipality fixed effects, which helps account for regions that might be more suitable for pasture degradation because of soil conditions; and last, but not least, column four considers possible legislation changes over time, as it includes the interaction of state and time fixed effects.

Table 2: Municipality-Level Econometric Outcomes

Municipality level — 2011–2017

	Degradation (fraction)			*Degradation (thousand ha)*	
Variables	(1)	(2)	(3)	(4)	(5)
Panel A. Trase Beef Exports (Imputed)					
CWE, Million KG	0.0037***	-0.0063***	0.0010	10.1417***	-0.9869**
	(0.0013)	(0.0009)	(0.0006)	(1.4594)	(0.4400)
R^2	0.0006	0.0025	0.0001	0.2054	0.0092
Panel B. Trase Beef Exports (Known-Only)					
CWE, Million KG	0.0040**	-0.0073***	0.0009	12.4114***	-1.1400**
	(0.0016)	(0.0011)	(0.0006)	(1.5835)	(0.4782)
R^2	0.0005	0.0030	0.0001	0.2248	0.0107
Panel C. Cattle Pressure (Lag-Weighted Density)					
Cattle per ha, lag-weighted ($\lambda = 0.9$, $K = 5$, $t-1$ to $t-5$)	-0.1312***	-0.0574***	-0.0047*	-6.9124***	-2.1822***
	(0.0043)	(0.0038)	(0.0029)	(0.3633)	(0.1830)
R^2	0.1850	0.0330	0.0003	0.0254	0.0071
Observations	32543	32543	32536	32543	32543
Municipality FE	No	Yes	Yes	No	Yes
Year FE	No	Yes	No	No	Yes
State×Year FE	No	No	Yes	No	No

Notes: The dependent variables are both an index of measured degradation. Fractional Index: (0.5 × Intermediate ha + Severe ha)./Total pasture ha. Total Area Index: (0.5 × Intermediate ha + Severe ha), expressed in thousand ha. R^2 reports OLS R^2 for pooled models and within-R^2 for fixed-effects models. Robust standard errors clustered by municipality are in parentheses. Sample span: 2011–2017; N = 4,649 municipalities: 920 municipalities were dropped as a part of the data-quality screen. Trase export flows with unknown municipality of production were imputed (scored allocation). Export quantities are scaled in million kg. Cattle pressure is a lag-weighted average of prior cattle density (cattle/pasture ha) using geometrically decaying weights with $K = 5$ lags and $\lambda = 0.9$. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We present outcomes for three different independent variables: imputed data of beef exports, only those recorded exports, and cattle pressure. When investigating whether exports are able to affect pasture degradation, our outcomes suggest that initially they seem to operate in a different direction: more exports are correlated with higher degradation, absent of control and solely controlling along the time axis. However, results shift negative when region fixed effects are considered in the specification. Therefore, higher export performance is related to lower degradation in Brazilian regions. This might be explained by the fact that export performance requires higher productivity and, therefore, better pastures. Nonetheless, this negative association changes when we control for time-varying characteristics at the state level. Any state changes over time, either due to legislation or any other state characteristic time-variant, reduces the possibility of a relationship between exports and pasture degradation. This might suggest that export performance is not related to GHG emissions, probably because of the increase in productivity as suggested in Graph 5.

When investigating the link between productivity, measured by lagged cattle per ha regressed against the degradation index, our results show a negative association between both, which is consistent across all specifications. This means that higher productivity is negatively correlated to higher degradation index, which suggests that productivity might pave the way to lower pasture degradation. This is an indication that increasing external demand might not increase GHG emissions because of higher pasture degradation; instead, it might even cut GHG emissions. However, this association is not a causality, and a proper investigation using instrumental variables is essential to investigating this issue.

5. Concluding Remarks

In this paper, we provided evidence indicating that higher demand for Brazilian meat may not be a main driver of pasture degradation and higher levels of pasture-sourced GHG emissions. Moreover, it suggests that advances in agricultural productivity may play a larger role in dictating pasture degradation, as we observe a negative correlation between levels of productivity and degradation. However, this evidence alone cannot address the issue of causality. Knowing that those variables might be correlated does not allow us to say that increasing one variable will lead to better outcomes. In other words, export volumes may still adversely impact pasture vigor, provided that a rigorous empirical approach separates export-driven variation in trade exposure from confounding factors. One such economic exercise that remains to be explored is the utilization of a demand shift/share instrument or other meat exports not related to pasture (chicken and pork), as the ability to cleanly isolate the effect of exports on pasture degradation is fundamentally constrained by the absence of an instrument for export demand.

Without instrumental variable approach, the relationship between exports and pasture degradation is likely confounded by productivity that chronologically varies, improvements in management processes, and shifts between domestic and export-oriented production that fixed effects cannot fully account for. The problem of domestic/export identification specifically arises when domestic demand in a geographic area, and consequently domestic production, changes over time in a way that correlates with export activity in that same geographic area.

The current model does not consider potential environmental confounders, such as weather shocks like rainfall and temperature anomalies, that directly affect pasture vigor and may interact with cattle-induced degradation. The timing of lags and leads is another problem: degradation observed via remote sensing appears in a lagged manner; similarly, some biological processes associated with degradation operate with lag. On the other hand, export flows occur after years of grazing, creating both lags and leads that need to be modeled. Next steps will involve the implementation of a shift-share instrument to isolate foreign demand in export variation; by using that variation to predict pasture pressure, we can then estimate pasture pressure and relate it to degradation effects within a distributed lag structure. This framework should also incorporate weather anomaly controls and other time-varying confounders alongside fixed effects. In doing so, our research will improve the interpretability of the export demand-pressure-degradation chain of causality.

References

Arias D, Vieira PA, Contini E, Farinelli B, Morris M. Agriculture productivity growth in Brazil. Agriculture Productivity Growth in Brazil. World Bank, Washington, DC. DOI: https://doi.org/10.1596/32202. 2017 Sep 24.

Assunção J, Lipscomb M, Mobarak AM, Szerman D. Agricultural productivity and deforestation in Brazil. Climate Policy. 2017 Feb 28:1-46.

ATLAS DAS PASTAGENS. Data of Brazilian Pastures Quality Mapping Between 2000 and 2020. 2022 January, Goiania.

https://s3.lapig.iesa.ufg.br/storage/methodologies/October2023/YmN5VB4XHcKp3fk74yTd.pdf

Brasil. Mapas das Áreas de Pastagens Degradadas por Estado Rede Floresta + Iniciativa Conexão Florestal - Anexo. 2024.

https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/floresta-plantada/publicacoes/anexo-mapas-areas-pastagens-degradadas-estado/view

Bustos P, Caprettini B, Ponticelli J. Agricultural productivity and structural transformation: Evidence from Brazil. American Economic Review. 2016 Jun 1;106(6):1320-65.

Carreira I, Costa F, Pessoa JP. The deforestation effects of trade and agricultural productivity in Brazil. Journal of development economics. 2024 Mar 1;167:103217.

Contini E, Martha GB. Brazilian agriculture, its productivity and change. Forestry. 2010 Aug 29.

Crippa M., Guizzardi D., Pagani F., Banja M., Muntean M., Schaaf E., Becker, W., Monforti-Ferrario F., Quadrelli, R., Risquez Martin, A., Taghavi-Moharamli, P., Grassi, G., Rossi, S., Melo, J., Oom, D., Branco, A., San-Miguel, J., Manca, G., Pisoni, E., Vignati, E., Pekar, F., GHG emissions of all world countries – JRC/IEA 2024 Report, Luxembourg, 2024, JRC138862.

https://data.europa.eu/doi/10.2760/4002897

Martins, M.M., Spolador, H.F. and Njuki, E., Production environment and managerial techniques in explaining productivity growth in Brazilian beef cattle production. Agribusiness. 2022. Vol. 38(2), pp.371-385.

Oliveira GM, Jafari Y, Börner J. Heterogeneous effects of export-market preferences on deforestation in Brazil. European Review of Agricultural Economics. 2025 Oct 28:jbaf048.

Rada N, Helfand S, Magalhães M. Agricultural productivity growth in Brazil: Large and small farms excel. Food policy. 2019 Apr 1; 84:176-85.

TRASE. SEI-PCS Brazil Beef v2.2 Supply Chain Map: Data Sources and Methods. 2025 October.

https://resources.trase.earth/documents/data_methods/SEI_PCS_Brazil_beef_2.2._EN.pdf

Tsai D., Potensa R., Quintana G., Cardoso A.M., Alves P., Silva F.B., Graces I., Sousa H., Coluna I., Oliveira J., Zimbres B., Shimbo J., Silva C., Silva-Junior C., Silva W., Alencar A., Angelo C., Análise das Emissões de Gases de Efeito Estufa e Suas Implicações para as Metas Climáticas do Brasil 1970-2023, 2024 SEEG Report.

https://seeg.eco.br/wp-content/uploads/2024/11/SEEG-RELATORIO-ANALITICO-12.pdf