The Carbon Paradox of Clean Incentives: Evidence from Ethanol

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Abstract

When carbon pricing faces implementation barriers, promoting low-carbon production offers an alternative; it aims to reduce emissions by making cleaner substitutes more affordable. This paper develops a dynamic framework to assess whether incentives for cleaner production necessarily reduce emissions, considering both substitution toward cleaner goods and rebound effects from increased total consumption. I apply it to Brazil, the world's second-largest ethanol market, where *RenovaBio* uses incentives funded by fossil fuel distributors to promote ethanol, a cleaner substitute for gasoline. The estimated unified equilibrium model combines supply from heterogeneous ethanol producers, differentiated fuel demand under oligopolistic pricing, and dynamic carbon-credit banking. The answer is no: RenovaBio increases ethanol production but displaces very little gasoline, expanding total fuel consumption and raising emissions by 0.22% relative to policy removal over 2020–2024. In contrast, replacing RenovaBio with an ethanol blending mandate about one percentage point higher generates essentially the same ethanol production, with 1.20% lower emissions than RenovaBio and smaller fuel-price distortions.

1 Introduction

Reducing emissions in carbon-intensive sectors is a central climate-policy challenge. A conventional approach is to raise the cost of consuming polluting goods in proportion to the environmental damage they cause (Goulder and Parry, 2008). Concerns about household costs and distributional fairness can weaken public support for this approach (Douenne and Fabre, 2022; Dechezleprêtre et al., 2025). An alternative is to support the production of cleaner substitutes. The aim is to make cleaner goods more abundant and affordable, allowing them to replace more polluting alternatives (Fischer and Newell, 2008; Borenstein, 2012).

How do incentives for clean production affect aggregate emissions? To answer this question, I use a dynamic equilibrium model that captures three responses: (1) how much producers expand clean output in response to the incentive; (2) how strongly consumers substitute cleaner goods for more polluting alternatives; and (3) how lower prices expand total consumption, potentially offsetting emissions savings through a rebound effect (Gillingham et al., 2016). The empirical analysis uses this model to evaluate RenovaBio, a program designed to expand ethanol production and reduce gasoline use, in Brazil's ethanol production industry and retail fuel markets.

Ethanol offers a lower-carbon substitute for gasoline in a fuel system that remains heavily dependent on liquid fuels (Lade and Smith, 2025).[1] Brazil provides an especially informative setting, with one of the world's largest and longest-established ethanol markets (Cortez, ed, 2016; Sant'Anna, 2024). Ethanol is produced at large scale domestically (Ramirez Camargo et al., 2022) and sold both blended into gasoline and separately at the pump, while most light vehicles can run on either fuel (IRENA, 2025; EPE, 2024a).[2] Access to both fuels makes Brazil well suited to studying whether ethanol expansion reduces reliance on gasoline.

RenovaBio, implemented in Brazil in 2020, is the focus of the analysis. Under RenovaBio, annual emissions-reduction targets translate into annual carbon credit (CBIO) retirement requirements (ANP, 2019). Biofuel producers earn carbon credits in proportion to their output, while fossil fuel distributors must meet government-set targets by purchasing and retiring carbon credits in proportion to their fossil fuel sales (ANP, 2018, 2019). Credits are traded on a centralized exchange, and the resulting credit price links the downstream compliance burden to upstream supply incentives and determines the magnitude of both (B3, 2022). Thus, RenovaBio creates a self-financing decarbonization mechanism within the fuel supply chain.

The analysis links national upstream ethanol and carbon credit markets to state-level retail fuel markets. Downstream, households choose between gasoline and ethanol at the pump, a choice made especially relevant by the widespread adoption of flex-fuel vehicles (EPE, 2024a; Hoeckel and Alvim, 2023). Distributors sell both fuels and set retail prices within state markets. The sector is concentrated, with three firms accounting for just over half of national gasoline and ethanol sales (ANP, 2025a; CADE, 2026). Upstream, ethanol producers choose output in response to the ethanol price and carbon credit revenue, while the national carbon credit market clears credit supply from ethanol producers against compliance demand from fossil fuel distributors (Sant'Anna, 2024; B3, 2022). Interactions across these markets shape fuel prices and consumption, ethanol production, and the carbon credit price.

The data consist of monthly firm-level observations on retail fuel prices and quantities, state-level biofuel production, and carbon credit trading. The downstream sample covers 2010–2024; the production and carbon credit data cover 2018–2025. The main data sources are Brazil's National Agency of Petroleum, Natural Gas and Biofuels (ANP), including its ethanol and CBIO dashboards, B3, Brazil's stock exchange, and the National Supply Company (CONAB) (ANP, 2025a, 2026b; B3, 2022; CONAB, 2026).

The model's intuition rests on three elasticities. The ethanol supply elasticity determines how

[1] Ethanol's carbon intensity varies across feedstocks and production methods, but life-cycle estimates for Brazilian sugarcane ethanol are substantially lower than those for gasoline (Macedo et al., 2008; Seabra et al., 2011). Measurement remains debated, particularly regarding emissions from land-use change (Sant'Anna, 2024). Resolving these questions is beyond the scope of this study; Section 2 provides further background.

[2] Brazilian policies promoting ethanol use date to 1931, with large-scale expansion following the launch of Proalcool in 1975. During the study period, regular gasoline contained 27% ethanol by volume (IRENA, 2025).

production responds to the credit incentive. On the demand side, substitution between ethanol and gasoline determines gasoline displacement, while substitution between fuel and the outside good, representing no fuel purchase, determines the change in total fuel consumption. Whether additional ethanol replaces gasoline or expands total fuel use depends on the relative strength of these responses. Importantly, these elasticities are not fixed primitives; they are equilibrium objects shaped by market structure, policy rules, prices, and pass-through.

The model describes consumer choice among gasoline and ethanol products differentiated by distributor brand and Bertrand price competition among distributors within each state and month. An outside option for no fuel purchase separates ethanol–gasoline substitution from changes in total fuel consumption. State-specific ethanol supply elasticities capture heterogeneity in production technologies, including the expansion of corn ethanol in emerging producing regions. Finally, the model incorporates dynamic carbon credit banking, allowing credits to be carried forward to meet future government retirement targets. Banking links current credit prices to outstanding inventories and expected future targets, affecting current production incentives and distributors' compliance costs.

I estimate these responses. On the supply side, I instrument effective producer revenue with international oil price variation, which shifts gasoline prices and ethanol demand through fuel substitution, and estimate a national ethanol supply elasticity of about 3.09. On the demand side, I estimate a random coefficients nested logit model and instrument retail prices with international oil prices as fuel-cost shifters and sugar prices as ethanol opportunity-cost shifters. The estimates imply an aggregate fuel demand elasticity of about -0.68 for a uniform change in fuel prices, while only 5.2 percent of the additional ethanol demand generated by a lower ethanol price comes from displaced gasoline. Evidence from the credit market shows forward-looking behavior: holding 5 million additional carbon credits throughout a year lowers the current price relative to its discounted one-year-ahead value by about 21% of the average carbon-credit price. Overall, the estimates imply a strong upstream supply response, limited substitution between fuels, and a substantial total-demand response. These estimates foreshadow the central counterfactual result: RenovaBio raises ethanol output but displaces little gasoline, so most of the additional ethanol expands total fuel consumption and emissions.

The counterfactual analysis first evaluates RenovaBio relative to policy removal and then compares it with a higher mandate for blending ethanol into gasoline, a common policy in Brazil and elsewhere. Removing RenovaBio reduces ethanol production by only 0.5–1.8 percent because the resulting increase in the ethanol market price offsets 81–90 percent of the lost CBIO incentive. Downstream adjustment is concentrated in ethanol consumption: directly sold ethanol falls by 1.73 billion liters (2.3%), while gasoline consumption changes by only 8 million liters (0.004%). Total fuel consumption consequently falls by about 1.74 billion liters (0.7%) and CO_2e emissions decline by 1.01 million tons (0.22%), implying that RenovaBio increases emissions by expanding fuel consumption with almost no gasoline displacement. I then replace RenovaBio with a higher blending mandate, interpolating the mandate rate in each year to match ethanol production under

RenovaBio. The required increase averages roughly one percentage point but directs the additional ethanol toward replacing about 1.86 billion liters (1.4%) of fossil gasoline. The mandate therefore produces about 5.55 million fewer tons of CO_2e (1.20%) than RenovaBio and generates substantially smaller fuel-price distortions. Even before valuing emissions, welfare is about R$0.46 billion higher under the mandate.

In sum, the estimates reveal a strong ethanol supply response but limited substitution away from gasoline; how these responses interact with market structure and policy design governs what additional clean production replaces. RenovaBio and the higher blending mandate generate similar ethanol production, but RenovaBio induces a rebound in total fuel use that raises emissions, whereas the mandate replaces fossil gasoline and lowers emissions.

Related Literature. This paper contributes first to the literature on the design of clean-fuel regulation. Renewable fuel mandates, carbon-intensity standards, and ethanol subsidies create different incentives for biofuel production, with implications for land use and technological innovation (Holland et al., 2015; Lade and Smith, 2025). Holland et al. (2009) simulate a national low-carbon fuel standard and find that, although it is unlikely to increase emissions, it can generate substantial surplus losses and high abatement costs. Chen et al. (2014) evaluate the Renewable Fuel Standard against a low-carbon fuel standard and carbon pricing. Holding U.S. emissions reductions fixed, they find that the Renewable Fuel Standard achieves less global abatement. Building on these policy comparisons, I study a novel design in a joint upstream–downstream equilibrium with imperfect competition, heterogeneous production responses, and credit banking, where a government-set requirement links biofuel incentives to fossil fuel distributors' compliance obligations.

Second, the paper contributes to the literature on environmental regulation under imperfect competition. Buchanan (1969) establishes that corrective environmental policy interacts with preexisting product-market distortions. Fowlie et al. (2016) quantifies how market power can change the welfare effects and preferred design of emissions regulation. More recently, Domínguez-Iino (2025) shows that market power along a supply chain can weaken the transmission of environmental incentives to upstream producers, and Lade and Bushnell (2019) documents substantial heterogeneity in clean-fuel subsidy pass-through across retail market structures. In my setting, the obligated firms are concentrated fuel distributors that set prices for both gasoline and ethanol. Their pricing decisions therefore affect not only the incidence of the policy, but also whether the induced increase in ethanol supply lowers gasoline consumption or expands total fuel demand.

Third, the paper contributes to the empirical literature on biofuel policy and the environmental consequences of ethanol expansion. Roberts and Schlenker (2013) estimate agricultural supply and demand responses to quantify the effects of ethanol mandates on commodity markets, and Sant'Anna (2024) studies how Brazilian sugarcane ethanol expansion affects land use and carbon emissions. Related work examines the land-use and environmental consequences of expanding Brazilian corn ethanol production (Moreira et al., 2020; Gurgel et al., 2024). I study the complementary downstream margin by estimating ethanol supply and fuel demand, showing that additional ethanol can expand total fuel consumption rather than displace gasoline even when production responds strongly.

The remainder of the paper describes the institutional setting, presents the data, develops the model, and estimates its key components before using the framework to conduct counterfactual policy analysis.

2 Background

Road transport is a major source of carbon emissions. Cars and buses alone generate about 45 percent of global transport CO_2 emissions, which corresponds to roughly 15 percent of worldwide energy-related CO_2 emissions (IEA, 2022). In Brazil, ethanol is the main low-carbon substitute for gasoline (Sant'Anna, 2024; Ramirez Camargo et al., 2022). Although ethanol provides only about 65% of gasoline's volumetric energy content (IEA AMF, n.d.), sugarcane ethanol has a substantially lower life-cycle carbon footprint than gasoline (Goldemberg et al., 2008; Sant'Anna, 2024). This makes substitution from gasoline to ethanol a central margin for transport decarbonization (Hoeckel and Alvim, 2023).

Brazil has developed its ethanol market over several decades. The modern ethanol program began with Proalcool in 1975, when the government responded to the oil shocks by promoting domestic ethanol as an energy security strategy (Meyer et al., 2013; IRENA, 2025). The early program relied on mandated ethanol blending in gasoline and later on ethanol only vehicles, which were introduced in 1979 and became widespread in the 1980s (Cortez, ed, 2016). The major demand side change came in 2003 with flex fuel vehicles, which allowed the same car to use gasoline, ethanol, or any mixture of the two. By 2013, flex fuel engines accounted for about 94 percent of new passenger vehicle sales, making ethanol a regular choice at the pump rather than a vehicle specific commitment (ICCT, 2015).

The relevant market for this paper is therefore mainly Brazil's domestic ethanol market: producers supply ethanol, distributors purchase gasoline and ethanol for resale, and drivers choose between fuel options at the pump. The RenovaBio policy, introduced below, targets this domestic fuel chain.

2.1 Ethanol Supply

Ethanol is produced by fermenting agricultural feedstocks. Brazil is one of the world's leading ethanol producers, with production based mainly on sugarcane and, increasingly, corn (AFDC, 2026; USDA FAS, 2024; Ramirez Camargo et al., 2022). Sugarcane ethanol has a high fossil energy return because mills use sugarcane residue as an energy input, yielding roughly 8 to 9 units of renewable energy for each unit of fossil energy used (Macedo et al., 2008; Chum et al., 2014). Corn ethanol has expanded more recently and is largely based on second crop maize grown after soybeans, with renewable energy ratios of 7.1 to 9.4 (Gurgel et al., 2024; Moreira et al., 2020). Figure 1 shows this shift: sugarcane remains the dominant feedstock, but corn ethanol has become an increasingly visible part of Brazilian ethanol production. In the 2025/26 harvest season, Brazil produced 37.5

billion liters of ethanol, including 27.33 billion liters from sugarcane and 10.17 billion liters from corn (CONAB, 2026).

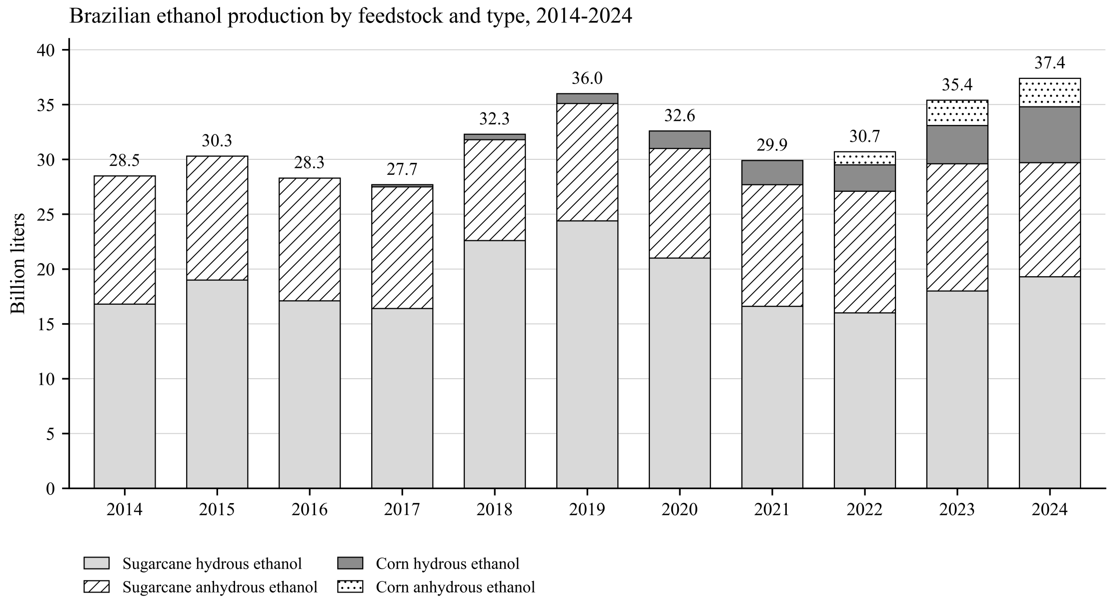


Figure 1: Brazilian ethanol production by feedstock and type, 2014–2024. Notes: The figure reports ethanol production from sugarcane and corn, separately for hydrous and anhydrous ethanol. Source: author's reproduction from EPE (EPE, 2025, Chart 10), based on MAPA and UNICA data.

Sugarcane mills allocate cane between sugar and ethanol, making ethanol supply sensitive to relative returns in sugar and fuel markets (Sant'Anna, 2024; Hoeckel and Alvim, 2023). Recent reports place the sugar–ethanol production mix close to one half for each product, with the allocation shifting in response to relative prices (USDA FAS, 2025b). Corn ethanol remains small relative to total corn production, using about 10 percent of Brazil's 2023/24 corn crop, but large second-crop harvests in the Center West have made ethanol a profitable outlet for local grain (USDA FAS, 2024; USDA, 2020). The Brazilian corn ethanol system relies on maize grown as a second crop after soybeans; because second-crop corn accounts for about 79 percent of national corn production, this system helps reduce the need for direct land expansion (USDA FAS, 2025a; Moreira et al., 2020).

Ethanol production is organized around mills located close to feedstock supplies.[3] Sugarcane mills are concentrated in the Center-South, especially in São Paulo and nearby producing states, because cane is bulky and costly to transport (Sant'Anna, 2024). Some mills in the Northeast are closer to ports and therefore have greater export potential. Corn ethanol plants are more concentrated in the Central-West, especially in states with large second-crop corn output. In December 2024, Brazil had 366 ethanol production units, including 11 flex sugarcane-corn ethanol plants and 18 dedicated corn ethanol plants. Some groups are vertically connected to fuel distribution, but

[3]The overview of the spatial distribution, feedstock concentration, and market structure of Brazilian ethanol mills presented in this section relies on data and reports from UNICA (2025b), ANP (2025b), EPE (2025), and ANP (2025c).

the mill side is much less concentrated than downstream fuel distribution and remains closer to a competitive upstream market.

Seasonality is central to ethanol supply (Sant'Anna, 2024; Ramirez Camargo et al., 2022). Sugarcane ethanol is concentrated in the April–November crushing season, with lower production in the December–March intercrop months. Corn ethanol can operate more evenly throughout the year when corn stocks are available (USDA FAS, 2024; EPE, 2024b).

Understanding the operation of ethanol mills is important for the analysis of RenovaBio because mills are the production-side entities targeted by the policy. Its effects therefore depend on feedstock choice, seasonality, and the ability of mills to adjust output in response to incentives.

2.2 Ethanol Demand

Ethanol moves from producers to fuel distributors and then to retail stations. Most Brazilian ethanol is used domestically, either blended into gasoline or sold directly to drivers with flexible fuel vehicles (USDA FAS, 2024). In 2023, Brazil consumed 30.7 billion liters of ethanol domestically and exported 2.6 billion liters, so exports were only about 8.5 percent of domestic consumption (USDA FAS, 2024). Brazil has also maintained a high blending mandate for decades: the early Proalcool program required gasoline to contain 15 to 20 percent ethanol, and the current mandatory blend is 30 percent after the 2025 increase from 27 percent (UNICA, 2025a). Flex vehicles also support demand, accounting for 77 percent of Brazil's 39.7 million light vehicles in 2023, or about 30.6 million vehicles (EPE, 2024a).

Market structure differs sharply across stages of the fuel supply chain. Ethanol production is dispersed across mills, while downstream fuel distribution is more concentrated. Distributors purchase fuel from producers and importers, move it through the wholesale supply chain, and sell to retail stations (CADE, 2026). Retail stations differ by brand relationship. Branded stations display the commercial brand of a distributor, such as Vibra, Ipiranga, or Raízen, and are typically linked to that distributor's supply network. Unbranded stations do not display a distributor brand and can purchase fuel from different distributors (MJSP, 2019).

A small number of national distributors account for a substantial share of fuel sales. In 2024, Vibra, Ipiranga, and Raízen jointly accounted for 51.4 percent of combined national distributor sales of gasoline and hydrous ethanol, as shown in Figure 2 (ANP, 2025a). Although these firms operate nationally, distributor market shares vary across states, and smaller regional distributors remain important in local markets (ANP, 2025a; CADE, 2026). Raízen is the only one of the three integrated into ethanol production: in 2024/25, its own ethanol output covered about 84 percent of its ethanol sales and about 8.3 percent of national ethanol production in 2024(Raízen, 2025; EPE, 2025).

Retail gasoline follows a separate refining chain in which distributors buy gasoline from refineries, blend it with mandated ethanol, and sell it through stations (ANP, 2026a). Among the main distributors, Vibra has the closest historical link to upstream gasoline supply because it was formerly controlled by Petrobras, the refiner that still produces about 80 percent of domestic fuels;

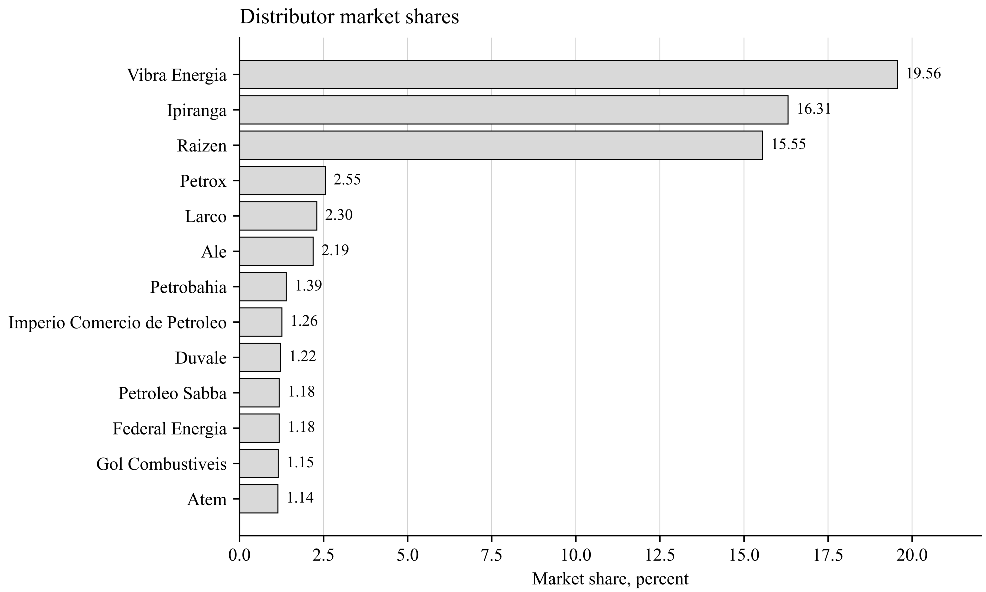


Figure 2: Combined national market shares of leading distributors in gasoline and hydrous ethanol sales, 2024. Source: ANP Ethanol Dashboard.

Petrobras reduced control in 2019 and exited in 2021 (Magalhaes and Nogueira, 2024; Moody's, 2023). In the analysis, I take upstream gasoline prices as exogenous and focus on downstream gasoline pricing as the rival product margin to ethanol.

Figure 3 illustrates the relevant price margins by comparing the retail price of gasoline with retail and upstream hydrous ethanol prices in São Paulo. Retail ethanol is persistently priced below retail gasoline, which is consistent with ethanol's lower energy content per liter.

Because fuel distributors are the regulated entities under RenovaBio, the structure of the distribution sector is central to understanding how the policy is transmitted to fuel prices and quantities.

2.3 RenovaBio

RenovaBio is Brazil's national policy to decarbonize transport fuels by incentivizing certified biofuel production through a tradable credit market. Established in 2017 and operational since December 2019, it is built around the CBIO, a tradable credit representing one metric ton of avoided CO_2 equivalent (EPE, 2025; B3, 2022; UNICA, 2025c). On the supply side, CBIOs are issued to certified biofuel producers. Registration and trading began on B3, Brazil's stock exchange, in April 2020, and the market-determined B3 price sets the incentive value (EPE, 2025; B3, 2022). The policy covers certified ethanol, biodiesel, and biomethane. On the demand side, the government allocates the annual national CBIO retirement target across distributors of common gasoline, premium gasoline, diesel B, and diesel BX by emissions-based fossil fuel market shares (ANP, 2019). Obligated distributors acquire and retire CBIOs, while non-obligated investors and other participants may also hold and trade them. I focus on ethanol and gasoline because ethanol dominates certification and gasoline is its light-vehicle competitor: as of May 2025, ethanol plants held 295 of 338 valid

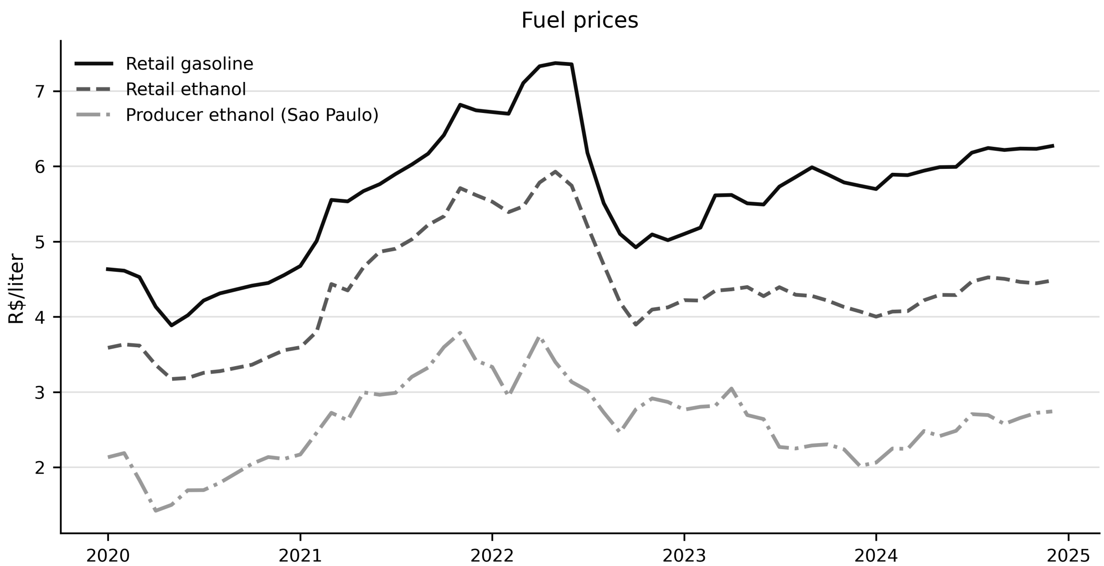


Figure 3: Retail gasoline prices, retail hydrous ethanol prices, and upstream hydrous ethanol prices in São Paulo. The persistent discount of retail ethanol relative to retail gasoline reflects ethanol's lower energy content per liter and the resulting need for more frequent refueling to travel the same distance.

producer certifications, or about 87 percent (author's calculation from EPE, 2025).

On the supply side, certified producers generate CBIOs when they sell eligible biofuels domestically (ANP, 2018, 2025c). Each producer has a certified credit yield, measured in CBIOs per liter sold. This yield depends on certified carbon intensity, so cleaner plants earn more credits per liter. CBIO revenue adds to the ethanol sale price: each liter of certified ethanol earns ordinary ethanol revenue plus the market value of its associated CBIOs. RenovaBio therefore raises the effective return to ethanol production, with the response depending on feedstock, seasonality, and capacity. In practice, an average ethanol mill earns roughly one CBIO for every 750 liters of ethanol sold (author's calculation from ANP, 2025c).

On the demand side, the government sets an annual national CBIO retirement target, Ω_y, for year y, and allocates it across obligated fuel distributors (ANP, 2019). Individual obligations are calculated from each distributor's share of total obligated fossil fuel emissions, obtained by converting covered gasoline and diesel sales into emissions using fuel specific emission factors. Thus, a distributor responsible for 5 percent of obligated fossil fuel emissions in the previous year must retire 5 percent of Ω_y. Distributors comply annually by buying CBIOs during the year and retiring them by the deadline, or face a large penalty. Retired credits leave the market permanently; unretired CBIOs do not expire and can be banked for future compliance or traded later (B3, 2022). Figure 4 summarizes these targets, retirements, and remaining banked credits by holder type.

These rules create two connected price channels in a revenue-neutral policy: because the gasoline market is larger, at the average 2024 CBIO price a small gasoline burden, about 2 percent of distributor revenue, financed a larger ethanol incentive, about 10 percent of producers' effective

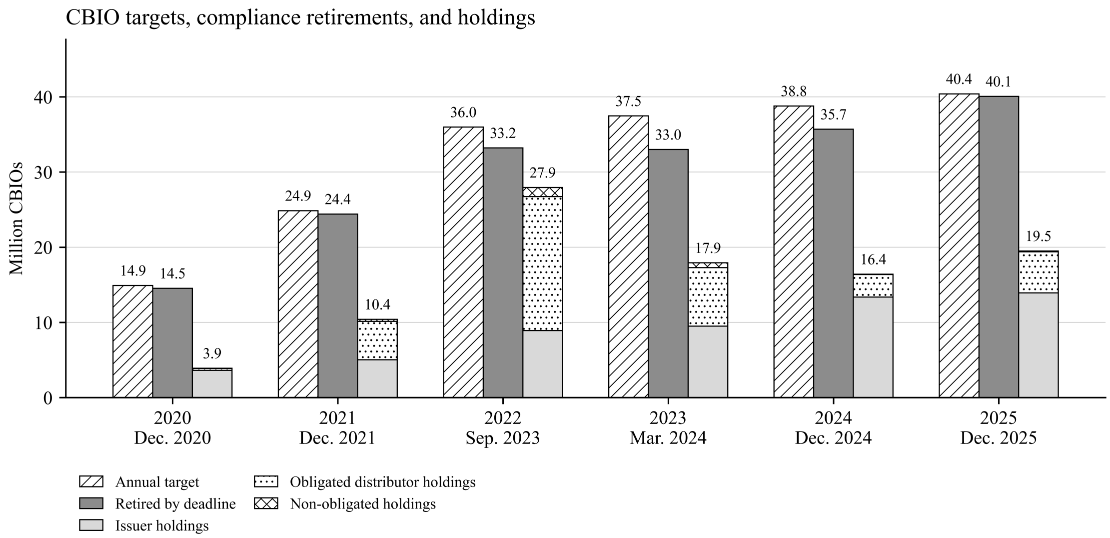


Figure 4: Bars report the national annual CBIO target, cumulative retirements by the applicable compliance deadline, and CBIO holdings at the compliance deadline, disaggregated into issuer, obligated distributor, and non-obligated agent holdings. Compliance deadlines were December 2020, December 2021, September 2023 (2022 target), March 2024 (2023 target), December 2024, and December 2025. Holdings represent remaining banked credits after compliance and illustrate the evolution of inventories across market participants (ANP, 2026b).

revenue (author's calculation from Minaspetro, 2025; ANP, 2025a, 2026b).

2.4 Economic Mechanism

RenovaBio can be interpreted as a quantity-based alternative to a fixed ethanol subsidy. Under a fixed subsidy, the government sets the per-liter incentive and ethanol production adjusts to demand and cost conditions. RenovaBio instead fixes the annual credit requirement, Ω_y, and firm credit yields, while letting the CBIO price adjust as the endogenous incentive needed to support the credited quantity of certified biofuel production. Figure 5 shows that the observed CBIO price fluctuates substantially over time.

Appendix A formalizes this logic in a stylized static model with an ethanol market and a separate CBIO market. When the credit target Ω_y binds, inelastic CBIO demand pins down the required credit quantity, and the CBIO price adjusts until producers supply it. Figure 11 shows the corresponding supply-and-demand interpretation: the CBIO price acts like an endogenous per-liter subsidy, creating a wedge between the ethanol market price and producers' effective price. Relative to the no-policy equilibrium, this raises ethanol production and producers' effective return while lowering the ethanol market price.

Appendix A discusses how shocks affect prices under the binding target. An increase in Ω_y requires higher ethanol production. The ethanol market absorbs this additional quantity through a lower ethanol price, while the CBIO price increases enough to raise producers' total effective revenue

Figure 5: Observed CBIO price over time.

and make the higher production level profitable. Ethanol marginal cost shocks are absorbed mainly through the CBIO price, while ethanol demand shocks are split between the ethanol price and the CBIO price. These incidence differences make welfare analysis central: the question is whether the value of stabilizing credited emissions reductions under RenovaBio outweighs the lost quantity flexibility of a fixed subsidy (Weitzman, 1974).

With downstream market power, the transmission of RenovaBio depends on distributors' pricing and quantity responses. Distributors set final gasoline and ethanol prices, so the upstream ethanol response induced by the CBIO price does not mechanically translate into gasoline displacement. Some additional ethanol may replace gasoline, while some may increase total fuel consumption. This distinction depends on fuel substitution, income effects, and strategic pricing in the downstream market. The policy's welfare effect therefore depends on the interaction between private surplus and emissions damages, making downstream market power central to the evaluation.

3 Data

I construct monthly panel datasets covering Brazilian fuel distribution, ethanol production, and CBIO credit-market outcomes. The downstream dataset contains fuel sales and prices at the state-month-brand-fuel level for 2010–2024. The upstream dataset contains ethanol production and CBIO-market outcomes at the state-month level for 2018–2025.

3.1 Downstream Market and Credit Demand

The monthly downstream demand data cover 2010–2024. Fuel quantities are measured using sales data reported by distributors to Brazil's fuel regulator, the National Agency of Petroleum, Natural Gas and Biofuels (ANP). The data report monthly fuel volumes by distributor and product; volumes sold to white-flag stations and final customers are grouped as non-branded fuel products. Each observation is a brand–fuel product, such as Raizen gasoline C, Ipiranga hydrated ethanol, or white-flag gasoline C, in a state-month market. After sample restrictions and missing-value cleaning, the estimation sample contains 62,901 product-market observations across 4,778 state-month markets. The same fuel-sales data are used to construct monthly implied CBIO obligations from gasoline and diesel volumes, after adjusting for mandated biofuel blend shares.

Retail fuel prices are measured using station-level price survey data. Station price observations are averaged by retail brand, fuel, state, and month when there are multiple observations in a month. White-flag station sales are aggregated into a single white-flag product within each state-month-fuel market. Nominal retail and distributor prices are converted to real terms using a monthly Brazilian consumer price index constructed from INPC inflation rates. ‘’

3.2 Upstream Supply and Credit Issuance

Ethanol production comes from the ANP ethanol dashboard. Hydrated and anhydrous ethanol production are aggregated to total ethanol output by state and month. The final upstream supply panel contains 1,399 state-month observations for 20 ethanol-producing states from January 2018 through December 2024. The upstream price panel uses the São Paulo hub price as the domestic ethanol price, averaged to monthly frequency.

CBIO market data come from the ANP CBIO dashboard. The monthly data contain CBIO prices, issued credits, retired credits, and inventories. These data provide both, aggregate market outcomes and the composition of issuance and holdings. Issuance is reported separately for ethanol, biodiesel, and biomethane, while inventories are reported separately for obligated distributors, non-obligated agents, and issuers. The final CBIO estimation panel contains 73 monthly observations.

3.3 Controls and Shifters

Demand controls are measured at the state-month level and enter the downstream demand estimation. Population comes from the Brazilian Institute of Geography and Statistics (IBGE) and is interpolated to monthly frequency before being used to construct per-capita controls and market size. Retail sales come from the Institute for Applied Economic Research (IPEA), electricity consumption from the Energy Research Office (EPE), and vehicle fleets from the National Traffic Department (DENATRAN) through Base dos Dados; each is converted to per-capita terms using the monthly population series. Aggregate economic activity is measured using the Central Bank of Brazil's IBC-Br index.

Cost shifters are used in both demand and supply estimation. International oil and sugar prices from the World Bank commodity price data, together with the Brazilian real/U.S. dollar exchange rate from Federal Reserve Economic Data (FRED), are used as instruments for retail fuel prices in the downstream demand estimation. Domestic corn and sugarcane prices from the National Supply Company (CONAB) are used as input-price controls in the upstream ethanol supply estimation.

4 Model

I model RenovaBio as a quantity-based carbon incentive that shifts ethanol production across Brazilian states over time. It connects a static fuel-market block to a dynamic monthly CBIO-market block.

The main object of the model is to measure how a fixed national credit target changes ethanol production, gasoline consumption, and total fuel use. The policy raises ethanol producers' effective revenue through the value of CBIO issuance and increases distributors' effective marginal cost of gasoline through their compliance obligations. Within the fuel market, these effects operate through two channels. First, cheaper ethanol relative to gasoline induces consumers to substitute ethanol for gasoline, reducing the carbon intensity of a given quantity of fuel. Second, a lower effective ethanol price may reduce the overall cost of fuel use and increase total fuel consumption. Downstream market power determines how strongly these policy-induced cost changes pass through to retail prices.

The policy is anchored by the annual aggregate CBIO retirement target Ω_y, which the government sets and all agents take as exogenous. Targets are announced several years in advance, and I represent the path used in the model by

$$\boldsymbol{\Omega}_y = \{\Omega_\tau\}_{\tau \geq y}.$$

Beyond the announced horizon, I assume the target path is extended to a stabilization year $\bar{Y}$ and remains constant thereafter,

$$\Omega_y = \bar{\Omega} \qquad \text{for all } y \geq \bar{Y}.$$

The announced target path also creates an intertemporal channel. Because CBIOs can be banked, expectations of future targets affect current CBIO values. A higher anticipated future target can therefore change ethanol-production incentives before compliance occurs and shift production over time.

The model has state-level ethanol producers, fuel distributors, households, and a representative CBIO portfolio holder. Ethanol producers are price takers in the national upstream ethanol market, while distributors buy ethanol and gasoline and compete in prices in state-level retail fuel markets. Households choose among retail products differentiated by fuel type and distributor. The upstream ethanol market clears nationally. Downstream fuel markets clear within state-months, and upstream gasoline is supplied perfectly elastically at an exogenous price. In the national CBIO market, the representative portfolio holder aggregates credit demand across obligated distributors, non-obligated investors, and other holders of unretired CBIOs. The CBIO price adjusts so that aggregate desired holdings equal the stock of credits available after issuance and retirement.

Conditional on the CBIO price and the marginal compliance value, the static fuel market determines ethanol production and hence ethanol-generated CBIO issuance. Conditional on total issuance and the target path, the dynamic CBIO market determines the CBIO price and the marginal compliance value that feed back into producers' and distributors' decisions. Joint equilibrium is the fixed point between these two blocks. Figure 6 summarizes the structure and the links between the two markets.

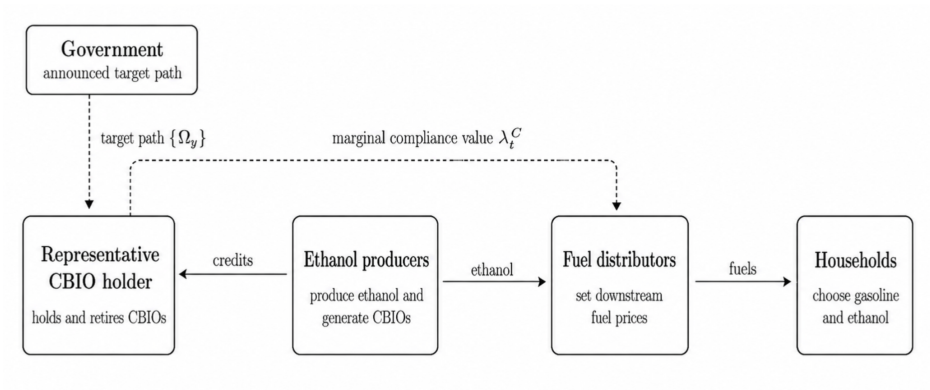


Figure 6: Model structure and links between the static fuel market and the dynamic CBIO market.

The model combines annual compliance with monthly market decisions. Years are indexed by y, months by $t \in \mathcal{T}_y$, states by s, distributors by i, and households by h. A downstream product is $j = (i, f)$, where $f \in \{G, E\}$ denotes gasoline or ethanol. In the fuel market, superscripts U and D denote upstream and downstream variables, and H denotes household demand. Superscript C denotes CBIO-market variables.

4.1 Fuel Market

Given the CBIO price and marginal compliance value determined by the dynamic model in the next subsection, the endogenous variables in the fuel market are the monthly national upstream ethanol price $P_t^{E,U}$ and state-level ethanol and gasoline quantities and retail prices. The upstream ethanol price clears the national ethanol market, while the CBIO price enters ethanol producers' returns and the marginal compliance value enters fuel distributors' gasoline costs. Equilibrium ethanol production determines monthly ethanol-generated CBIO issuance, $I_t^{C,E}$, in the dynamic CBIO market.

Agents.

1. *Ethanol producer.* The representative ethanol producer in each state s produces ethanol and receives income from both the national upstream ethanol price and the value of the CBIOs generated by production.[4] The producer is a price taker in both markets and chooses monthly

[4] At the mill level, producers may allocate sugarcane between sugar and ethanol production. To avoid introducing this additional production decision, the model captures the opportunity cost of sugar production and other mill-level conditions through the reduced-form ethanol cost function and its state-month shifters.

upstream ethanol production to maximize

$$\pi_{s,t}^{E,U} = \left(P_t^{E,U} + \underbrace{\gamma_s P_t^C}_{\text{policy incentive}} \right) q_{s,t}^{E,U} - C_{s,t}^{E,U}\left(q_{s,t}^{E,U}; X_{s,t}^{E,U}, \varepsilon_{s,t}^{E,U} \right), \tag{1}$$

where γ_s is the government-certified number of CBIOs generated per unit of ethanol produced in state s. As a modeling assumption, the opportunity value of each newly issued CBIO in the producer's production decision is equal to the current market price P_t^C.

For computational convenience, I assume an isoelastic cost function:

$$C_{s,t}^{E,U}\left(q_{s,t}^{E,U}; X_{s,t}^{E,U}, \varepsilon_{s,t}^{E,U} \right) = \frac{\exp\left[-\left(X_{s,t}^{E,U\prime}\delta + \varepsilon_{s,t}^{E,U} \right) / \eta_{s,t} \right]}{1 + 1/\eta_{s,t}} \left(q_{s,t}^{E,U} \right)^{1+1/\eta_{s,t}}.$$

The vector $X_{s,t}^{E,U}$ contains state-month cost shifters, including input and opportunity-cost variables, harvesting-season indicators, state and time effects, and differences in states' pre-policy exposure to corn ethanol production. The term $\varepsilon_{s,t}^{E,U}$ is an unobserved state-month productivity shock. The supply elasticity is allowed to vary across states:

$$\eta_s = \eta + \eta_{\text{corn}} PreCorn_s.$$

Here, η is the baseline supply elasticity, while η_{corn} captures variation with $PreCorn_s$, a state's initial exposure to corn-based ethanol production.

The profit-maximizing condition and the resulting state-level supply function are

$$\frac{\partial C_{s,t}^{E,U}}{\partial q_{s,t}^{E,U}} = P_t^{E,U} + \gamma_s P_t^C, \qquad q_{s,t}^{E,U} = \exp\left(X_{s,t}^{E,U\prime}\delta + \varepsilon_{s,t}^{E,U} \right) \left(P_t^{E,U} + \gamma_s P_t^C \right)^{\eta_{s,t}}.$$

Aggregate upstream ethanol production and monthly CBIO issuance generated by ethanol are

$$q_t^{E,U} = \sum_s q_{s,t}^{E,U}, \qquad I_t^{C,E} = \sum_s \gamma_s q_{s,t}^{E,U}.$$

Ethanol-generated CBIO issuance $I_t^{C,E}$ enters the dynamic CBIO market in the next subsection, while total ethanol production clears the upstream ethanol market.

2. *Fuel distributors.* Fuel distributors compete in prices in each state-level downstream fuel market. Let $p_{ist}^{f,D}$ and $q_{ist}^{f,D}$ denote the retail price and quantity of fuel $f \in \{G, E\}$ sold by distributor i in state s and month t. Quantities satisfy

$$q_{ist}^{f,D} = D_{ist}^{f,D}\left(\mathbf{p}_{ist}^D, \mathbf{p}_{-i,st}^D \right), \qquad f \in \{G, E\},$$

where $\mathbf{p}_{-i,st}^D$ denotes rival prices and non-price demand determinants are held fixed.

Let $e = 0.27$ denote the mandated ethanol share in retail gasoline. Distributor i's following-year RenovaBio obligation is described by the policy rule

$$O^R_{i,y+1} = O^R\left(\Omega_{y+1}, q^{G,D}_{i,y}; F_y\right).$$

Here, F_y is the total annual national emissions-weighted fossil-fuel sales across all fossil fuels and markets.

Let λ^C_t denote the common marginal value of one additional future CBIO compliance requirement, determined by the representative portfolio-holder problem in the next subsection. I assume that the national CBIO market is competitive, and obligated distributors are price takers in that market. Under these assumptions, trading equalizes marginal compliance values across distributors, and each distributor takes λ^C_t as given when setting retail prices.

Distributor i's pricing-relevant objective in month t, aggregated across the states in which it operates, is

$$\begin{aligned}\Pi^D_{i,t} = \sum_s \Bigg\{ & \Bigg[p^{G,D}_{ist} - \underbrace{\left((1-e)P^{G,U}_t + eP^{E,U}_t\right)}_{\text{blend cost}}\Bigg] q^{G,D}_{ist} \\ & + \left(p^{E,D}_{ist} - P^{E,U}_t\right) q^{E,D}_{ist} - \underbrace{C^D_{ist}\left(q^{G,D}_{ist}, q^{E,D}_{ist}\right)}_{\text{distribution cost}} \Bigg\} - \underbrace{\lambda^C_t O^R_{i,y+1}}_{\text{policy compliance cost}}.\end{aligned}$$

Downstream markets are separate across states, so a distributor's price in one state does not affect fuel quantities in another state. For $f \in \{G, E\}$, the firm-level Bertrand first-order condition is

$$\begin{aligned}0 = q^{f,D}_{ist} + & \left[p^{G,D}_{ist} - \left((1-e)P^{G,U}_t + eP^{E,U}_t\right) - \frac{\partial C^D_{ist}}{\partial q^{G,D}_{ist}} - \lambda^C_t \frac{\partial O^R_{i,y+1}}{\partial q^{G,D}_{ist}}\right] \frac{\partial q^{G,D}_{ist}}{\partial p^{f,D}_{ist}} \\ + & \left[p^{E,D}_{ist} - P^{E,U}_t - \frac{\partial C^D_{ist}}{\partial q^{E,D}_{ist}}\right] \frac{\partial q^{E,D}_{ist}}{\partial p^{f,D}_{ist}}.\end{aligned} \tag{2}$$

Appendix B derives the marginal CBIO compliance cost associated with gasoline sales that enters this first-order condition.

At the equilibrium downstream price vectors $\{\mathbf{p}^{D,*}_{st}\}_s$, total upstream ethanol demand by distributors is

$$q^{E,D}_t = \sum_s \left[\sum_i q^{E,D}_{ist}\left(\mathbf{p}^{D,*}_{st}\right) + e\sum_i q^{G,D}_{ist}\left(\mathbf{p}^{D,*}_{st}\right)\right].$$

3. *Household demand for fuels.* Consumers choose among gasoline and ethanol products differentiated by fuel type and distributor brand in state s and month t, together with an outside

option. A product is $j = (i, f)$, where i denotes the distributor brand and $f(j) \in \{G, E\}$ denotes the fuel nest. Household h's indirect utility from product j is

$$U_{hjst} = (\alpha + \sigma_p \nu_h) p^D_{jst} + X^{D\prime}_{st} \beta_{f(j)} + \Lambda_{jst} + \xi_{jst} + \rho \zeta_{h,f(j),st} + (1 - \rho)\epsilon_{hjst}.$$

Here, p^D_{jst} is the retail price, α is the mean price coefficient, σ_p measures heterogeneity in price sensitivity, and ν_h is household h's price-sensitivity draw. The vector X^D_{st} contains vehicles per capita, electricity consumption per capita, the national economic activity index, and real sales per capita, with fuel-specific coefficients $\beta_{f(j)}$. The term Λ_{jst} collects distributor-brand, state, fuel-specific calendar-month, and four-year-block fixed effects. The term ξ_{jst} captures unobserved product quality, $\zeta_{h,f(j),st}$ is a household-specific shock shared by products in the same fuel nest, and ϵ_{hjst} is an idiosyncratic product-level extreme-value shock. The common nesting parameter is $\rho \in [0, 1)$.

The outside option, whose utility is normalized to zero, represents not purchasing one of the observed fuel products, such as postponing refueling or relying on public transit or other transportation modes. Fuel-specific coefficients β_f, together with prices, market shares, choice sets, and household heterogeneity, allow gasoline and ethanol elasticities to differ and to vary across products, states, and months.

Let s_{jst} denote the aggregate market share of product j implied by the random-coefficients nested logit (RCNL) demand model, derived in Appendix C. Final product demand is

$$q^H_{jst} = M_{st} s_{jst},$$

where M_{st} is the size of the state-month fuel market.

4.2 CBIO Market

Let χ_t collect the static fuel-market conditions that shift ethanol supply and downstream demand, including observed supply and demand shifters, seasonality, and unobserved market shocks. Given the current upstream ethanol price $P^{E,U}_t$, the market state χ_t, and the government-determined path of annual retirement requirements $\{\Omega_y\}_{y \geq 1}$, the CBIO market determines the CBIO price P^C_t, ethanol-generated issuance $I^{C,E}_t$, and aggregate desired holdings $B^{C,d}_{t+1}$.

On the issuance side, as specified in equation (1), ethanol-generated issuance responds to the CBIO price, while issuance from other eligible biofuels enters total CBIO supply exogenously. On the demand side, the representative CBIO holder aggregates portfolio demand from non-obligated investors and issuers with the holding and retirement demand of obligated distributors.

Representative CBIO holder. The representative CBIO holder aggregates the portfolio demand of obligated and non-obligated market participants. It takes P^C_t as given and chooses monthly net CBIO acquisitions q^C_t to minimize current and expected future portfolio and compliance costs. Let R_t denote required CBIO retirement in month t, equal to the applicable annual target Ω_y in the compliance month and zero otherwise. Credits that are not retired may be banked for future periods.

Its Bellman equation is

$$V^C(B_t^C, \mathbf{\Omega}, \chi_t) = \min_{q_t^C \geq 0} \left\{ P_t^C q_t^C + \Phi_t \left(B_{t+1}^C, \chi_t \right) + \beta E_t \left[V^C \left(B_{t+1}^C, \mathbf{\Omega}, \chi_{t+1} \right) \right] \right\},$$

subject to

$$B_{t+1}^C = B_t^C + q_t^C - R_t, \qquad B_{t+1}^C \geq 0.$$

The function Φ_t captures non-price costs associated with carrying CBIO inventories, including risk and balance-sheet costs. I assume

$$\Phi_t \left(B_{t+1}^C, \chi_t \right) = - \left(\phi_0 + X_t^{C\prime} \phi_X \right) B_{t+1}^C - \frac{\phi_B}{2} \left(B_{t+1}^C \right)^2.$$

The linear bank component captures the state-dependent benefit of carrying credits for future compliance. Under $\phi_B < 0$, the quadratic bank component generates a convex portfolio- holding cost, so the marginal value of additional banking declines with the size of the bank. This captures risk aversion, balance-sheet exposure, and the risk of future CBIO price declines.

Within each compliance year, the problem is a finite sequence of monthly portfolio decisions. The bank evolves recursively across months, with retirement occurring in the compliance month. At the compliance boundary, the remaining bank becomes the initial bank of the next compliance year, and the continuation value is

$$\beta E_t \left[V^C \left(B_{1,y+1}^C, \mathbf{\Omega}, \chi_{t+1} \right) \right].$$

Here, $B_{1,y+1}^C$ is the banked amount at the start of year $y+1$.

For interior acquisitions and a nonbinding banking constraint, the Euler condition is

$$P_t^C + \partial_B \Phi_t \left(B_{t+1}^C, \chi_t \right) = \beta E_t \left[P_{t+1}^C \right]. \tag{3}$$

Using the specification for Φ_t, this becomes

$$P_t^C - \beta E_t \left[P_{t+1}^C \right] = \phi_0 + \phi_B B_{t+1}^C + X_t^{C\prime} \phi_X. \tag{4}$$

This condition equates the marginal value of acquiring a CBIO today with its discounted expected value next month, accounting for the marginal value of carrying CBIO inventories. The market state χ_t summarizes current fuel-market conditions that are informative about future ethanol production and CBIO issuance. Because future realizations of these conditions are uncertain, they make the future CBIO price stochastic, which gives rise to the expectation in the Euler condition.

For a candidate CBIO price path, the upstream ethanol price path, and the exogenous target path, the Bellman problem defines aggregate desired CBIO holdings:

$$B_{t+1}^{C,d} = \mathcal{D}_t^C \left(\{P_\tau^C\}_{\tau \geq t}, \{P_\tau^{E,U}\}_{\tau \geq t}, \mathbf{\Omega}, \{\chi_\tau\}_{\tau \geq t} \,\middle|\, B_t^C \right).$$

The stabilized annual-cycle fixed point determines the terminal continuation value. The problem is solved backward from this terminal value through the transition period, and the resulting policy functions generate the forward path of desired CBIO holdings.

For an interior acquisition decision, an additional CBIO can be purchased at the current market price. The marginal value of an additional CBIO in the holder's compliance position therefore satisfies

$$\lambda_t^C \equiv -\frac{\partial V^C \left(B_t^C, \mathbf{\Omega}, \chi_t \right)}{\partial B_t^C} = P_t^C.$$

Thus, the CBIO market price is both the marginal compliance value entering distributors' downstream pricing decisions and the additional CBIO revenue received by upstream ethanol producers. Banking affects this value through the intertemporal evolution of CBIO prices characterized by equation (3).

4.3 Equilibrium

Static fuel-market equilibrium. The static fuel-market outcome consists of the national upstream ethanol price, state-level ethanol production, downstream fuel prices and quantities, net ethanol storage demand, and ethanol-generated CBIO issuance:

$$\left(P_t^{E,U}, q_{s,t}^{E,U}, p_{ist}^{f,D}, q_{ist}^{f,D}, D_t^{\text{stor}}, I_t^{C,E} \right), \qquad \text{for all } s, i, \text{ and } f \in \{G, E\}.$$

Household quantities q_{jst}^H coincide with distributor sales through downstream market clearing.

Given $\{P_t^C, \lambda_t^C\}$, ethanol producers maximize profits, fuel distributors choose retail prices to maximize profits, and households choose fuel products to maximize utility. All static fuel markets clear monthly.

For each downstream product $j = (i, f)$, distributor sales equal household demand,

$$q_{ist}^{f,D} = q_{jst}^H = M_{st} s_{jst}, \qquad f \in \{G, E\}.$$

Because ethanol production is highly seasonal, I introduce a competitive monthly storage sector to preserve consistency between monthly production and downstream use and to allow the national ethanol market to clear each month. Accordingly,

$$\sum_s q_{s,t}^{E,U} = \sum_s \left[\sum_i q_{ist}^{E,D} + e \sum_i q_{ist}^{G,D} \right] + D_t^{\text{stor}}.$$

For the annual counterfactual, I impose zero net storage demand within each year, so storage drops out after annual aggregation. The annual clearing condition determines the counterfactual upstream ethanol price. I then recover implied monthly ethanol production by evaluating the estimated state-month supply functions at this price, with monthly quantities varying through the estimated fixed effects and state- and season-specific supply elasticities. The implementation is described in detail in the counterfactual section.[5]

Upstream gasoline supply is assumed to be perfectly elastic at the exogenous price $P_t^{G,U}$ and meets the gasoline requirement implied by downstream sales. Equilibrium ethanol production determines $I_t^{C,E}$, which together with other biofuel issuance $I_t^{C,O}$ determines total monthly CBIO issuance I_t^C.

Dynamic CBIO-market equilibrium. The dynamic CBIO-market outcome is

$$\left(P_t^C, q_t^C, B_t^C, \lambda_t^C\right).$$

Given the market state χ_t and the exogenous target path $\mathbf{\Omega}_y$, the representative CBIO holder chooses its desired net acquisition q_t^C. Ethanol-generated issuance $I_t^{C,E}$, together with exogenous[6] issuance from other eligible biofuels $I_t^{C,O}$, determines total CBIO issuance,

$$I_t^C = I_t^{C,E} + I_t^{C,O}.$$

The CBIO price P_t^C clears the market each month by equating aggregate net credit demand with total newly issued CBIOs:

$$q_t^C = I_t^C.$$

The aggregate CBIO bank then evolves according to

$$B_{t+1}^C = B_t^C + I_t^C - R_t.$$

Thus, newly issued credits are either added to the aggregate bank or retired for compliance, while transactions among existing holders only reallocate credits across portfolios.

At the stabilized annual-cycle fixed point, the equilibrium price, bank, marginal-value, and issuance paths repeat across years. With the target fixed at $\bar{\Omega}$ and the aggregate bank stationary, $B_{y+1}^C = B_y^C$, the annual stock identity becomes

$$\sum_{t \in \mathcal{T}_y} I_t^C = \bar{\Omega}.$$

[5] I use April as the baseline month for annual market clearing because it marks the beginning of the Center-South crop year, when ethanol inventories are seasonally low. In recent crop years, opening inventories have been roughly equivalent to one month of consumption. This minimizes the role of intertemporal inventory adjustment in the annual equilibrium. The storage demand function is therefore not estimated separately, since only its zero-net annual condition is required for the counterfactual analysis.

[6] Section 2.3 documents ethanol's dominant role in RenovaBio certification. I therefore assume that the CBIO-price response of other eligible biofuel production is too small to materially affect the results.

Thus, annual CBIO issuance equals annual retirement at the stabilized fixed point, while the monthly equilibrium may continue to vary within the annual cycle.

Joint equilibrium. A joint equilibrium is a fixed point in which the static fuel-market equilibrium generates the endogenous ethanol component of the issuance path used in the dynamic CBIO market, while the CBIO price and marginal compliance value generated by the dynamic market are the same values entering producers' and distributors' static decisions. Thus,

$$\begin{aligned}\{P_t^C, \lambda_t^C\} &\longrightarrow \text{static fuel-market equilibrium} \longrightarrow I_t^{C,E} \\ &\longrightarrow \text{dynamic CBIO-market equilibrium} \longrightarrow \{P_t^C, \lambda_t^C\}.\end{aligned}$$

5 Empirical Strategy and Results

I estimate the three components of the model separately and combine them in the counterfactual equilibrium in Section 6. First, the household fuel-demand estimates identify substitution across fuels, recover downstream markups and marginal costs under Bertrand competition among distributors, and determine distributors' aggregate demand for upstream ethanol. Second, the upstream ethanol-supply estimates identify the elasticity of ethanol production with respect to effective producer revenue from ethanol sales and CBIOs, allowing the response to vary across months and with exposure to corn and sugarcane production. Third, the CBIO Euler equation identifies how credit demand responds to portfolio costs and proximity to the compliance deadline, conditional on the government-set retirement targets.

5.1 Household Fuel Demand and Markup Recovery

I estimate the RCNL demand system in Section 4.1 using state-month markets. For product $j = (i, f)$, let $i \in \mathcal{I}$ denote the observed distributor brand and $f \in \{G, E\}$ the fuel type. The estimation sample contains 87 distributor brands, so the potential product set contains 174 distributor-brand–fuel pairs. Product availability varies across state-month markets because not all distributors operate in every state or throughout the entire sample period. The products are organized into two fuel nests, one for gasoline and one for ethanol. Using downstream market clearing, observed product and outside-option shares are calculated as

$$s_{jst}^{obs} = \frac{q_{jst}^H}{M_{st}}, \qquad s_{0st}^{obs} = 1 - \sum_{j \in \mathcal{J}_{st}} s_{jst}^{obs}.$$

Market size evolves according to

$$M_{st} = \psi_M Q_{s,t_0} \left(\frac{\text{Pop}_{st}}{\text{Pop}_{s,t_0}} \right) (1 + g_M)^{(t-t_0)/12}.$$

Here, Q_{s,t_0} is the observed state-level fuel quantity in the first sample month t_0, Pop_{st} is state population, ψ_M is a scale parameter, and g_M is the annual growth rate. The rule assumes that market size grows proportionally with population and at a constant rate.

For each candidate value of (σ_p, ρ), I invert the RCNL shares to recover mean utility $\bar{U}_{jst}$:

$$\mathbf{s}_{st}^{obs} = \mathbf{s}_{st}\left(\bar{\mathbf{U}}_{st}, \mathbf{p}_{st}^{D}; \sigma_p, \rho\right).$$

The implied unobserved demand shock is

$$\xi_{jst} = \bar{U}_{jst} - \left[\alpha p_{jst}^{D} + X_{st}^{D\prime}\beta_{f(j)} + \Lambda_{jst}\right].$$

Retail prices are endogenous. A positive local demand shock can raise both willingness to pay and the price chosen by distributors. Thus, p_{jst}^{D} may be correlated with ξ_{jst}. I use international oil prices to shift gasoline acquisition costs and international sugar prices to shift the opportunity cost of ethanol production, since sugar is an alternative use of sugarcane. For the instruments, I group distributor brands into $g(i) \in \mathcal{G} = \{\text{Vibra}, \text{Ipiranga}, \text{Raízen}, \text{White}, \text{Other}\}$. Vibra, Ipiranga, and Raízen are the three major national brands, and this grouping allows the first-stage effects of oil and sugar prices to vary across distributor groups and fuels. For product $j = (i, f)$, the excluded instruments are

$$Z_{jst}^{D,\text{excl}} = \left\{P_t^{oil} d_{j,gf},\ P_t^{sugar} d_{j,gf}\right\}_{g\in\mathcal{G},\ f\in\{G,E\}}, \qquad d_{j,gf} \equiv \mathbf{1}\{g(i(j)) = g,\ f(j) = f\}.$$

With five distributor groups and two fuel types, this construction gives 20 excluded instruments. In the corresponding first-stage regression for retail prices, the excluded oil- and sugar-price instruments are strongly jointly relevant: clustering by calendar month gives a joint Wald statistic equivalent to an F-statistic of 86.5.

The exclusion restriction is that, conditional on X_{st}^{D} and Λ_{jst}, international oil and sugar prices affect household fuel choices through retail prices rather than through unobserved product demand ξ_{jst}. Let $\widetilde{X}_{jst}^{D}$ collect the included exogenous demand shifters with their fuel-specific interactions. The full instrument vector and corresponding moment condition are

$$Z_{jst}^{D} \equiv \left(\widetilde{X}_{jst}^{D\prime}, Z_{jst}^{D,\text{excl}\prime}\right)', \qquad E\left[Z_{jst}^{D}\xi_{jst}\right] = 0,$$

with the fixed effects in Λ_{jst} absorbed in estimation.

I estimate the model by two-step IV-GMM. The estimator is

$$\widehat{\theta}^{D} = \arg\min_{\theta^D} m_D(\theta^D)' W_D m_D(\theta^D), \qquad m_D(\theta^D) = \frac{1}{N_D}\sum_{j,s,t} Z_{jst}^{D}\,\xi_{jst}(\theta^D), \tag{5}$$

where θ^D collects the nonlinear demand parameters (σ_p, ρ), the mean price coefficient α, and the coefficients on observed demand shifters. N_D is the number of product-market observations, and W_D is the GMM weighting matrix.

I estimate the model by two-step IV-GMM using a heteroskedasticity-robust second-step weighting matrix and corresponding robust standard errors. Household price heterogeneity follows $\nu_h \sim N(0,1)$ and is integrated using 25 quadrature nodes. The estimation sample contains 62,901 product-market observations across 4,778 state-month markets.

Table 1 reports the main demand parameters. The downstream demand system implies an average own-price elasticity of about -1.43 for hydrous ethanol. By contrast, total upstream ethanol absorption, including hydrous and mandated anhydrous ethanol, has an annual elasticity of only about -0.10 because the blending requirement makes anhydrous demand less responsive to ethanol prices.

Table 1: Household Fuel Demand Parameters

	RCNL demand parameters	
Parameter	Estimate	Robust s.e.
Mean price effect, α	-0.3195	(0.0482)
Price heterogeneity, σ_p	0.2523	(0.0602)
Within-fuel correlation, ρ	0.7690	(0.0485)
Demand controls	Yes	
Fixed effects	Yes	
Product-market observations	62,901	
State-month markets	4,778	
Excluded instruments	20	

Note: Estimates are from two-step IV-GMM. Products are distributor-brand–fuel pairs, with gasoline and ethanol as separate nests. Retail prices are instrumented with international oil and sugar prices interacted with five distributor groups and fuel type. Demand controls are allowed to have fuel-specific coefficients. The specification includes distributor-group, state, fuel-specific calendar-month, and four-year-block fixed effects. Standard errors are heteroskedasticity robust.

Fuel distributor markup recovery. Using the estimated RCNL demand system, I recover the own- and cross-price derivatives entering distributors' Bertrand pricing conditions. Define the ownership-adjusted derivative matrix as

$$\widehat{\Delta}^D_{jk,st} = -\mathbf{1}\{i(j) = i(k)\} \left. \frac{\partial q^H_{kst}}{\partial p^D_{jst}} \right|_{\widehat{\theta}^D}.$$

The implied product-level markups and recovered marginal costs are

$$\widehat{\boldsymbol{\mu}}^D_{st} = \left(\widehat{\Delta}^D_{st}\right)^{-1} \mathbf{q}^H_{st}, \qquad \widehat{\mathbf{mc}}^D_{st} = \mathbf{p}^D_{st} - \widehat{\boldsymbol{\mu}}^D_{st}. \tag{6}$$

The recovered marginal costs include upstream fuel costs, marginal distribution costs, and, for gasoline, the marginal compliance burden. Table 2 reports median markup rates across state-month observations in 2024 of about 7.2–7.6 percent for ethanol and 6.5–6.6 percent for gasoline among the three largest branded distributors.

Table 2: Recovered Retail Fuel Markup Rates, 2024

	Median markup rate (%)	
Distributor	Ethanol	Gasoline
Vibra	7.62	6.60
Ipiranga	7.20	6.46
Raízen	7.31	6.58

Note: Entries report the median recovered product markup divided by its retail price for each distributor–fuel pair in 2024. Markups are recovered from the estimated RCNL demand derivatives under Bertrand pricing.

In the counterfactuals, I hold marginal distribution costs fixed and re-solve distributors' pricing conditions under alternative upstream fuel costs, with CBIO obligations removed.

5.2 Upstream Ethanol Supply Estimation

I estimate the state-month ethanol supply equation implied by the producer problem in equation (1):

$$\log(1+q^{E,U}_{s,t}) = \eta \log P^{E,\text{eff}}_{s,t} + \eta_{\text{corn}} \left(\log P^{E,\text{eff}}_{s,t} \times PreCorn_s\right) + X^{E,U\prime}_{s,t}\delta + \varepsilon^{E,U}_{s,t}. \quad (7)$$

Here, $P^{E,\text{eff}}_{s,t} \equiv P^{E,U}_t + \gamma_s P^C_t$ is effective producer revenue per liter.

$PreCorn_s$ is the share of corn in state s's ethanol feedstock use during 2018–2019, before RenovaBio. The vector $X^{E,U}_{s,t}$ contains log sugar and corn prices controlling for input and opportunity costs, a linear trend interacted with $PreCorn_s$, and state, calendar-month, and year fixed effects absorbing persistent state differences, seasonality, and common annual shocks. I use $\log(1+q^{E,U}_{s,t})$ to retain state-months with zero ethanol production.

Effective producer revenue is endogenous. Unobserved shocks to ethanol productivity or marginal production costs shift production and, through market clearing, the upstream ethanol price. They can also change ethanol-generated CBIO issuance and hence the equilibrium CBIO price. Thus, both components of $P^{E,\text{eff}}_{s,t} = P^{E,U}_t + \gamma_s P^C_t$ may be correlated with the supply shock $\varepsilon^{E,U}_{s,t}$.

I therefore instrument effective producer revenue using demand-side variation. The excluded shifters are the international oil-price level and its twelve-month change, which shift gasoline prices and, through fuel substitution, ethanol demand:

$$\Delta_{12} \log P^{oil}_t \equiv \log P^{oil}_t - \log P^{oil}_{t-12}.$$

I interact these shocks with the same source of heterogeneity as effective price:

$$Z^{E,U}_{s,t} = \left\{\log P^{oil}_t,\ \log P^{oil}_t \times PreCorn_s,\ \Delta_{12}\log P^{oil}_t,\ \Delta_{12}\log P^{oil}_t \times PreCorn_s\right\}.$$

The exclusion restriction is that, conditional on feedstock prices and fixed effects, the oil-price level and twelve-month oil-price change affect state ethanol production through demand-induced changes in effective producer revenue, rather than directly through state-specific marginal costs or productivity. Formally,

$$E\left[Z_{s,t}^{E,U}\varepsilon_{s,t}^{E,U}\right] = 0.$$

I estimate equation (7) by linear IV/2SLS. With four excluded instruments and two endogenous regressors, the specification is overidentified. Second-stage standard errors are clustered by state to allow for within-state correlation in ethanol supply shocks. Because the excluded oil-price shocks vary at the month-year level, first-stage inference is clustered accordingly. Instrument relevance in the presence of two related endogenous effective-price terms is assessed using Sanderson–Windmeijer conditional F-statistics. Table 3 reports values of 17.09 and 30.30 for the effective-price and pre-corn terms, respectively, supporting conditional instrument relevance. Conventional first-stage statistics under month-year and two-way state-by-month-year clustering are reported in Appendix D.

Table 3: Identification of Upstream Ethanol Supply

Endogenous effective-price term	Conditional first-stage SW F
Effective producer revenue, $\log P_t^{E,\text{eff}}$	17.09
Pre-policy corn exposure, $\log P_t^{E,\text{eff}} \times PreCorn_s$	30.30
Observations	1,114

Note: The excluded instruments are the log international oil-price level and its twelve-month change, together with their interactions with $PreCorn_s$. Reported statistics are Sanderson–Windmeijer conditional first-stage F-statistics using month-year clustered inference.

Table 4 presents the supply estimates. The positive effective-price response implies that ethanol production increases with effective producer revenue. The positive η_{corn} implies greater responsiveness in states with more corn capacity. Table 5 reports the resulting average elasticities nationally and for states with and without meaningful corn exposure.

In the counterfactuals, these elasticities determine how ethanol production and CBIO issuance respond to changes in effective producer revenue.

5.3 CBIO Demand Estimation

The estimating equation is

$$P_t^C - \beta P_{t+1}^C = \varphi_0 + \varphi_B B_t^C + X_t^{C\prime}\varphi_X + \varepsilon_{t+1}^C, \tag{8}$$

where $\beta = (1.10)^{-1/12} \simeq 0.9921$ is the monthly discount factor implied by a 10 percent annual rate. where $\beta = (1.10)^{-1/12} \simeq 0.9921$ is the monthly discount factor implied by a 10 percent annual rate. The vector X_t^C contains sine and cosine calendar-month terms that control for seasonality, lagged early CBIO retirement, and the beginning-of-month share of the total CBIO bank held by

Table 4: Upstream Ethanol Supply Estimates

	Estimate	State p-value	Two-way p-value
Effective-price response			
Effective producer revenue, η	2.8779	0.0478	< 0.001
Pre-policy corn exposure, η_{corn}	11.5192	0.0045	0.0554
Sugar-price control		Yes	
Corn-price control		Yes	
Pre-policy corn exposure $\times$ linear trend		Yes	
State fixed effects		Yes	
Month fixed effects		Yes	
Year fixed effects		Yes	
Observations		1,114	
Adjusted R^2		0.6845	

Note: The dependent variable is $\log(1 + q^{E,U}_{s,t})$. Estimates are from linear IV/2SLS. The two endogenous effective-price terms are instrumented with the log international oil-price level and its twelve-month change, together with their interactions with $PreCorn_s$. The state p-values cluster inference by state; the two-way p-values cluster inference by state and month-year.

Table 5: Implied Upstream Supply Elasticities

Group	Implied supply elasticity
National production-weighted average	3.0861
States with meaningful corn exposure: MT and GO	3.5843
No corn exposure	2.8779

Note: Elasticities are computed as $\eta + \eta_{\text{corn}} PreCorn_s$. Averages are weighted by ethanol production in the estimation sample. States with meaningful corn exposure are defined as those with $PreCorn_s \geq 0.01$.

non-obligated agents.[7] Early retirement excludes mandatory retirement in the applicable compliance month. The error ε^C_{t+1} captures unobserved shocks to next-month CBIO market conditions.

The CBIO bank is potentially endogenous. The bank B^C_t reflects past issuance, purchase, and retirement decisions and may therefore be correlated with persistent unobserved portfolio costs, such as liquidity risk or financial constraints, that also enter the current Euler-equation error. Thus, OLS need not recover φ_B.

I therefore instrument the CBIO bank using upstream ethanol-supply variation. The excluded shifter is

$$Z^C_t = \{\log P^{sugar}_t\}.$$

Sugar prices shift the opportunity cost of allocating sugarcane toward ethanol and therefore shift ethanol production, CBIO issuance, and the accumulation of CBIO inventories. Conditional on calendar seasonality, recent early retirement, and the composition of CBIO holdings, this variation identifies the effect of the aggregate CBIO bank on intertemporal CBIO prices. The resulting estimation sample contains 48 monthly observations.

The exclusion restriction is that, conditional on these controls, the sugar-price instrument affects the Euler condition only through ethanol production and CBIO availability and is uncorrelated with the unobserved shock ε^C_{t+1}. The corresponding moment condition is

$$E\left[Z^C_t \varepsilon^C_{t+1}\right] = 0.$$

I estimate equation (8) by linear IV/2SLS and compute Newey–West standard errors with three monthly lags to allow for serial correlation in the monthly Euler-equation residuals. Table 6 reports the excluded-instrument first-stage F-statistic.

Table 6: First-Stage Diagnostics for the Dynamic CBIO Equation

Endogenous variable	First-stage F
CBIO bank, B^C_t	22.85
Observations	48

Note: This table reports the excluded-instrument first-stage F-statistic for the representative CBIO holder's bank in equation (8). The excluded instrument is the log sugar price. Controls include calendar-month seasonality, lagged early CBIO retirement, and the beginning-of-month non-obligated share of the total CBIO bank.

With one excluded instrument and one endogenous regressor, the specification is exactly identified. Table 7 presents the second-stage estimate. The negative bank coefficient is consistent with

[7] The latter two controls separate the effect of the aggregate CBIO bank from variation in compliance pressure and in the composition of credit holdings. Recent early retirement captures changes in compliance demand that can reduce available inventories independently of the total bank, while the non-obligated share allows a given aggregate bank to have different implications for market availability depending on who holds the credits. Both variables are predetermined relative to the current Euler-equation innovation: early retirement enters with one lag, and the holder share is measured at the beginning of the month.

a declining marginal value of additional banking as CBIO inventories increase. Holding recent retirement behavior, holder composition, and seasonality fixed, an additional one million banked CBIOs lowers $P_t^C - \beta P_{t+1}^C$ by about R$0.314 per CBIO.

Table 7: Second-Stage Estimates for the Dynamic CBIO Equation

	Euler-equation parameters	
Parameter	Estimate	NW(3) t-statistic
CBIO bank, φ_B	−0.314	−1.73
Seasonal controls	Yes	
Early-retirement control	Yes	
Holder-composition control	Yes	
Observations	48	

Note: This table reports the second-stage linear IV/2SLS estimate of equation (8). Reported t-statistics use Newey–West standard errors with three monthly lags.

The estimated Euler equation characterizes how CBIO inventories affect the intertemporal evolution of CBIO prices and disciplines the price path in counterfactual exercises in which RenovaBio and CBIO trading remain in place.

6 Counterfactual and Policy Evaluation

I use the estimated model to evaluate RenovaBio under alternative policy environments. I compare the observed policy with a policy-removal counterfactual and with a higher ethanol blending mandate. I quantify effects on ethanol production, fuel prices and consumption, emissions, the distribution of surplus across market participants, and welfare.

I evaluate the counterfactuals from 2020 to 2024 using the estimated demand and supply parameters. In each year, I solve for the upstream ethanol price that clears the annual ethanol market and re-solve distributors' Bertrand pricing conditions using the estimated RCNL demand system. I hold observed residual ethanol absorption fixed.[8] I also hold diesel and biodiesel quantities fixed, given their limited response to the CBIO wedge.[9] The upstream gasoline price and recovered non-policy distribution costs are also held fixed.

I measure welfare as the sum of household consumer surplus, total downstream profits, and ethanol producer surplus, net of climate damages. I value CO_2 emissions at USD 100 per ton in the baseline. I report sensitivity at USD 50, USD 200, and USD 1,000 per ton.

[8] The main components are net exports and annual inventory adjustments, which generally range from approximately −6 to 6 percent of annual production. Author's calculations using USDA FAS (2024).

[9] Biodiesel is not sold separately; it is blended into diesel at a statutory rate, so its use follows diesel demand and the mandated share. The RenovaBio compliance cost for Diesel B was only R$0.01–0.04 per liter over 2020–2024, implying a negligible quantity response (Ministério de Minas e Energia, 2025).

6.1 Policy Removal

I first consider a counterfactual in which RenovaBio is not implemented. Ethanol producers no longer receive CBIO revenue, and distributors no longer face the marginal compliance cost associated with the CBIO purchases required by gasoline sales.

Ethanol production falls by only 0.5–1.8% across years. A higher upstream ethanol price offsets 81–90% of the lost CBIO incentive, or about 88% on average, so effective producer revenue falls by only 0.1–0.6%. This incidence reflects the relative elasticities: annual ethanol absorption is much less responsive to the upstream price, with an elasticity of about -0.10,[10] than ethanol supply, with an elasticity of about 3.09. Consequently, removing CBIO revenue is largely offset by a higher ethanol market price, leaving only a small decline in effective producer revenue and ethanol production.

Downstream, policy removal mainly reduces hydrous ethanol consumption, which falls by 1.73 billion liters (2.3%), while gasoline consumption changes negligibly, falling by only 8 million liters (0.004%). Gasoline marginal cost also falls slightly, by about R$0.0070 per liter (0.1% of the average retail gasoline price), because eliminating the CBIO compliance cost more than offsets the higher cost of the ethanol blend component. Despite this small decline in marginal cost, the retail gasoline price rises by about R$0.0100 per liter (0.2%), and modeled downstream profits increase by R$3.13 billion (0.4%). This counterintuitive pricing response reflects cross-fuel competition. The higher hydrous ethanol price under policy removal shifts some demand toward gasoline but also weakens ethanol's competitive pressure, allowing distributors to raise gasoline markups and retail prices. Together, these offsetting cost, substitution, and markup effects leave gasoline consumption nearly unchanged and increase downstream profits.

Emissions fall by about 1.01 million tons of CO_2e (0.22%) under policy removal, while total fuel volume declines by about 1.74 billion liters (0.7%). Because gasoline consumption remains nearly unchanged, the decline in ethanol consumption reflects primarily lower hydrous ethanol use rather than substitution toward gasoline. This is a central result: RenovaBio expands biofuel consumption without materially displacing gasoline and therefore increases emissions relative to policy removal.

In welfare terms, relative to policy removal, RenovaBio raises consumer surplus by R$12.02 billion. Consumers are the largest private beneficiaries because most of the CBIO incentive is capitalized into a lower ethanol market price, which lowers retail hydrous ethanol prices and strengthens competitive pressure on gasoline, slightly lowering retail gasoline prices as well. Total downstream profits fall by R$12.28 billion (1.5%), of which R$3.13 billion reflects lower modeled fuel-market profits and R$9.15 billion reflects CBIO payments associated with other obligated fuels. Ethanol producer surplus increases by only R$1.65 billion (1.5%), despite R$14.50 billion in gross CBIO revenue, consistent with most of the subsidy being passed through through lower ethanol prices. Because emissions increase by 1.01 million tons of CO_2e (0.22%), climate damages rise by R$0.50 billion at a social cost of carbon of USD 100 per ton. Combining these effects, RenovaBio raises

[10] As discussed in Section 5.1, aggregate downstream ethanol absorption is relatively inelastic because a substantial share consists of anhydrous ethanol required by the gasoline blending mandate.

welfare by R\$0.89 billion relative to policy removal. Welfare remains above policy removal for social costs of carbon below approximately USD 276 per ton.

6.2 Production-Equivalent Ethanol Mandate

I next compare RenovaBio with a higher blending mandate. Both are quantity-based instruments for expanding biofuel use, but blending mandates are the conventional approach, whereas RenovaBio is a newer policy that rewards upstream production. RenovaBio supports both hydrous ethanol, sold directly as a fuel, and anhydrous ethanol, blended into gasoline, while the mandate directly increases the required anhydrous share. To make the policies comparable, I remove RenovaBio and choose each year's anhydrous ethanol share to match total ethanol production under RenovaBio. This design reveals how welfare, emissions, and gasoline consumption differ between the two policies for a given level of ethanol production.

Matching RenovaBio's production requires blend shares of 27.46–28.65%, or 0.46–1.65 percentage points above the 27% baseline, depending on the year. The additional mandated demand raises the upstream ethanol price by only 0.16–0.56% relative to policy removal. Figure 7 illustrates the different upstream mechanisms: RenovaBio shifts ethanol supply through CBIO revenue and lowers the market-clearing price, whereas the mandate shifts ethanol demand outward and raises the market price.

Downstream fuel-price effects under the production-equivalent mandate are limited in magnitude. Relative to policy removal, the mandate raises the upstream ethanol price by 0.16–0.56%, whereas RenovaBio lowers it by about 1.1–4.9%. This produces a modest increase in the retail hydrous ethanol price under the mandate, while the retail gasoline price changes negligibly, falling by about R\$0.002 per liter (roughly 0.04%) on average. A key counterfactual finding is therefore that, for the same ethanol production, the mandate generates substantially smaller retail fuel-price distortions than RenovaBio. Figure 8 displays these price differences.

Turning to fuel-consumption composition, the mandate shifts ethanol use toward the anhydrous blend; all percentage changes below are relative to policy removal. Anhydrous ethanol use rises by 1.94 billion liters (4.0%), while hydrous ethanol consumption falls slightly by 0.20 billion liters (0.3%), as the higher ethanol price reduces direct hydrous demand. Total ethanol absorption therefore rises by 1.74 billion liters (1.41%). Gasoline consumption changes negligibly, increasing by only 0.08 billion liters (0.05%). In contrast, RenovaBio generates the same increase in total ethanol use primarily through higher hydrous ethanol consumption. Figure 9 highlights this difference in how the two policies absorb additional ethanol.

Under the mandate, total energy use falls by about 0.34% relative to policy removal. Emissions decline by 4.54 million tons of CO_2e (0.98% of policy-removal emissions), whereas RenovaBio increases emissions by 1.01 million tons (0.22%). This contrast arises because gasoline consumption changes little under either policy, but the higher blending requirement directly replaces about 1.86 billion liters (1.4%) of fossil gasoline with anhydrous ethanol. Thus, despite generating essentially the same ethanol production, the mandate produces about 5.55 million tons less CO_2e than

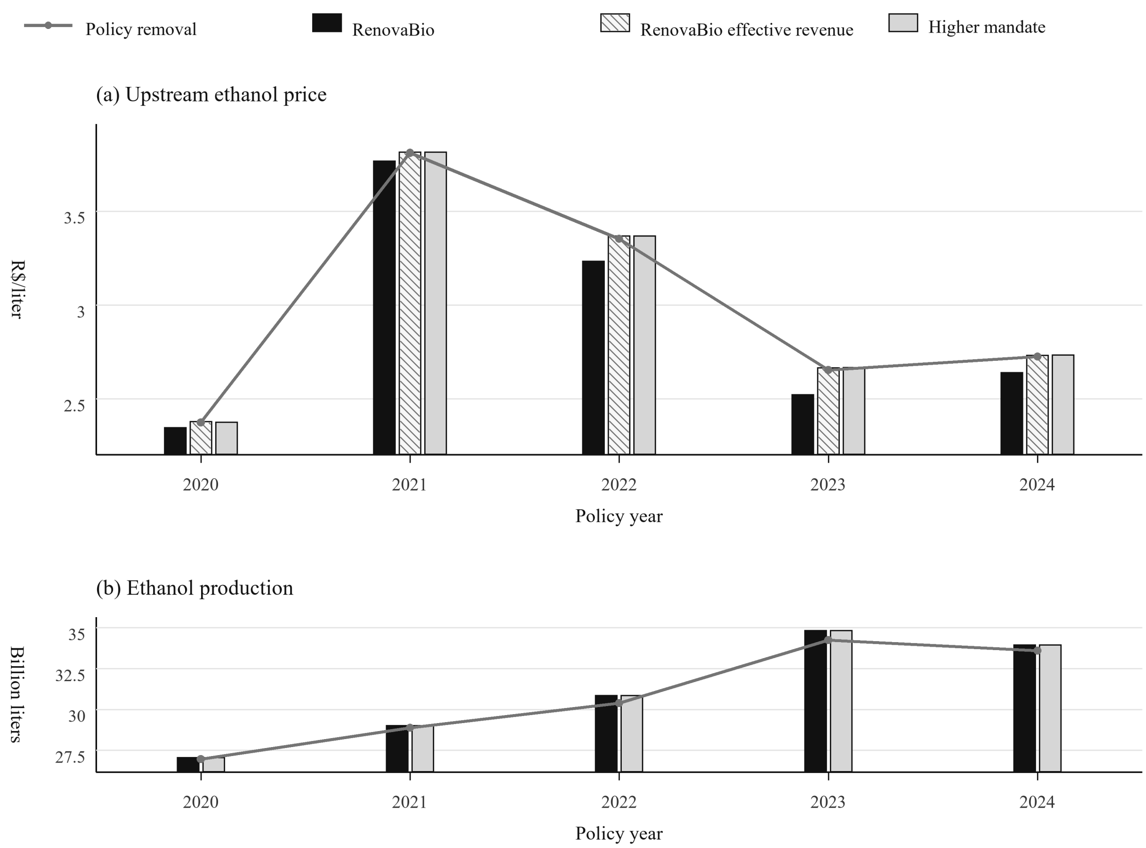


Figure 7: Upstream ethanol prices and production across policy environments. Panel (a) reports the upstream ethanol market price under policy removal, RenovaBio, and the production-equivalent higher ethanol mandate, together with effective producer revenue under RenovaBio (the ethanol market price plus per-unit CBIO revenue). The lower ethanol market price under RenovaBio is largely offset by CBIO revenue, leaving effective producer revenue close to the policy-removal level. Panel (b) reports annual ethanol production; by construction, the higher mandate matches RenovaBio production in each year.

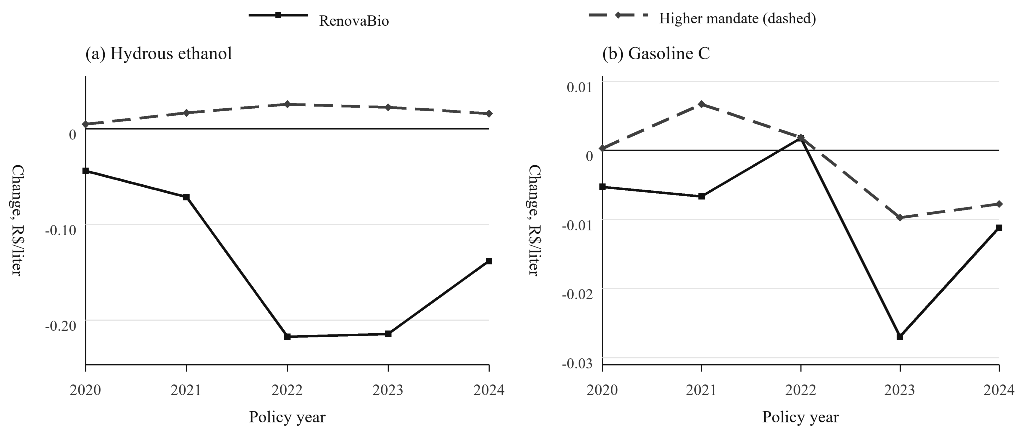


Figure 8: Downstream fuel prices under RenovaBio and the production-equivalent ethanol mandate.

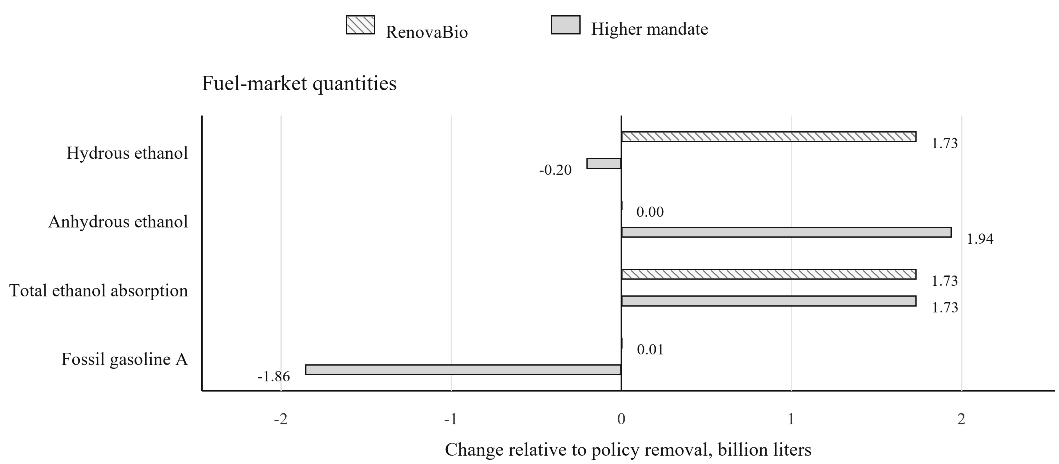


Figure 9: Fuel-market quantities across policy environments. Bars report cumulative 2020–2024 changes under RenovaBio and the higher ethanol mandate relative to policy removal.

RenovaBio by directing more ethanol toward direct fossil-gasoline displacement.

In welfare terms, relative to policy removal, the production-equivalent mandate reduces consumer surplus only slightly, by R$0.91 billion (0.005%). Downstream profits increase by R$1.11 billion (0.14%). Ethanol producer surplus rises by R$1.65 billion (1.46%), reflecting the counterfactual's construction to match ethanol production under RenovaBio. Even before valuing emissions, the mandate generates about R$0.46 billion more welfare than RenovaBio, as its downstream-profit advantage more than offsets the small consumer-surplus loss while producer gains are nearly identical. At a social cost of carbon of USD 100 per ton, the mandate's 4.54 million ton reduction in CO_2e (0.98%) adds R$2.27 billion in climate benefits, raising its total welfare gain to R$4.12 billion, compared with R$0.89 billion under RenovaBio.

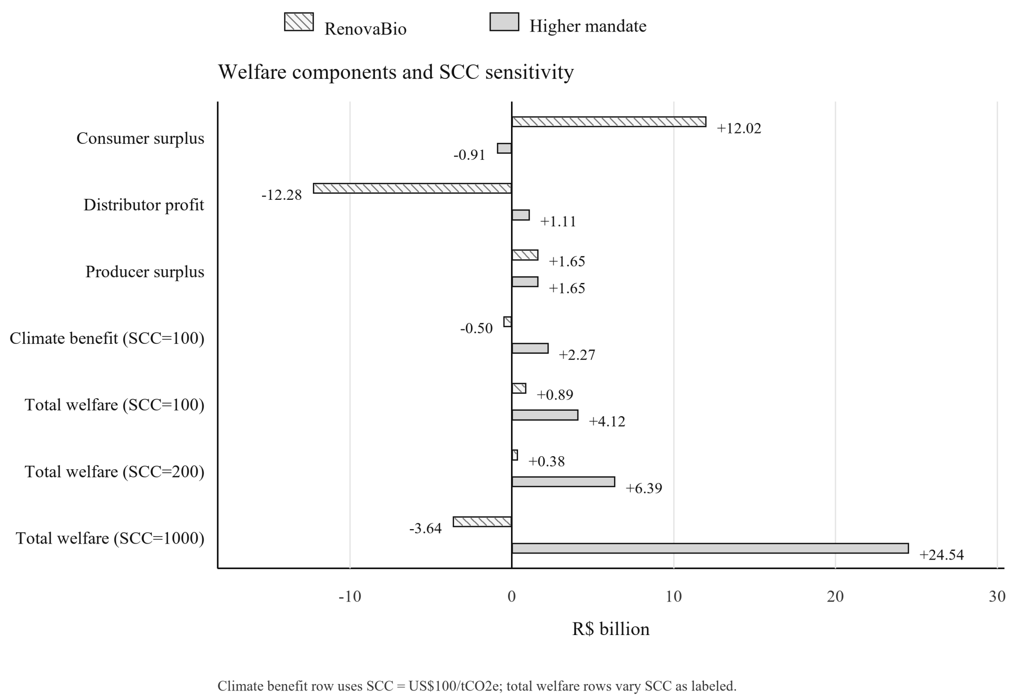


Figure 10: Welfare effects across policy environments. Bars report cumulative 2020–2024 welfare changes under RenovaBio and the higher ethanol mandate relative to policy removal. Climate benefits are valued using a social cost of carbon of USD 100 per ton of CO_2e.

7 Conclusion

This paper asks whether expanding low-carbon fuel production is sufficient to reduce emissions. I study Brazil's RenovaBio program, a quantity-based carbon credit policy in which the government fixes an aggregate credit requirement and the CBIO price adjusts to provide the incentive for certified biofuel production. I develop and estimate a model linking ethanol supply, differentiated downstream fuel demand and pricing, and the dynamic CBIO market. The model traces how the policy's production incentive passes through upstream and downstream prices and ultimately determines how much additional ethanol displaces gasoline.

The main result is that RenovaBio expands ethanol production, but does little to substitute ethanol for fossil fuel or reduce emissions. This follows the familiar subsidy-incidence logic with relatively inelastic demand. CBIO revenue encourages producers to supply more ethanol, but consumers increase total ethanol use only slightly. The ethanol market price therefore falls to absorb the additional supply. In the estimates, this price decline offsets roughly 88% of the RenovaBio incentive, so producers retain only a small increase in effective revenue and much of the benefit reaches consumers through cheaper fuel. The lower ethanol price makes ethanol more attractive relative to gasoline and also puts downward pressure on gasoline markups charged by fuel distributors. Gasoline consumption changes very little, while most of the additional ethanol expands total fuel consumption rather than replacing gasoline. As a result, RenovaBio increases emissions by about 1.01 million tons of CO_2e.

The comparison with a conventional ethanol mandate also shows that RenovaBio creates much larger fuel-price distortions. Increasing the mandated ethanol share by only about one percentage point on average generates essentially the same ethanol production with much smaller price changes. This difference also matters for welfare: even before valuing emissions, the mandate generates about R$0.46 billion more surplus than RenovaBio.

More generally, a policy that targets low-carbon production does not necessarily target emissions reductions. Its effectiveness depends on what the additional clean output replaces: if it displaces the high-carbon alternative, production incentives translate into abatement; if instead lower prices expand total consumption, the same policy can increase clean production without reducing emissions. The broader lesson is that climate policy should be evaluated by the substitution it induces, not by the amount of low-carbon output it creates.

References

AFDC, "Global Ethanol Production by Country or Region," Alternative Fuels Data Center 2026. Data through 2024. Source: Renewable Fuels Association.

ANP, "ANP Resolution No. 758 of November 23, 2018," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2018. English translation. Certification of efficient production or importation of biofuels under RenovaBio.

_ , "ANP Resolution No. 791 of June 12, 2019," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2019. English translation. Individualization of annual compulsory emission reduction targets for fuel distributors under RenovaBio.

_ , "Ethanol Dashboard," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2025. Power BI dashboard. Filters used: 2024, gasoline C and hydrous ethanol, national distributor sales. Accessed June 2026.

_ , "Oil, Natural Gas and Biofuels Statistical Yearbook 2025," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2025. Data for 2015 to 2024.

_ , "Painel Dinâmico de Certificação de Biocombustíveis RenovaBio," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2025. Dynamic panel of certified biofuel production units and certified credit generation information.

_ , "Gasolina," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2026. Published November 9, 2020; updated February 2, 2026.

_ , "Painel Dinâmico da Plataforma CBIO," Agência Nacional do Petróleo, Gás Natural e Biocombustíveis 2026. Power BI dashboard. Updated January 27, 2026. Used for author's calculations of CBIO prices, issuance, retirement, and market values. Accessed July 2026.

B3, "Decarbonization Credit (CBIO)," B3 S.A. – Brasil, Bolsa, Balcão 2022. Product information sheet on the Brazilian Decarbonization Credit market. Available at B3.

Borenstein, Severin, "The Private and Public Economics of Renewable Electricity Generation," *Journal of Economic Perspectives*, 2012, *26* (1), 67–92.

Buchanan, James M., "External Diseconomies, Corrective Taxes, and Market Structure," *American Economic Review*, 1969, *59* (1), 174–177.

CADE, "Mercados de Distribuição e Varejo de Combustíveis Líquidos," Technical Report, Conselho Administrativo de Defesa Econômica 2026.

Camargo, Luis Ramirez, Gabriel Castro, Katharina Gruber, Jessica Jewell, Michael Klingler, Olga Turkovska, Elisabeth Wetterlund, and Johannes Schmidt, "Pathway to a land-neutral expansion of Brazilian renewable fuel production," *Nature Communications*, 2022, *13*.

Chen, Xiaoguang, Haixiao Huang, Madhu Khanna, and Hayri Önal, "Alternative Transportation Fuel Standards: Welfare Effects and Climate Benefits," *Journal of Environmental Economics and Management*, 2014, *67* (3), 241–257.

Chum, Helena L., Ethan Warner, Joaquim E. A. Seabra, and Isaias C. Macedo, "A comparison of commercial ethanol production systems from Brazilian sugarcane and US corn," *Biofuels, Bioproducts and Biorefining*, 2014, *8* (2), 205–223.

CONAB, "Acompanhamento da Safra Brasileira de Cana-de-Açúcar: Safra 2025/26, Quarto Levantamento," Technical Report, Companhia Nacional de Abastecimento April 2026.

Cortez, Luís Augusto Barbosa, ed., *Proálcool 40 Anos: Universidades e Empresas: 40 Anos de Ciência e Tecnologia para o Etanol Brasileiro*, São Paulo: Blucher, 2016.

Dechezleprêtre, Antoine, Adrien Fabre, Tobias Kruse, Bluebery Planterose, Ana Sanchez Chico, and Stefanie Stantcheva, "Fighting Climate Change: International Attitudes toward Climate Policies," *American Economic Review*, 2025, *115* (4), 1258–1300.

Domínguez-Iino, Tomas, "Efficiency and Redistribution in Environmental Policy: An Equilibrium Analysis of Agricultural Supply Chains," 2025. Working paper.

Douenne, Thomas and Adrien Fabre, "Yellow Vests, Pessimistic Beliefs, and Carbon Tax Aversion," *American Economic Journal: Economic Policy*, 2022, *14* (1), 81–110.

EPE, "Demanda de Energia dos Veículos Leves: 2025–2034," Technical Report, Empresa de Pesquisa Energética 2024.

_ , "Ethanol Supply Scenarios and Otto Cycle Demand from 2025 to 2034," Technical Report, Empresa de Pesquisa Energética 2024.

_ , "Analysis of Current Biofuels Outlook: Year 2024," Technical Report EPE/DPG/SDB/2024/06, Empresa de Pesquisa Energética August 2025.

Fischer, Carolyn and Richard G. Newell, "Environmental and Technology Policies for Climate Mitigation," *Journal of Environmental Economics and Management*, 2008, *55* (2), 142–162.

Fowlie, Meredith, Mar Reguant, and Stephen P. Ryan, "Market-Based Emissions Regulation and Industry Dynamics," *Journal of Political Economy*, 2016, *124* (1), 249–302.

Gillingham, Kenneth, David Rapson, and Gernot Wagner, "The Rebound Effect and Energy Efficiency Policy," *Review of Environmental Economics and Policy*, 2016, *10* (1), 68–88.

Goldemberg, José, Suani Teixeira Coelho, and Patrícia Guardabassi, "The Sustainability of Ethanol Production from Sugarcane," *Energy Policy*, 2008, *36* (6), 2086–2097.

Goulder, Lawrence H. and Ian W. H. Parry, "Instrument Choice in Environmental Policy," *Review of Environmental Economics and Policy*, 2008, *2* (2), 152–174.

Gurgel, Angelo C., Marcelo M. R. Moreira, Joaquim E. A. Seabra, and Lee R. Lynd, "Contribution of double-cropped maize ethanol in Brazil to sustainable development," *Nature Sustainability*, 2024.

Hoeckel, Paulo Henrique and Augusto Alvim, "The ethanol market in Brazil: price behavior and regional differences," *Biofuels, Bioproducts and Biorefining*, 2023, *17* (4), 884–903.

Holland, Stephen P., Jonathan E. Hughes, and Christopher R. Knittel, "Greenhouse Gas Reductions under Low Carbon Fuel Standards?," *American Economic Journal: Economic Policy*, 2009, *1* (1), 106–146.

_ , _ , _ , and Nathan C. Parker, "Unintended Consequences of Carbon Policies: Transportation Fuels, Land-Use, Emissions, and Innovation," *The Energy Journal*, 2015, *36* (3), 35–74.

ICCT, "Brazil Passenger Vehicle Market Statistics," Technical Report, International Council on Clean Transportation 2015.

IEA, "Transport sector CO2 emissions by mode in the Sustainable Development Scenario, 2000–2030," International Energy Agency, Paris 2022. Licence: CC BY 4.0.

IEA AMF, "Fuel Information: Ethanol Fuel Properties," IEA Advanced Motor Fuels n.d. Accessed June 2026.

IRENA, "Brazil's Biofuel Industry: Lessons, Challenges and Opportunities," Technical Report, International Renewable Energy Agency 2025.

Lade, Gabriel E. and Aaron Smith, "Biofuels: Past, Present, and Future," *Annual Review of Resource Economics*, 2025, *17*, 105–125.

_ and James Bushnell, "Fuel Subsidy Pass-Through and Market Structure: Evidence from the Renewable Fuel Standard," *Journal of the Association of Environmental and Resource Economists*, 2019, *6* (3), 563–592.

Macedo, Isaias C., Joaquim E. A. Seabra, and Joao E. A. R. Silva, "Greenhouse gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020," *Biomass and Bioenergy*, 2008, *32* (7), 582–595.

Magalhaes, Luciana and Marta Nogueira, "Petrobras Wrapping Up Due Diligence to Buy Back Refinery from Mubadala, Sources Say," *Reuters*, July 2024.

Meyer, Dustin, Lynn Mytelka, Paulo Teixeira de Sousa, and Arnulf Grubler, "Brazilian Ethanol: Unpacking a Success Story of Energy Technology Innovation," in Arnulf Grubler and

Charlie Wilson, eds., *Energy Technology Innovation: Learning from Historical Successes and Failures*, Cambridge University Press, 2013, pp. 275–291.

Minaspetro, "Nova lei acirra conflito entre distribuidoras de combust'iveis sobre cr'editos de carbono; entenda," 2025.

Ministério de Minas e Energia, "Balanço 2024: Política Nacional de Biocombustíveis RenovaBio," Technical Report, Ministério de Minas e Energia 2025.

MJSP, "Nota Técnica No. 25/2019," Technical Report, Ministério da Justiça e Segurança Pública, Secretaria Nacional do Consumidor 2019. Discusses the distinction between branded fuel stations and postos bandeira branca.

Moody's, "Vibra Energia S.A.: Update to Credit Analysis," Technical Report, Moody's Investors Service July 2023.

Moreira, Marcelo M. R., Joaquim E. A. Seabra, Lee R. Lynd, Sofia M. Arantes, Marcelo P. Cunha, and Joaquim J. M. Guilhoto, "Socio-environmental and land-use impacts of double-cropped maize ethanol in Brazil," *Nature Sustainability*, 2020, *3* (3), 209–216.

Raízen, "Integrated Report: Crop Year 24/25," Technical Report, Raízen 2025.

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.

Sant'Anna, Marcelo, "How Green Is Sugarcane Ethanol?," *Review of Economics and Statistics*, 2024, *106* (1), 202–216.

Seabra, Joaquim E. A., Isaias C. Macedo, Helena L. Chum, Carlos E. Faroni, and Celso A. Sarto, "Life Cycle Assessment of Brazilian Sugarcane Products: GHG Emissions and Energy Use," *Biofuels, Bioproducts and Biorefining*, 2011, *5* (5), 519–532.

UNICA, "E30: A New Important Step in Brazil's Journey toward Low Carbon Transportation," July 2025.

_ , "Ethanol," 2025.

_ , "RenovaBio," 2025.

USDA, "Corn Ethanol Production Booms in Brazil," Technical Report, United States Department of Agriculture October 2020. Global Agricultural Information Network report.

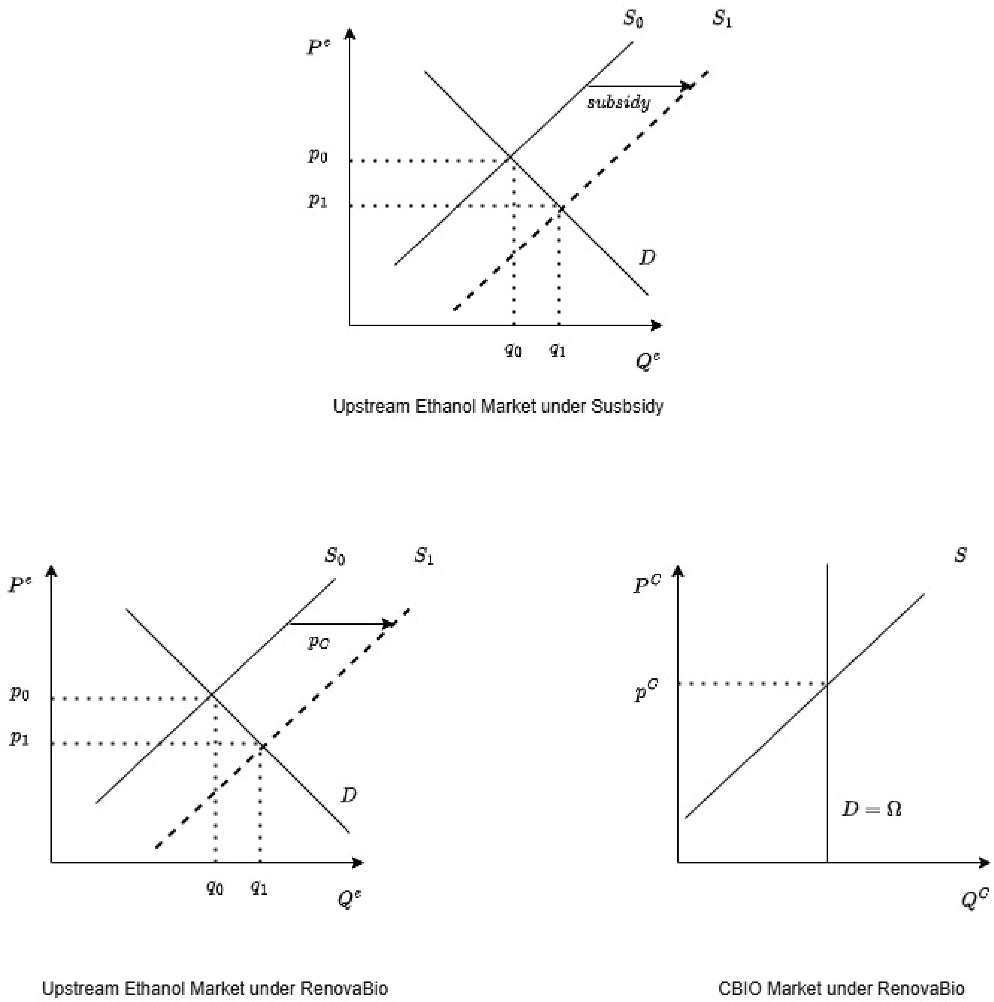
USDA FAS, "Biofuels Annual: Brazil," Technical Report BR2024-0022, United States Department of Agriculture, Foreign Agricultural Service August 2024.

_ , "Grain and Feed Update: Brazil," Technical Report BR2025-0023, United States Department of Agriculture, Foreign Agricultural Service August 2025.

_ , "Sugar Annual: Brazil," Technical Report BR2025-0011, United States Department of Agriculture, Foreign Agricultural Service April 2025.

Weitzman, Martin L., "Prices vs. Quantities," *The Review of Economic Studies*, 1974, *41* (4), 477–491.

A A Stylized Model of RenovaBio versus a Subsidy



This figure shows how RenovaBio and an equivalent subsidy shift the ethanol market.

Figure 11: Supply and demand interpretation of the RenovaBio credit mechanism.

B Marginal Obligation from Gasoline Sales

Distributor i's following-year RenovaBio obligation under the policy rule is

$$O^R_{i,y+1} = O^R\left(\Omega_{y+1}, q^{G,D}_{i,y}; F_y\right) = \Omega_{y+1} \frac{a^G \sum_{\ell \in y} \sum_s q^{G,D}_{is\ell}}{F_y}.$$

The numerator aggregates distributor i's gasoline sales across all states and months of year y and converts them into emissions-weighted fossil-fuel exposure. Thus, the fraction measures distributor i's share of total national annual emissions-weighted fossil-fuel sales, which determines its share of the national target Ω_{y+1}.

When distributors choose monthly prices, F_y has not yet been realized. I therefore assume that firms use a common forecast $\widehat{F}_y$, predicted from previous-year trends, and take it as predetermined in their pricing problems. Hence,

$$\frac{\partial O^R_{i,y+1}}{\partial q^{G,D}_{ist}} = \frac{\Omega_{y+1} a^G}{\widehat{F}_y}.$$

C RCNL Market Shares

The shocks $\rho\zeta_{h,f(j),st} + (1-\rho)\epsilon_{hjst}$ are assumed to follow the nested extreme-value structure that generates the choice probabilities below. For household h, define utility excluding the nested-logit shocks as

$$V_{hjst} = (\alpha + \sigma_p \nu_h) p^D_{jst} + X^{D\prime}_{st} \beta_{f(j)} + \Lambda_{jst} + \xi_{jst}.$$

For each fuel nest $f \in \{G, E\}$, let

$$A_{hfst} = \sum_{k \in \mathcal{J}_{fst}} \exp\left(\frac{V_{hkst}}{1-\rho}\right),$$

where $\mathcal{J}_{fst}$ is the set of products in fuel nest f available in state s and month t. Household h's probability of choosing product j is

$$s_{hjst} = \frac{\exp\left(\frac{V_{hjst}}{1-\rho}\right) A^{-\rho}_{h,f(j),st}}{1 + \sum_{f \in \{G,E\}} A^{1-\rho}_{hfst}}.$$

The term 1 in the denominator corresponds to the outside option. Aggregate product share and demand are

$$s_{jst} = \int s_{hjst}\, dF(\nu_h), \qquad q^H_{jst} = M_{st} s_{jst}.$$

D Additional Upstream Supply First-Stage Diagnostics

Table 8 reports conventional first-stage Wald F-statistics with inference clustered by month-year, reflecting the level of variation in the national oil-price shocks.

Table 8: Alternative First-Stage Diagnostics

Endogenous effective-price term	Month-year Wald F
Effective producer revenue, $\log P_t^{E,\text{eff}}$	11.415
Pre-policy corn exposure, $\log P_t^{E,\text{eff}} \times PreCorn_s$	22.883
Observations	1,114

Note: Entries are conventional first-stage Wald F-statistics with inference clustered by month-year. The excluded instruments are the log international oil-price level and its twelve-month change, together with their interactions with $PreCorn_s$.