Beyond Commodity Prices: Exchange Rates and Amazon Deforestation*

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Abstract

This paper investigates the aggregate and dynamic effects of exchange rate movements and commodity price fluctuations on deforestation in the Brazilian Amazon. We identify exogenous shocks to the exchange rate, as well as to the prices of two key commodities, soybean and cattle, and use these shocks as external instruments in a Structural Vector Autoregression (SVAR) framework. We uncover a new channel through which exchange rate depreciations increase deforestation, operating via their impact on commodity prices in domestic currency. Utilizing structural counterfactual scenarios, we show that shutting down this price channel substantially attenuates the deforestation response. This underscores the importance of macroeconomic conditions, beyond global commodity markets alone, in shaping deforestation dynamics.

JEL Classification: Q54, F31, E32

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1. Introduction

Deforestation in the Amazon is widely recognized as a major global concern due to its far-reaching implications for climate change. By releasing large amounts of carbon and simultaneously reducing the forest's ability to act as a carbon sink, deforestation directly accelerates global warming. Understanding the determinants of deforestation is therefore essential to mitigating the environmental crisis. Among the most frequently cited drivers are increases in global commodity prices, which create incentives to clear forest land for agricultural expansion, particularly for crops such as soybeans and corn, as well as for cattle ranching. By contrast, little is known about the effect of the exchange rate on deforestation. Yet, it plays a crucial role in shaping agricultural profitability, as Brazil's main commodities are largely destined for export markets. By affecting revenues in local currency, exchange rate movements influence production decisions and, ultimately, land-use pressures.

This paper studies the role played by the exchange rate as a driver of Amazon deforestation. Quantifying this relationship using observational data is challenging, as the observed data reflect the simultaneous interactions among the exchange rate, commodity prices, and deforestation. Endogeneity arises because increases in commodity prices or a depreciation of the exchange rate raise revenues in local currency, thereby strengthening incentives for deforestation. Conversely, changes in deforestation may influence global commodity prices, given Brazil's central role as a major supplier, and may also affect the exchange rate by altering Brazil's export revenues and terms of trade. In addition, global financial conditions can simultaneously shape commodity prices and exchange rate movements, further complicating the identification of their separate effects.

In order to address endogeneity concerns and enable the isolation of the dynamic effects of the exchange rate and commodity prices on deforestation, we em-

ploy a high-frequency identification strategy to obtain credibly exogenous variation. Specifically, we measure changes in futures prices within narrow time windows surrounding selected events to isolate surprise series. Within these short intervals, reverse causality can be effectively ruled out, as conditions are already incorporated into prices before the events and unlikely to change in this window. Exchange rate surprises are identified around foreign exchange swap interventions conducted by the Brazilian Central Bank. Surprises to the prices of two key commodities, soybean and cattle, are identified around USDA Grain Stocks Report releases and extreme weather events in major cattle-producing regions, respectively. These surprises are used as external instruments in a Structural Vector Autoregression (SVAR) approach.[2]

Importantly, the interplay between these price incentives and deforestation is inherently dynamic, a dimension that has only recently begun to receive attention in the literature. In the case of grains, landowners are more likely to incur the costs of converting forests to cropland when price increases are expected to be persistent rather than temporary (Scott, 2013). In the case of cattle, temporarily high prices may lead ranchers to increase slaughter rates, reducing deforestation pressures, whereas price increases expected to persist can instead induce herd expansion in anticipation of higher future profits, increasing deforestation pressures (Scott et al., 2025). At the same time, increases in international commodity prices are often accompanied by exchange-rate appreciations in commodity-exporting economies (Chen and Rogoff, 2003), so that higher international prices do not fully translate into higher local currency returns. This exchange rate response is also more likely when price increases are sustained rather than transitory and can partially offset incentives for land-use expansion.

[2] Curatola-Melo and Guimaraes (2025) propose using USDA Grain Stocks Report releases as a source of plausibly exogenous variation in global agricultural prices. However, their identification relies on heteroskedasticity-based approach, whereas we instead use surprises around these events as external instruments.

The role of the exchange rate in shaping deforestation outcomes gains prominence as financial incentives aimed at reducing deforestation have become increasingly debated. On the theoretical front, examples include direct payments to avoid deforestation (Souza-Rodrigues, 2019), carbon pricing schemes to incentivize Brazil to choose policies to capture greenhouse gases (Assunção et al., 2025), and carbon taxes to make farmers internalize the social cost of carbon (Araujo, 2024). On the policy front, examples include international mechanisms designed to transfer resources to countries committed to forest preservation, such as the Tropical Forests Forever Facility (TFFF), proposed by Brazil at the 30th Conference of the Parties (COP30). To the extent that these incentives and transfers are denominated in U.S. dollars, they may also affect deforestation through general equilibrium effects: large dollar inflows can lead to exchange rate appreciation, reducing the profitability of agricultural expansion in local currency terms and thereby amplifying deforestation-reducing impacts.

We find that, following a 1% depreciation of the exchange rate, deforestation increases, with the 12-month cumulative response peaking at approximately 0.8% 21 months after the shock. This occurs even though commodity prices quoted in U.S. dollars remain stable or decline, suggesting that local-currency prices are key to understanding deforestation dynamics and underscoring the crucial role of the exchange rate, an insight that, to the best of our knowledge, has no precedent in the literature thus far. In turn, following 1% increase in commodity prices quoted in U.S. dollars, the exchange rate appreciates by about 1.2% within the first 4 months. Such appreciation in response to higher commodity prices is a well-documented phenomenon in commodity-exporting emerging economies (Chen and Rogoff, 2003; Fernández et al., 2018). This mechanism offsets the increase in commodity prices in local currency terms, thereby attenuating its effect on deforestation. Consistent with these findings, the forecast error variance decomposition shows that exchange rate shocks account for a larger share of deforestation fluc-

tuations at most horizons and dominate in the long run. To isolate the underlying mechanism, we construct counterfactual scenarios that shut down the response of commodity prices in BRL; doing so attenuates the deforestation response to exchange rate shocks, rendering it statistically insignificant, and is consistent with local-currency commodity prices being the key transmission channel.

Related literature. This paper relates to and contributes to four strands of the literature. The first strand examines the relationship between agricultural production and deforestation in the Amazon. Within this strand, studies can be divided into two broad categories. On the one hand, microeconometric studies use reduced-form empirical designs to estimate the partial-equilibrium effects of commodity prices on deforestation, holding other macroeconomic variables, including the exchange rate, constant (Assunção et al., 2015; Harding et al., 2021; Berman et al., 2023; Da Mata and Dotta, 2021). On the other hand, model-based studies analyse this relationship. Early contributions in this literature rely on static frameworks, abstracting from dynamic adjustment (Souza-Rodrigues, 2019; Dominguez-Iino, 2025; Araujo et al., 2025a,b), while more recent work incorporates explicit dynamic processes in land-use change (Araujo, 2024; Assunção et al., 2025; Farrokhi et al., 2025; Scott et al., 2025). However, none of these studies incorporates or explicitly models feedback effects from commodity prices to the exchange rate.

This paper contributes to the literature along three fundamental dimensions. First, it is the first study to estimate the dynamic effects of commodity prices on aggregate deforestation while explicitly accounting for their impacts on the exchange rate. Second, we are the first to estimate the dynamic causal effects of the exchange rate on deforestation and to compare the relative magnitude of these effects vis-à-vis those associated with commodity prices. Third, from a methodological perspective, this is the first paper to employ structural vector autoregressions to in-

vestigate the drivers of deforestation in the Amazon. Unlike the existing empirical literature, our SVAR framework exploits time-series variation combined with external instruments constructed from high-frequency data. This approach allows us to identify general-equilibrium effects by incorporating feedbacks among aggregate variables, without the need to impose a fully specified structural model.

The second strand is a growing area of the literature that studies the interactions between climate change, environmental policy, and the macroeconomy, typically using macroeconometric time series methods. Topics addressed in this literature include the effects of carbon taxes on the real economy (Känzig, 2025; Metcalf and Stock, 2023), the impacts of extreme weather events (Kim et al., 2025), and the macroeconomic consequences of rising temperatures (Bilal and Känzig, 2024; Berg et al., 2024; Lucidi et al., 2024; Ciccarelli et al., 2024; Nath et al., 2024). Building on a similar methodological approach, our contribution to this literature is to explore a new question: How do commodity prices and exchange rate fluctuations affect deforestation in the Amazon? Also, while existing research looks at how climate influences the macroeconomy, our study turns the lens around by examining how the macroeconomy, in turn, can drive climate change.

The third strand of the literature to which this paper contributes examines the effects of commodity price shocks on the broader economy. Most of the existing literature focuses on oil (see Kilian and Zhou (2023) for a comprehensive review), which explains the lack of ready-made proxies for our commodities of interest. More closely related to this work, Curatola-Melo and Guimaraes (2025) and Stein (2025) use high-frequency strategies to identify shocks to grain and milk, respectively. We draw on the USDA Grain Stocks Report releases used by Curatola-Melo and Guimaraes (2025) as a source of plausibly exogenous variation in soybean prices. However, rather than relying on their heteroskedasticity-based identification strategy, we construct high-frequency price surprises around these releases and use them as external instruments. We also propose a novel instrument to iden-

tify shocks to cattle prices. While the use of weather variation to identify exogenous movements in commodity prices is well established (Roberts and Schlenker, 2013; Peersman and De Winne, 2021; Peersman, 2022), we embed such variation within a high-frequency identification framework, which could be extended to virtually any commodity.

The fourth and final strand of the literature to which this paper contributes focuses on the identification of exchange rate shocks. Existing approaches include zero and sign restrictions (Forbes et al., 2018), as well as narrative sign restrictions (An et al., 2021). Lane and Stracca (2018) construct an external instrument that exploits the institutional setting of a monetary union in the euro area. We are, to the best of our knowledge, the first to use a high-frequency identification strategy to identify exchange rate shocks. We implement this approach by exploiting foreign exchange swap interventions conducted by the Brazilian Central Bank.[3]

Outline. The paper is organized as follows. In the next section, the institutional background is discussed. Section 3 presents details on the construction of the instruments. Section 4 outlines the econometric approach. Section 5 presents the main results, followed by sensitivity analyses in Section 6.

2. Background

Brazil is a key player in global commodity markets. It is the world's largest exporter of beef and veal, accounting for 28% of world trade, and the largest soybean producer, supplying 40% of global output (USDA, 2024). Within Brazil, the Amazon Biome is a vast and economically important region whose activity combines agriculture, livestock, and mining. The Biome alone accounts for 22% of Brazil's national cattle herd (IBGE, 2023). Although soybean production in the region still

[3] The effects of these inverventions have been studied previously by Kohlscheen and Andrade (2014); Luna Santos (2021).

represents a modest share of national output, its cultivated area has expanded rapidly, increasing by 126% over the past decade (MapBiomas, 2024). As a result, the Amazon Biome has become an increasingly important contributor to both national and global agricultural markets. In the region, cattle ranching and soybean farming stand out as the main economic drivers, accounting for 39% and 17% of regional production value, respectively (MAPA, 2024).[4]

Cattle ranching also plays a central role in land use dynamics, particularly in relation to deforestation. Among all areas that transition from forest formation to other land uses, 75% are converted to pasture, which is by far the most common change, whereas only 11% are converted to agriculture. Conversely, when pastures are converted to other uses, agriculture is the dominant destination, accounting for 37% of such changes (MapBiomas, 2024). This suggests that, while both cattle ranching and soy cultivation are important in the broader deforestation process, cattle ranching plays a particularly prominent role in direct forest conversion. This pattern can be at least partly attributed to the structure of production, as animals are highly mobile and typically move between several ranches before slaughter. This mobility makes it difficult to ensure that all properties involved in the supply chain comply with environmental regulations and complicates efforts to monitor deforestation through satellite remote sensing (Lambin and Furumo, 2023).[5]

[4] The Amazon Biome is an ecologically defined region corresponding to the area covered by tropical rainforest in Brazil. It differs from the Legal Amazon, which is a government-defined politico-administrative region encompassing nine states. For instance, Mato Grosso (MT), one of Brazil's largest agricultural producers, is included in the Legal Amazon but is only partially within the Amazon Biome. In this study, we consider the following states whose territory falls within the Amazon Biome: Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), and Roraima (RR).

[5] While the commercial motives driving cattle expansion and deforestation are the main focus here, other research has highlighted the role of cattle ranching as a means of land grabbing, used to establish claims of productive use and legitimize property ownership. For a non-academic reference on this topic, see Lima-Filho et al. (2021).

3. Identification Strategy

We employ a high-frequency identification strategy to isolate plausibly exogenous variation in the exchange rate and commodity prices, and estimate their dynamic causal effects. The approach exploits changes in futures prices within tight windows around selected events. By focusing on such short intervals, reverse causality can be effectively rule out, as pre-existing conditions are already incorporated into prices at the time of the event and are unlikely to change within this period.

We consider three distinct types of events. Exchange rate shocks are identified around foreign exchange (FX) swap auctions conducted by the Brazilian Central Bank. Also, as described in Section 2, cattle and soybean are the most important commodities produced in the Amazon Biome, both in terms of the region's economic structure and its deforestation dynamics. Soybean price shocks are identified around releases of the USDA Grain Stocks report. Cattle price shocks are captured by days of extreme rain in top cattle-producing regions.

3.1. Exchange rate surprises

Brazil operates under a floating exchange rate regime. Although the Brazilian Central Bank (BCB) does not intervene to target a specific exchange rate level, it may intervene to mitigate excessive exchange rate volatility, with FX swap operations serving as one such instrument (BCB, 2026). These interventions influence the exchange rate without directly affecting the supply of currency in the spot market (Kohlscheen and Andrade, 2014). Since 2002, the BCB has conducted FX swap operations through auctions, which are announced in advance with the ex-

act timing of the auction.[6,7]

We construct price surprises using the (log) futures price observed 10 minutes before the auction (or the closest available quote) and 20 minutes after the auction, as defined above. Intraday exchange rate data are obtained from FirstRate Data. There are 990 auctions in the sample period.[8]

$$\text{Surprise}^{FX}_{h,a} = F^{FX}_{h,a,+20} - F^{FX}_{h,a,-10}$$

where $F^{FX}_{h,a,m}$ denotes the logarithm of the settlement price of the h-month-ahead exchange rate futures contract observed m minutes relative to auction a. The resulting surprises are aggregated to a monthly series.

3.2. Commodity price surprises

To construct a series of cattle price surprises, we examine changes in futures prices around days with extreme rainfall in top-producing states in the United States, the world's largest producer of beef and veal (USDA, 2024). We focus on states with the largest cattle inventories in 2022, excluding those that are also major grain producers (specifically, states accounting individually for more than 4% of national grain production in that year). This selection yields the following states: Texas, California, Oklahoma and Kansas, which together account for approximately 30% of the national cattle inventory. We then identify days with extreme rainfall as

[6] The mechanics of an FX swap operation are as follows: the BCB sells (buys) FX swap contracts in which it pays (receives) the USD exchange rate variation plus an FX coupon, while the counterparty pays (receives) the daily Selic rate. As a result, the counterparty is hedged against BRL depreciation (appreciation).

[7] The frequency and style of the FX interventions have varied over time. The Central Bank began using currency swap auctions in March, 2002, announcing in advance the timing, quantity, and maturities of the contracts to be traded. From 2002 until August 22, 2013, interventions occurred frequently but in an irregular and discretionary manner. After this date, the BCB shifted to a rule-based program with fixed daily sales, a framework that remained in place until March 31, 2015 (Luna Santos, 2021).

[8] FirstRate Data reports information only when there is trading volume. We exclude auctions for which the gap between the auction and the corresponding trading data exceeds 36 hours.

those in which precipitation exceeds the 99th percentile for a given state and calendar day, using daily gridded weather data from NOAA's National Centers for Environmental Information for the period 1951 to 2025.[9]

Soybean price surprises are constructed based on changes in futures prices around the release of the USDA Grain Stocks report as in Curatola-Melo and Guimaraes (2025). The USDA is a government agency responsible for a wide range of activities, including the collection and dissemination of agricultural statistics for both the United States and global markets. The Grain Stocks report is published quarterly, typically in mid-January and at the end of March, June, and September, and provides aggregate and state-level estimates of U.S. stocks for various crops, with particular emphasis on soybeans, corn, and wheat.

Surprises are constructed as the (log) difference between the futures price on the day of the event and the price on the last trading day preceding the event:

$$Surprise^{i}_{h,d} = F^{i}_{h,d} - F^{i}_{h,d-1}$$

where $F^{i}_{h,d}$ is the (log) settlement price of the h-month ahead future contract for commodity i on day d. For the baseline specification, we consider 6-month-ahead future prices. Daily surprises are aggregated to a monthly series, taking value zero when there are no announcements and the sum if there are multiple announcements.[10]

To capture the overall role of commodities, we construct a measure of commodity price surprises by combining soybean and cattle surprises into an overall

[9] One potential concern is that these extreme weather events may be widespread across the United States and thus influence Brazilian outcomes through channels unrelated to cattle markets. Reassuringly, on the event days considered here, an average of only 2.1 states experience extreme rainfall simultaneously, indicating that these shocks are largely localized rather than national in scope.

[10] The corresponding Bloomberg tickers for the futures contracts are `BCOMSYXT` for soybeans and `BCOMLIX` for livestock, where `X` indicates the contract maturity in months ahead, ranging from 1 to 6.

commodity price surprises. The weights reflect each commodity's share in the Gross Value of Agricultural Production in the states of the Amazon Biome in 2024 and are re-normalized to sum to one across the two commodities. This yields weights of 70.0% for cattle and 30.0% for soy. The Ministry of Agriculture and Livestock reports these data monthly as a measure of the real value of agricultural and livestock production.[11]

Formally, we define the aggregate commodity price surprise as:

$$Surprise_{h,t}^{Com} = \omega_{Ca} Surprise_{h,t}^{Ca} + \omega_S Surprise_{h,t}^{S}$$

where$Surprise_{h,t}^{Ca}$ and $Surprise_{h,t}^{S}$ and are the calculated cattle and soybean prices surprises on month t, respectively, and ω_{Ca} and ω_S are the considered weights.

4. Econometric Approach

The surprise series introduced in the previous section serve as external instruments for the identification of structural shocks in an SVAR framework. The next section formally sets out the econometric framework and states the identifying assumptions.

4.1. Framework

We assume that the dynamics between these variables are described by an SVAR given by:

$$\mathbf{B_0}\, \mathbf{y}_t = \sum_{j=1}^{p} \mathbf{B_j}\, \mathbf{y}_{t-j} + \varepsilon_t \tag{1}$$

[11] Cattle and soy together account for 55.8% of the region's total agricultural production value in 2024.

where $\mathbf{B_0}$ is a nonsingular $n \times n$ matrix of coefficients, $\mathbf{B_j}$ where $j = 1, \ldots, p$, are $n \times n$ coefficient matrices, and ε_t is an $n \times 1$ vector of *structural shocks* with $\mathbb{E}[\varepsilon_t] = \mathbf{0}_{n\times 1}$, $\mathbb{E}[\varepsilon_t, \varepsilon_t'] = \mathbf{I}_n$, and $\mathbb{E}[\varepsilon_t, \varepsilon_s'] = \mathbf{0}_{n\times n}$ for $s \neq t$, where $\mathbf{I}_n$ is the identity matrix of order n. In order to quantify the effects of commodity price shocks and exchange rate shocks on the economy and its transmission channels, our goal is, based on specification (1), to obtain the dynamic causal effects of two structural shocks, which we will refer to as the *exchange rate shock* and *commodity price shock* on all variables contained in $\mathbf{y}_t$.[12]

4.2. Identification Strategy

Due to simultaneity, the coefficients of system (1) are not identified by the linear projection of $\mathbf{y}_t$ on its lagged values. An equivalent representation of the dynamics of $\mathbf{y}_t$ is given by:

$$\mathbf{y}_t = \sum_{j=1}^{p} \mathbf{A_j} \mathbf{y}_{t-j} + \mathbf{u}_t \tag{2}$$

where $\mathbf{A_j} = \mathbf{\Theta_0}, \mathbf{\Theta_0} \equiv \mathbf{B_0^{-1}}$, $\mathbf{B_j}$, $j = 1, \ldots, p$, and $\mathbf{u}_t$ denotes the reduced-form residuals, which are related to the structural shocks by $\mathbf{u}_t = \mathbf{\Theta_0}\varepsilon_t$. The coefficients $\mathbf{A_j}$ and the covariance matrix of the reduced-form residuals are identified by the linear projection in (2). However, since the matrix $\mathbf{\Theta_0}$ has n^2 elements and an estimate of the covariance matrix of $\mathbf{u}_t$ provides only $n(n+1)/2$ independent identification restrictions, additional restrictions are required to identify one or more columns of $\mathbf{\Theta_0}$ and thus recover the dynamic causal effects of interest.

As an identification strategy, we obtain the additional restrictions needed by using external instruments, as proposed by Stock and Watson (2012) and Mertens and Ravn (2013). More specifically, let $\mathbf{z}_t$ denote a 2×1 vector of *proxy* variables

[12] For notational brevity, deterministic terms and exogenous regressors are omitted in (1).

that are correlated with the commodity price and exchange rate shocks but orthogonal to all other structural shocks. Partitioning the vector of structural shocks as $\varepsilon_t = [\varepsilon'_{1t}; \varepsilon'_{2t}]'$, where ε_{1t} is a 2×1 vector containing the two shocks of interest and ε_{2t} is an $(n-2) \times 1$ vector containing the remaining structural shocks, the *proxy* variables are sufficient to identify the dynamic causal effects of the shocks in ε_{1t} if they satisfy the following conditions:

$$\mathbb{E}[\mathbf{z}_t \boldsymbol{\varepsilon}'_{\mathbf{1t}}] = \text{diag}(\alpha_1, \alpha_2) \tag{3}$$

$$\mathbb{E}[\mathbf{z}_t, \boldsymbol{\varepsilon}'_{\mathbf{2t}}] = \mathbf{0}_{2\times(n-2)} \tag{4}$$

where $\alpha_j \neq 0$ for $j = 1, 2$. Condition 3 is a relevance condition, and condition (4) is an exogeneity condition. Together, these conditions state that each *proxy* variable is correlated *exclusively* with one of the structural shocks of interest. Estimation is performed using Bayesian techniques and assuming a Jeffrey (uninformative) prior.

4.3. Empirical Specification

The baseline specification includes three variables: Commodity prices, exchange rate, and deforestation. Data is monthly covering the period from March, 2008 to March, 2025. The VAR is estimated in log levels, using 14 lags and including a constant term as the deterministic component. Data is detailed in Appendix A.

Commodity prices. Commodity production requires farmers to commit to specific land uses months in advance. To approximate producers' ex ante incentives, we use six-month-ahead futures prices. We construct a measure of commodity prices as a weighted average of cattle and soybean futures prices, with weights given by each commodity's share in the Gross Value of Agricultural Production in the states of the Amazon Biome in 2024, as reported by the Ministry of Agriculture

and Livestock and described in Section 3.2.

Exchange rate. To ensure consistency with our choice of commodity prices, we also employ six-month-ahead exchange rate futures.

Deforestation. Official deforestation data are released annually, which limits the analysis of short-term dynamics. To address this limitation and obtain higher-frequency information, we use DETER alerts, which was introduced in Section 2, accumulated over 12 months as a proxy for deforestation.[13]

5. Dynamic Causal Effects

This section presents the results based on the baseline external instruments VAR.

5.1. First Stage

In the first step, it is important to evaluate the strength of the instrument, as weak correlation between the instrument and the structural shock can lead to unreliable inference. Instrument strength is assessed using the F-statistic from the first-stage regression. The F-statistics and heteroskedasticity-robust values are reported in Table 1. Since the commonly recommended threshold is 10, all of our instruments can be considered strong (Staiger and Stock, 1997). The external instruments approach rests on the assumption that the instrument is correlated with the structural shock of interest but uncorrelated with all other structural shocks. Although this assumption cannot be directly tested, we carefully select the events underlying our surprise series to ensure that the resulting variation is plausibly exogenous.

[13] It is important to consider that DETER alerts directly trigger policy responses, which may affect the interpretation of causal effects. To address this, we have implemented alternative deforestation measures which are described in Section 6.

Table 1: Results of first-stage regression

	Exchange rate	Commodity price
F-statistics	19.8	24.7
F-statistics (robust)	29.5	31.2

Notes: Values above 10 indicate strong instruments. Robust F-statistics allow for heteroskedasticity.

5.2. Commodity Prices, Exchange Rates and Deforestation

The next subsection presents the results obtained from the baseline model. As the variables are in logs, the responses correspond to elasticities. The solid line shows the point estimates, while the shaded areas indicate the 68% and 90% confidence intervals.

Figure 1 shows the deforestation responses to a 1% exchange rate depreciation (left panel) and a 1% commodity price increase (right panel). Following a 1% depreciation of the exchange rate, deforestation begins rising approximately 12 months after the shock, peaking at 0.8% around 20 months after impact. By contrast, a 1% increase in commodity prices yields a more modest and statistically insignificant response, with deforestation peaking at around 0.5% 11 months after the shock. Taken together, these results underscore the central role of the exchange rate in shaping deforestation dynamics. This channel at least as important as commodity price movements, yet one that has remained largely unexplored in the literature.

5.3. Forecast Error Variance Decomposition

Figure 2 reports the forecast error variance decomposition (FEVD) for deforestation, showing the contribution of commodity price and exchange rate shocks across horizons. For most horizons, exchange rate shocks are at least as important as, and

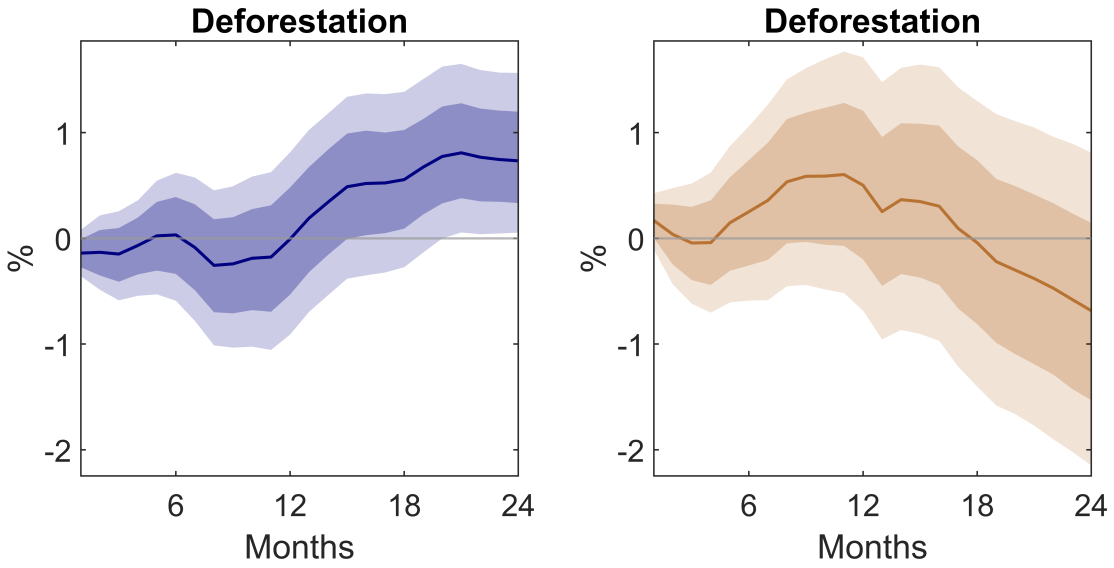


Figure 1: Deforestation responses to a 1% exchange rate depreciation (left) and a 1% commodity price increase (right).

often more important than, commodity price shocks. An exception arises in the medium run (approximately months 3 to 12), when commodity price shocks temporarily account for a larger share. Notably, in the long run, exchange rate shocks dominate, explaining a substantially larger share of the variance.

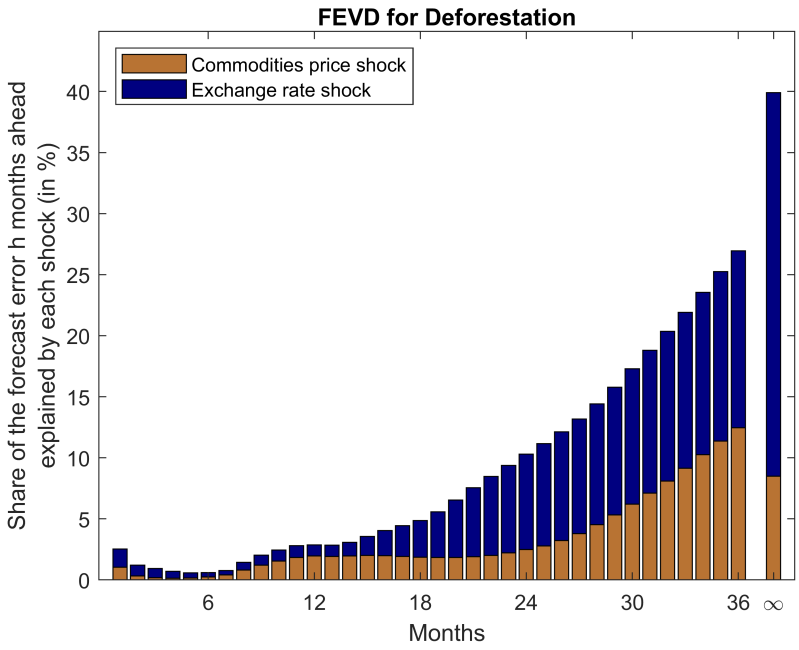


Figure 2: Forecast error variance decomposition for deforestation.

5.4. Transmission Mechanisms

To shed light on the channels underlying these results, this section examines how exchange rate and commodity price shocks propagate through local prices and incentives for the expansion of agricultural land. The key distinction lies in how these shocks affect commodity prices in domestic currency.

Figure 3 shows the responses to a 1% exchange rate depreciation. The depreciation directly raises commodity prices in BRL, which increase by about 0.7% on impact and remain persistently elevated over the horizon considered, while commodity prices in USD remain largely unchanged. This rise in local prices strengthens incentives for land-intensive activities, leading to higher deforestation.

By contrast, a positive commodity price shock in USD is accompanied by a persistent exchange rate appreciation, which peaks at -1.2% approximately four months after the shock. Such appreciation in response to higher commodity prices is well documented in commodity-exporting emerging economies (Chen and Rogoff, 2003; Fernández et al., 2018). As a result, the increase in commodity prices in BRL is dampened and remains statistically insignificant over the horizon, attenuating the associated incentives for deforestation.

5.5. Counterfactual Scenarios

In the previous section, we showed that the response of deforestation closely follows movements in commodity prices in BRL. In this section, we aim to isolate this channel. We construct counterfactual scenarios by choosing a sequence of shocks such that the response of commodity prices in BRL is zero, while allowing the remaining variables to adjust endogenously. If deforestation is driven by changes in commodity prices in BRL that alter incentives for local agricultural expansion, then deforestation should not respond once this channel is shut down. We implement this approach using the methodology of Antolín-Díaz et al. (2021), which

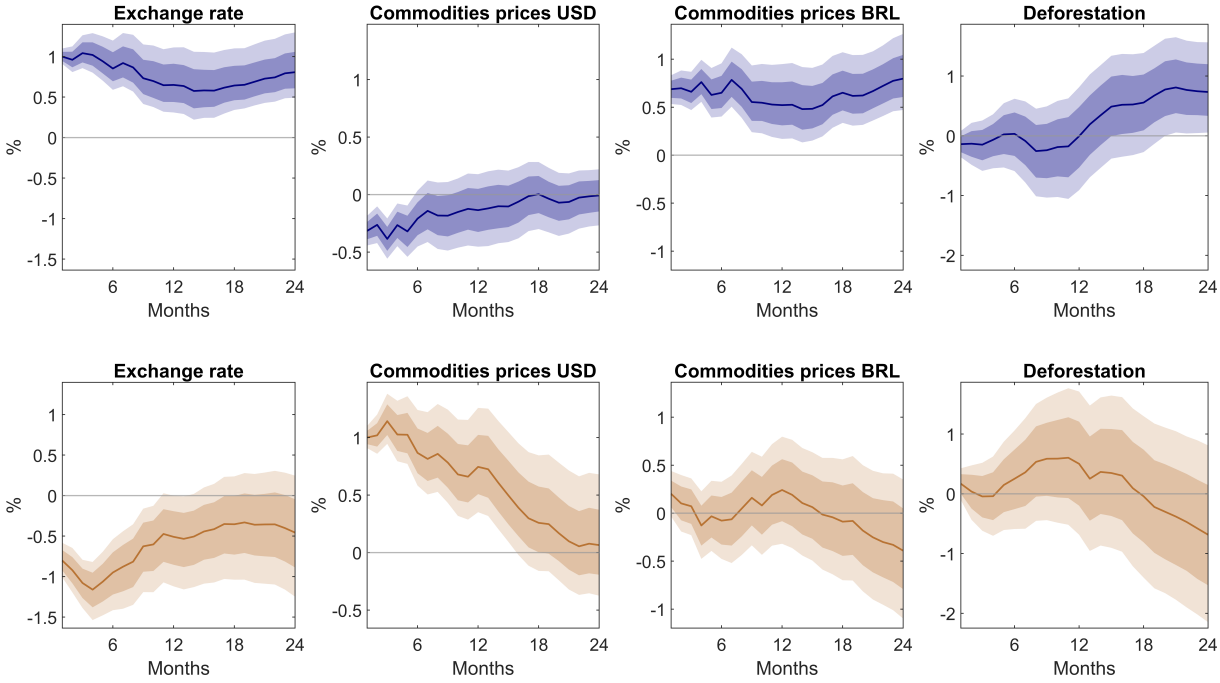


Figure 3: Impulse responses to a 1% increase in exchange rate (depreciation) (top panel) and 1% increase in commodity prices (bottom panel). The solid line shows the point estimates, while the shaded areas indicate the 68% and 90% confidence intervals.

allows for the construction of such structural scenarios.

Structural Scenario 1: Exchange rate shock with no response from commodity prices in BRL. The top panel of Figure 4 reports the response to an exchange rate shock under the restriction that commodity prices in BRL do not respond. Consistent with the proposed mechanism, the deforestation response is no longer statistically significant at any horizon. Moreover, the point estimates are uniformly lower than in the baseline specification (shown in pink in the figure). This result indicates that the effect of exchange rate shocks on deforestation operates primarily through their impact on commodity prices in domestic currency.

Structural Scenario 2: Commodity price shock with no response from commodity prices in BRL. The bottom panel of Figure 4 reports the response to a commodity price shock under the restriction that commodity prices in BRL do not

respond. In contrast to the previous scenario, the deforestation response remains largely unchanged relative to the baseline (shown in pink in the figure). This reflects the fact that, in the baseline specification, the exchange rate appreciation following a positive commodity price shock already offsets the increase in commodity prices in BRL. As a result, imposing a zero response of commodity prices in BRL has little additional effect, and the deforestation response remains small and statistically insignificant.

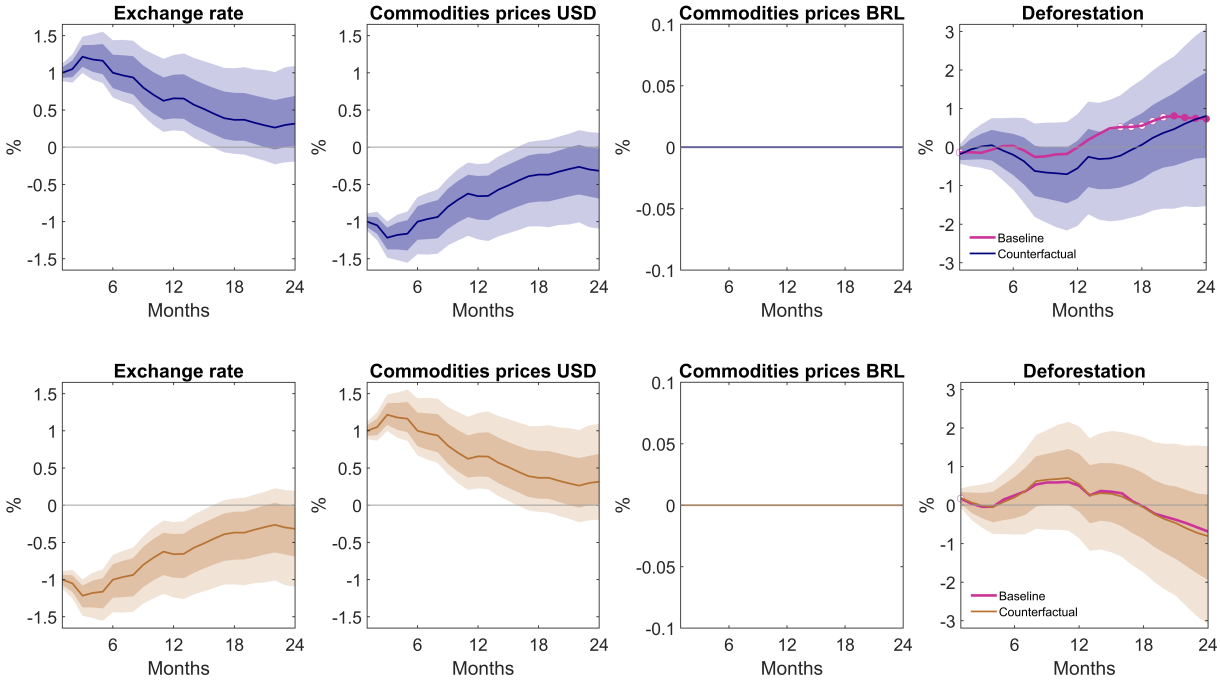


Figure 4: Impulse responses under counterfactual scenarios in which commodity prices in BRL are constrained to have zero response following methodology by Antolín-Díaz et al. (2021). The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

6. Sensitivity Analysis

We conduct a series of robustness checks, presented below. The corresponding figures are reported in Appendix B.

Alternative deforestation measures. Because DETER alerts may trigger enforcement responses that confound causal interpretation, we use deforestation data from the Deforestation Alert System (SAD) developed by Imazon as an alternative measure. We construct seasonally adjusted and a 12-month accumulated index. The main patterns are preserved (Figures A.1 – A.2), although the response to commodity price shocks becomes persistently negative.

Controlling for the Covid-19 period. Despite the well-documented impact of the pandemic on economic activity and commodity prices through both the collapse and subsequent recovery of demand, as well as widespread supply chain disruptions, this period also had significant implications for deforestation in the Amazon. As anecdotal evidence of this, in May, 2020, Brazil's then Minister of the Environment suggested "passing the cattle through," meaning taking advantage of the public and media's focus on the pandemic to push through changes to environmental and agricultural regulations. To address that, dummy variables are also included for the period from March, 2020 to December, 2021, when Brazil was most affected by the Covid-19 pandemic. The results are quantitatively similar to the baseline (Figure A.3).

Co-movement in commodity prices. Because commodity prices exhibit substantial comovement, which complicates the identification of individual commodity effects (Delle Chiaie et al., 2021), we additionally control for a Brazil-specific commodity price index by weighting individual commodity prices according to their shares in Brazil's export basket (Shousha, 2016; Fernández et al., 2018). The main results remain stable under this specification (Figure A.4).

Demand for commodities . A potential concern is that shifts in external commodity demand not captured in the baseline VAR may be driving the observed results.

To address this issue, we incorporate a measure of China's commodity imports. This measure is particularly relevant because UN Comtrade data show that, on average, nearly 30% of Brazil's commodity exports were destined for China between 2006 and 2024, making China a central determinant of external demand for Brazilian commodities. The results remain consistent with the baseline (Figure A.5).

Controlling for anti-deforestation policies. Over time, a range of policies aimed at curbing deforestation in the Legal Amazon have been introduced and progressively strengthened. A potential concern is that the estimated responses may reflect changes in enforcement intensity rather than the economic mechanisms of interest. To address this, we include a measure of environmental enforcement given by the number of fines issued for deforestation-related infractions. The results remain consistent with the baseline specification, suggesting that our findings are not driven by changes in anti-deforestation policy intensity (Figure A.6).

7. Conclusion

Identifying the relationship between commodity prices, the exchange rate and deforestation in the Amazon is challenging, as these variables are jointly determined. To address this, this paper develops three novel external instruments within a structural VAR framework, allowing for a credible separation of exchange rate and commodity price shocks. The results show that deforestation is primarily driven by commodity prices in local currency. Exchange rate depreciations lead to higher deforestation by raising local-currency prices, even when international prices remain unchanged, while the effect of commodity price shocks is attenuated by exchange rate appreciation. Together, these findings underscore the central role of the exchange rate in shaping deforestation dynamics and emphasize the importance of the exchange rate in driving land-use change.

References

An, Lian, Mark A. Wynne, and Ren Zhang, "Shock-dependent exchange rate pass-through: Evidence based on a narrative sign approach for Japan," *Journal of International Money and Finance*, November 2021, *118*, 102462.

Antolín-Díaz, Juan, Ivan Petrella, and Juan F. Rubio-Ramírez, "Structural Scenario Analysis with SVARs," *Journal of Monetary Economics*, January 2021, *117*, 798–815.

Araujo, Rafael, "When Clouds Go Dry: An Integrated Model of Deforestation, Rainfall, and Agriculture," 2024.

_ , Francisco Costa, and Marcelo Sant'Anna, "Efficient Conservation of the Brazilian Amazon: Estimates from a Dynamic Model," *The Review of Economic Studies*, May 2025, p. rdaf031.

_ , Juliano Assunção, and Arthur Bragança, "Transportation Infrastructure and Deforestation in the Amazon," *Journal of Development Economics*, October 2025, *177*, 103559.

Assunção, Juliano, Clarissa Gandour, and Rudi Rocha, "Deforestation Slowdown in the Brazilian Amazon: Prices or Policies?," *Environment and Development Economics*, December 2015, *20* (6), 697–722.

Assunção, Juliano J., Lars Peter Hansen, Todd Munson, and José A. Scheinkman, "Carbon Prices and Forest Preservation over Space and Time in the Brazilian Amazon," June 2025.

BCB, "Foreign Exchange Policy," 2026. Accessed: 15 Jan 2026.

Berg, Kimberly A., Chadwick C. Curtis, and Nelson C. Mark, "GDP and Temperature: Evidence on Cross-Country Response Heterogeneity," *European Economic Review*, October 2024, *169*, 104833.

Berman, Nicolas, Mathieu Couttenier, Antoine Leblois, and Raphael Soubeyran, "Crop Prices and Deforestation in the Tropics," *Journal of Environmental Economics and Management*, May 2023, *119*, 102819.

Bilal, Adrien and Diego R Känzig, "The Macroeconomic Impact of Climate Change: Global vs. Local Temperature," 2024.

Chiaie, Simona Delle, Laurent Ferrara, and Domenico Giannone, "Common Factors of Commodity Prices," *Journal of Applied Econometrics*, 2021, *36* (7), 875–895.

chin Chen, Yu and Kenneth Rogoff, "Commodity Currencies," *Journal of International Economics*, 2003, *60* (1), 133–160.

Ciccarelli, Matteo, Friderike Kuik, and Catalina Martínez Hernández, "The Asymmetric Effects of Temperature Shocks on Inflation in the Largest Euro Area Countries," *European Economic Review*, September 2024, *168*, 104805.

Curatola-Melo, Alisson and Bernardo Guimaraes, "The Causal Effects of Commodity Shocks," Working Paper, FGV-EESP April 2025. Available at SSRN: https://ssrn.com/abstract=5219522 or http://dx.doi.org/10.2139/ssrn.5219522.

Dominguez-Iino, Tomas, "Efficiency and Redistribution in Environmental Policy: An Equilibrium Analysis of Agricultural Supply Chains," *Journal of Political Economy*, October 2025.

Farrokhi, Farid, Elliot Kang, Heitor S. Pellegrina, and Sebastian Sotelo, "Deforestation: A Global and Dynamic Perspective," Technical Report w34150, National Bureau of Economic Research August 2025.

Fernández, Andrés, Andrés González, and Diego Rodríguez, "Sharing a Ride on the Commodities Roller Coaster: Common Factors in Business Cycles of Emerging Economies," *Journal of International Economics*, March 2018, *111*, 99–121.

Forbes, Kristin, Ida Hjortsoe, and Tsvetelina Nenova, "The shocks matter: Improving our estimates of exchange rate pass-through," *Journal of International Economics*, September 2018, *114*, 255–275.

Harding, Torfinn, Julika Herzberg, and Karlygash Kuralbayeva, "Commodity Prices and Robust Environmental Regulation: Evidence from Deforestation in Brazil," *Journal of Environmental Economics and Management*, July 2021, *108*, 102452.

IBGE, "Pesquisa Agrícola Municipal (PAM)," 2023. Accessed: 2025-07-01.

Känzig, Diego R, "The Unequal Economic Consequences of Carbon Pricing," 2025.

Kilian, Lutz and Xiaoqing Zhou, "The Econometrics of Oil Market VAR Models," in "Essays in Honor of Joon Y. Park: Econometric Methodology in Empirical Applications," Vol. 45B of *Advances in Econometrics*, Leeds: Emerald Publishing Limited, 2023, pp. 65–95.

Kim, Hee Soo, Christian Matthes, and Toàn Phan, "Severe Weather and the Macroeconomy," *American Economic Journal: Macroeconomics*, April 2025, *17* (2), 315–341.

Kohlscheen, Emanuel and Sandro C. Andrade, "Official FX interventions through derivatives," *Journal of International Money and Finance*, October 2014, *47*, 202–216.

Lambin, Eric F. and Paul R. Furumo, "Deforestation-Free Commodity Supply Chains: Myth or Reality?," *Annual Review of Environment and Resources*, November 2023, *48* (1), 237–261.

Lane, Philip R. and Livio Stracca, "Can appreciation be expansionary? Evidence from the euro area," *Economic Policy*, 2018, *33* (94), 225–264.

Lima-Filho, Francisco Luis, Arthur Bragança, and Juliano Assunção, "The Economics of Cattle Ranching in the Amazon: Land Grabbing or Pushing the Agricultural Frontier?," Technical Report, Climate Policy Initiative, Rio de Janeiro oct 2021.

Lucidi, Francesco Simone, Marta Maria Pisa, and Massimiliano Tancioni, "The Effects of Temperature Shocks on Energy Prices and Inflation in the Euro Area," *European Economic Review*, July 2024, *166*, 104771.

MAPA, "Valor Bruto da Produção Agropecuária (VBP)," 2024. Accessed: March 2026.

MapBiomas, "Project MapBiomas – Collection 9 of Brazilian Land Cover & Use Map Series," 2024. Accessed: 2024-08-02.

Mata, Daniel Da and Mario Dotta, "Commodity Booms and The Environment," *SSRN Electronic Journal*, 2021.

Mertens, Karel and Morten O Ravn, "The dynamic effects of personal and corporate income tax changes in the United States," *American Economic Review*, 2013, *103* (4), 1212–1247.

Metcalf, Gilbert E. and James H. Stock, "The Macroeconomic Impact of Europe's Carbon Taxes," *American Economic Journal: Macroeconomics*, July 2023, *15* (3), 265–286.

Nath, Ishan B., Valerie A. Ramey, and Peter J. Klenow, "How Much Will Global Warming Cool Global Growth?," Technical Report w32761, National Bureau of Economic Research July 2024.

of Agriculture USDA, United States Department, "World Markets and Trade," Technical Report 2024.

Peersman, Gert, "International Food Commodity Prices and Missing (Dis)Inflation in the Euro Area," *The Review of Economics and Statistics*, January 2022, *104* (1), 85–100.

_ **and Jasmien De Winne**, "The Adverse Consequences of Global Harvest and Weather Disruptions on Economic Activity," *Nature Climate Change*, 2021, *11*, 665–672.

Roberts, Michael J. and Wolfram Schlenker, "Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate," *American Economic Review*, 2013, *103* (6), 2265–2295.

Santos, Francisco Luna, "Comparing the Impact of Discretionary and Pre-Announced Central Bank Interventions," 2021, *110*, 102307.

Scott, Paul, Eduardo Souza-Rodrigues, Ted C. Rosenbaum, and Skand Goel, "Cows and Trees," 2025. Working Paper.

Scott, Paul T, "Dynamic Discrete Choice Estimation of Agricultural Land Use," 2013. Working Paper.

Shousha, S., "Macroeconomic Effects of Commodity Booms and Busts: The Role of Financial Frictions," Technical Report, Working Paper 2016.

Souza-Rodrigues, Eduardo, "Deforestation in the Amazon: A Unified Framework for Estimation and Policy Analysis," *The Review of Economic Studies*, November 2019, *86* (6), 2713–2744.

Staiger, Douglas and James H. Stock, "Instrumental Variables Regression with Weak Instruments," *Econometrica*, 1997, *65* (3), 557–586.

Stein, Hillary, "Got Milk? The Effect of Export Price Shocks on Exchange Rates," *Journal of International Economics*, May 2025, *155*, 104080.

Stock, James H and Mark W Watson, "Disentangling the Channels of the 2007-2009 Recession," *Brookings Papers on Economic Activity*, 2012, *Spring 2012*, 81–135. PDF.

Online appendix to

Beyond Commodity Prices: Exchange Rates and Amazon Deforestation

by Miguel Bandeira, Marco Bonomo and Heloísa De Paula

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A. Data

This section outlines the data sources and key variables used in the analysis.

Commodity prices. We use six-month futures contracts as our measure of commodity prices. The data come from Bloomberg, where the relevant tickers are `BCOMSYXT` for soybeans and `BCOMLIXT` for livestock, with `X` indicating the contract maturity in months ahead (from 1 to 6). Livestock futures are used as our primary proxy for cattle prices. We construct weighted average of commodity futures as our measure of commodity prices, using weights based on each commodity's share in the Gross Value of Agricultural Production in the states of the Amazon Biome in 2024, reported monthly by the Ministry of Agriculture and Livestock as a measure of the real value of agricultural and livestock production. Formally,

$$PCom_t = \omega_{Ca} F_{h,t}^{Ca} + \omega_S F_{h,t}^{S}$$

where he reported weights are 70.0% for cattle (ω_{Ca}) and 30.0% for soy (ω_S). Let $F_{h,t}^{i}$, with $i \in \{S, Ca\}$, denote the value of the futures contract for soybeans and cattle, respectively, on the last trading day of a given month.

Exchange rate. For consistency, we use the six-month futures exchange rate as well, retrieved from Bloomberg under the ticker `BRX Curncy`. Futures contract data are available at a daily frequency, and we use the last trading day of each month to construct monthly values.

Deforestation. Official deforestation data are released annually by PRODES, operated by the *National Institute for Space Research* ("Instituto Nacional de Pesquisas Espaciais" - INPE), which uses high-resolution satellite imagery to measure clear-cut deforestation in the Brazilian Amazon since 1988. INPE also operates DETER, which is a rapid-alert system created in 2005 that uses satellite imagery to detect evidence of deforestation and forest degradation in near real time, supporting enforcement actions by IBAMA and other environmental agencies. Initially based on MODIS data (with a minimum detectable area of 25 ha), the system was upgraded in 2015 to identify much smaller deforested areas, down to roughly 3 ha. We use DETER alerts as a high-frequency proxy for deforestation, summing the reported areas of detected forest loss.

B. Sensitivity Analysis

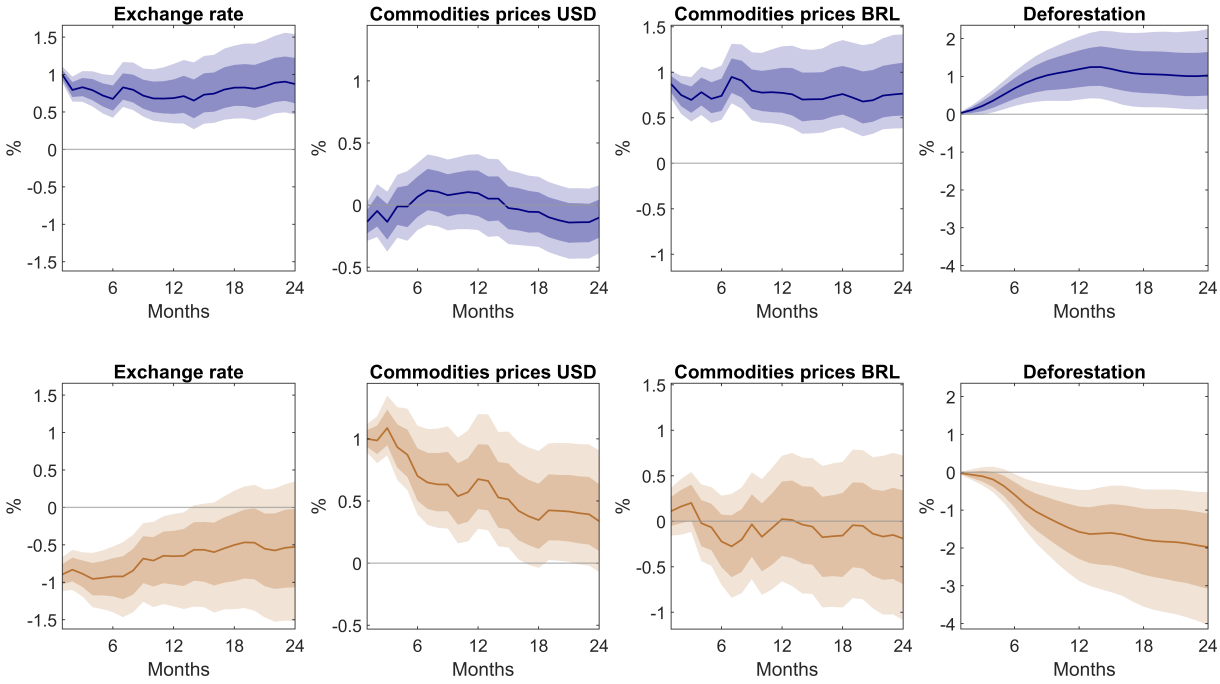


Figure A.1: Impulse responses using deseasonalized SAD as the deforestation measure. The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

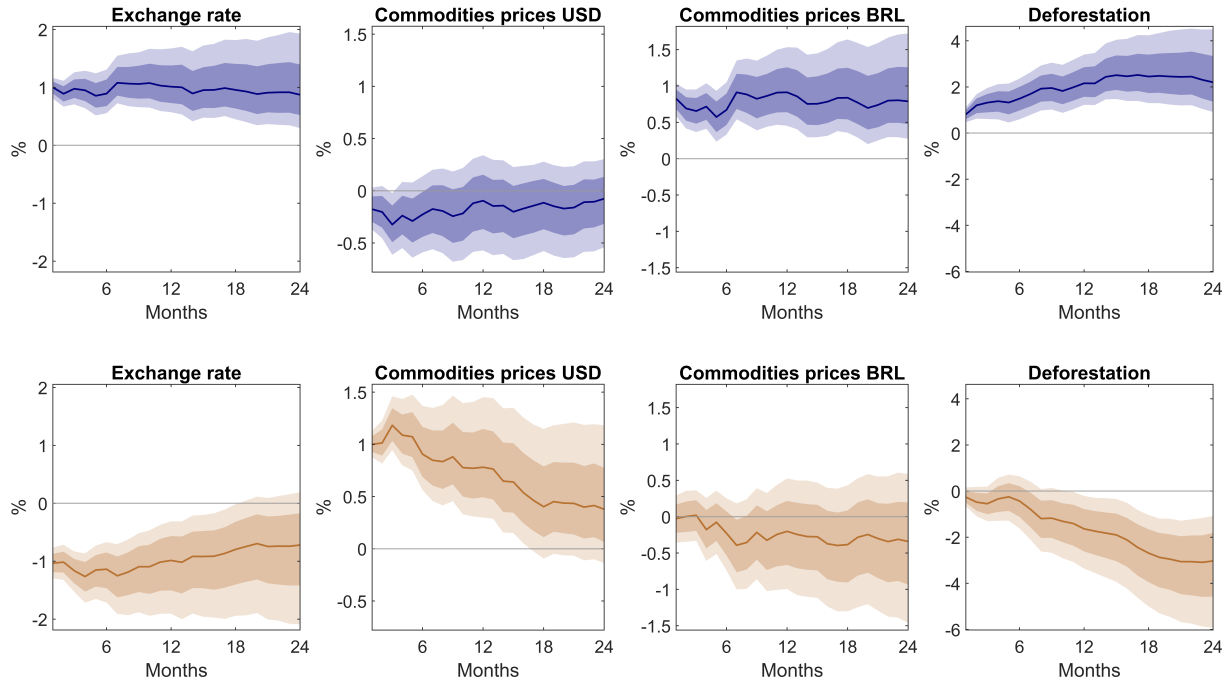


Figure A.2: Impulse responses using 12-month accumulated SAD as the deforestation measure. The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

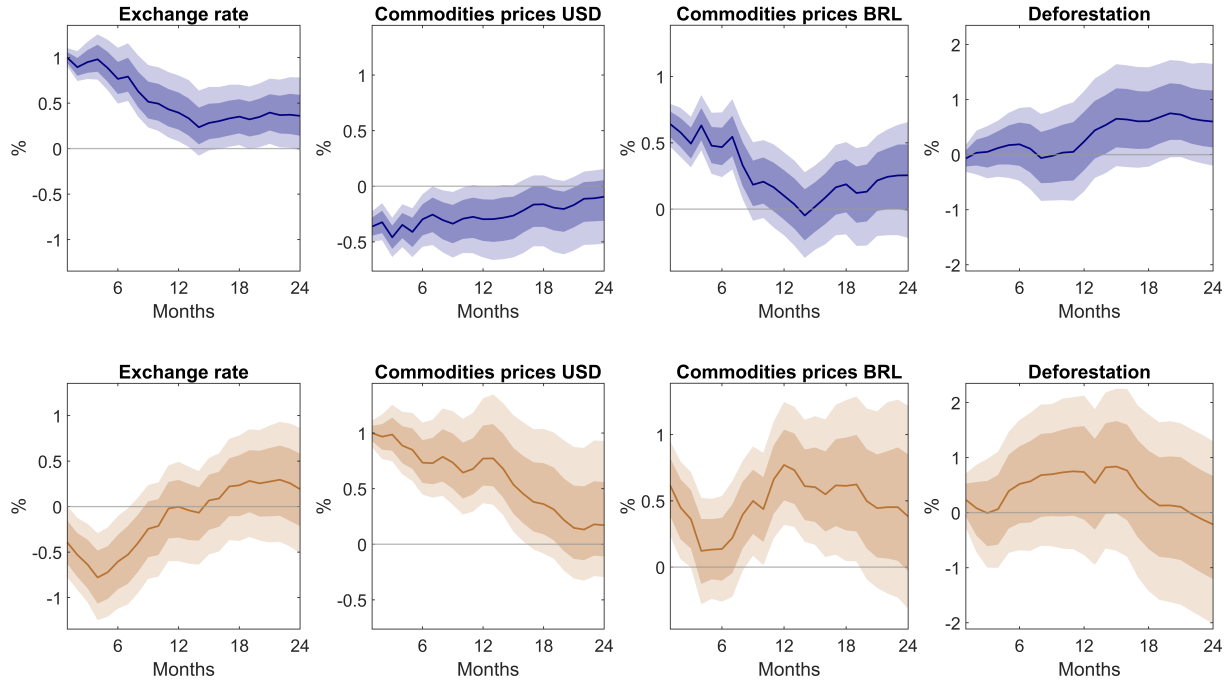


Figure A.3: Impulse responses including a dummy for the Covid-19 period (Mar, 2020 - Dec, 2021). The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

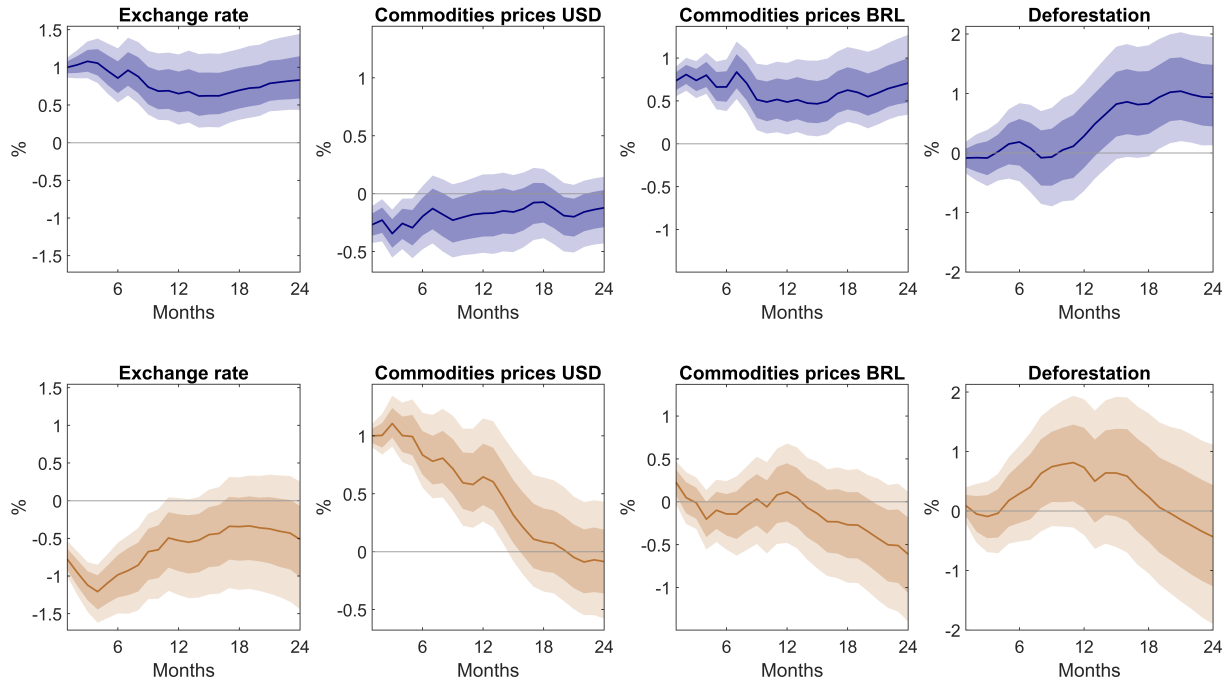


Figure A.4: Impulse responses controlling for a Brazil-specific commodity price index. The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

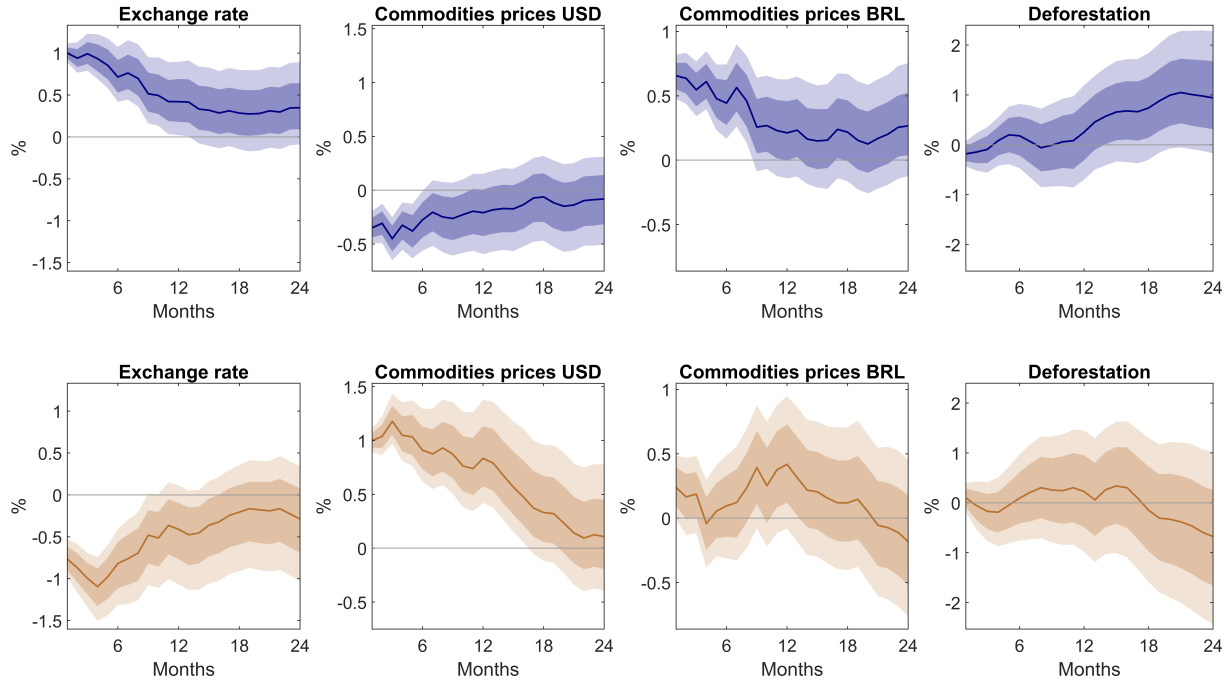


Figure A.5: Impulse responses controlling for global demand using China's commodity imports. The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.

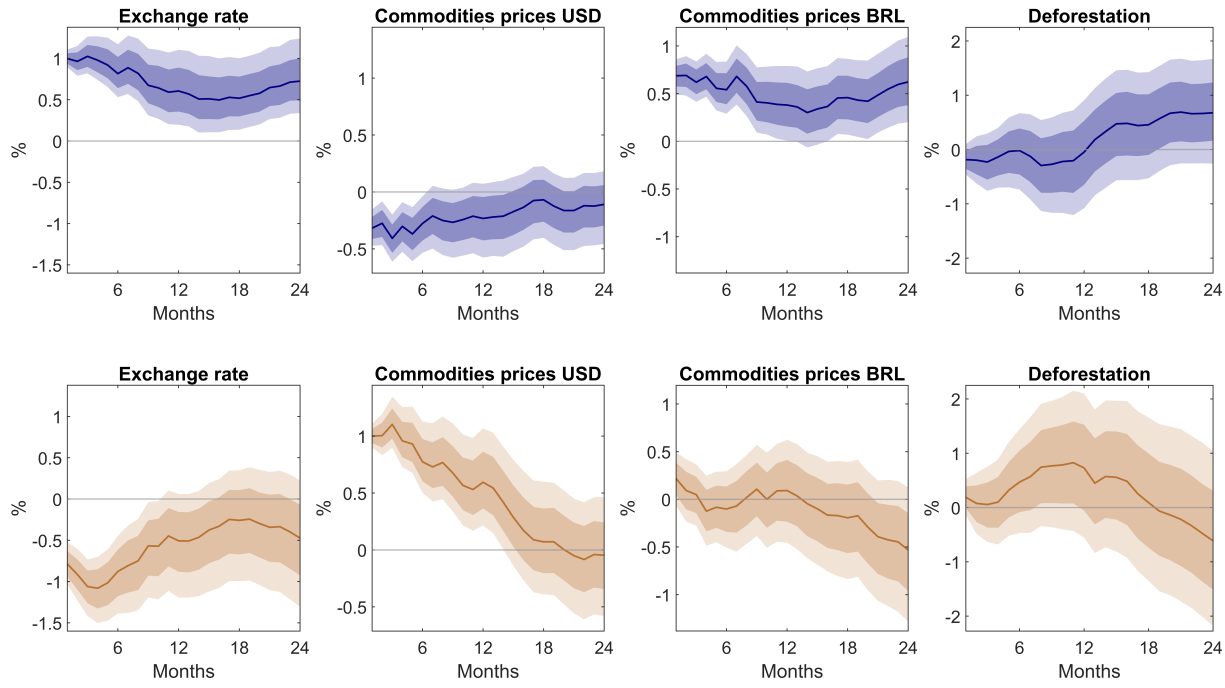


Figure A.6: Impulse responses controlling for environmental enforcement, measured by the number of deforestation-related fines. The top panel shows responses to a 1% exchange rate depreciation, and the bottom panel to a 1% increase in commodity prices. Solid lines denote point estimates, and shaded areas indicate the 68% and 90% confidence intervals.