Decarbonization Policy Along the Fuel Supply Chain: A Structural Analysis of Brazil's RenovaBio

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  - Aiming to shift consumption toward cleaner fuels.
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  - Brazil takes ethanol beyond blending: a direct gasoline substitute.

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$\rightarrow$ This paper: A structural model of fuel and emissions responses to clean-fuel incentives.

Brazil: Clean-Fuel Policy on a Massive Scale

- Brazil offers lessons for clean-fuel policy worldwide.
- It has one of the world's largest ethanol markets.
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  - The market-determined credit price rewards ethanol production.
- 2024: Ethanol output reached a record high.

$\rightarrow$ Government claims RenovaBio cut transport emissions by 15%.

Emissions Along the Supply Chain: Core Mechanisms

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$\rightarrow$ These responses are outcomes of **supply-chain** and **carbon-market** equilibrium.

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  - **Downstream retail**
    - Household demand over *brand-differentiated* fuels.
    - *Strategic* retail fuel pricing by *multiproduct* distributors.
  - **Ethanol wholesale**
    - *Equilibrium* wholesale ethanol price sets retail marginal costs.
    - Carbon-intensity *heterogeneity* of supply technologies.
  - **Carbon market**
    - *Equilibrium* credit price incentivizes ethanol supply.
    - *Dynamic* demand for bankable credits.

Overview

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- **Data:** Monthly firm-level and weekly Brazilian data.
- **Counterfactual:** Evaluate RenovaBio removal and a higher blending mandate.

- Average measures implied by the structural model:
  1. Aggregate ethanol supply elasticity: 3.09.
  2. An additional 100 L of ethanol displaces only 17.5 L of pure gasoline.
  3. Aggregate fuel-demand elasticity: -0.68.

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Emissions impact along the supply chain:

→ **RenovaBio does not cut CO_2 emissions; it raises them by 1.12 Mt (0.26%).**

→ A 1 pp higher blending mandate yields similar ethanol output but lower emissions.

Contributions

- **Core Contribution**
  Develop an integrated structural model of fuel supply and carbon-credit markets to assess the separate and combined equilibrium effects of alternative carbon policies.

- **Clean-fuel regulation**
  - Bento et al. (2015); Holland, Hughes & Knittel (2009); Holland et al. (2015); Lade & Bushnell (2019); Lade & Smith (2025); Rajagopal et al. (2011)

    → RenovaBio interacts with an output-equivalent mandate in fuel-supply-chain equilibrium.

- **Environmental regulation under imperfect competition**
  - Buchanan (1969); Misiolek & Elder (1989); Fowlie, Reguant & Ryan (2016); Knittel et al. (2017); Lade et al. (2018); Domínguez-Iino (2025)

    → Quantifies how distributor concentration shapes policy effects across fuel-supply-chain

- **Biofuel policy and ethanol expansion**
  - Anderson (2012); Gurgel et al. (2024); Kim & Thompson (2025); Moreira et al. (2020); Roberts & Schlenker (2013); Salvo & Huse (2013); Sant'Anna (2024)

    → Links policy-induced ethanol production to gasoline displacement and emissions impacts.

Outline

1. Introduction

2. Industry and Policy Background

3. Data & Descriptive Statistics

4. Model and Estimation

5. Counterfactuals

Brazilian Retail Fuel Market

- Brazil has promoted ethanol since the 1970s oil crisis.
- Dual-fuel cars since 2003; now 85% of fleet.
  - Compatible engines cost very little.

    → Global potential for affordable adoption.



Source: Getty Images

Brazilian Retail Fuel Market

- Brazil has promoted ethanol since the 1970s oil crisis.
- Dual-fuel cars since 2003; now 85% of fleet.
  - Compatible engines cost very little.
    → Global potential for affordable adoption.
- Ethanol has 30% less energy per liter.
  - Lower price offsets the gap.
  - Drivers need to refuel more often.
  - Beliefs about acceleration and engine wear.
- Brazilian gasoline contains 27% ethanol



Source: Getty Images

Ethanol Production

- Ethanol is mainly sugarcane-based and seasonal.
  - Mills produce sugar and ethanol simultaneously.
  - Biomass-powered mills reduce emissions.



Source: Shutterstock

Ethanol Production

- Ethanol is mainly sugarcane-based and seasonal.
  - Mills produce sugar and ethanol simultaneously.
  - Biomass-powered mills reduce emissions.
- Corn ethanol is growing rapidly.
  - Enables year-round ethanol production.
  - Second-crop corn limits direct land-use change.
- Many estimates suggest 50–80% lower ethanol carbon intensity.
  - Substantial debate over land-use emissions.

→ *This paper:* Studies downstream fuel responses.



Source: Shutterstock

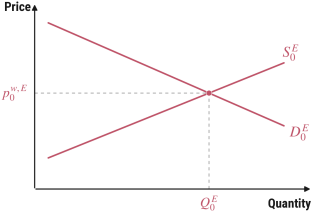
- Introduced in 2020 to expand low-carbon biofuels and cut emissions.
  - Each CBIO is a financial asset representing 1 ton of avoided CO_2.
- Ethanol producers earn CBIOs when certified ethanol is sold.
  - Ethanol supplies $\sim$85% of CBIOs; the rest is likely price-inelastic.

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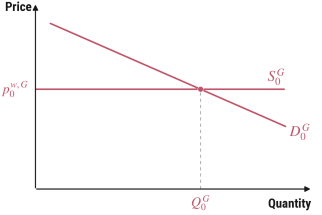
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- Government sets a minimum annual CBIO retirement target.
  $\rightarrow$ CBIO price adjusts to provide the profit margin needed to meet the target.
- Distributors' obligations are based on fossil-fuel sales, mainly gasoline and diesel.
- CBIOs can be traded and banked across years.

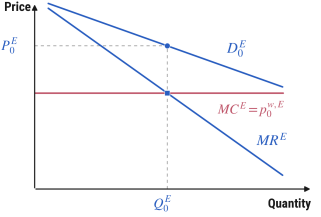
0. Before RenovaBio: upstream and downstream fuel markets.



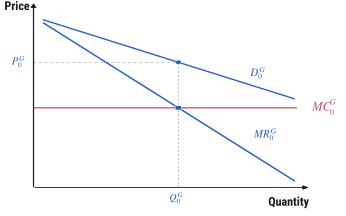
Ethanol – Upstream



Gasoline – Upstream

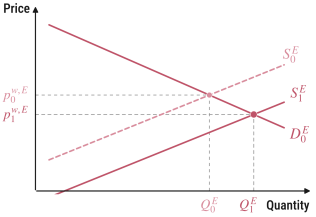


Ethanol – Downstream

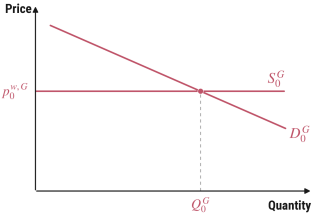


Gasoline Mix – Downstream

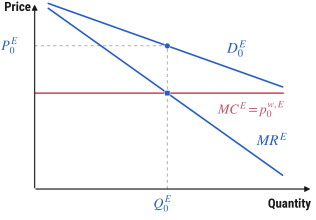
1. Clean-fuel incentive shifts ethanol supply upward.



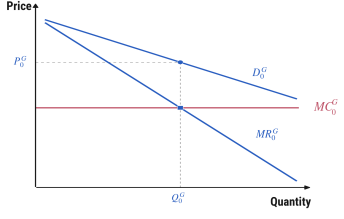
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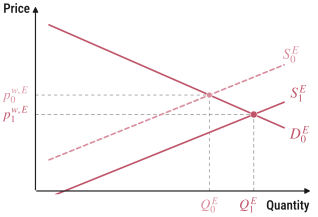


Ethanol – Downstream

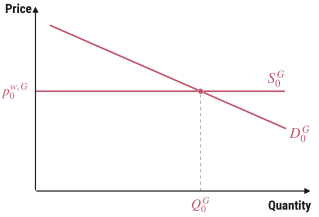


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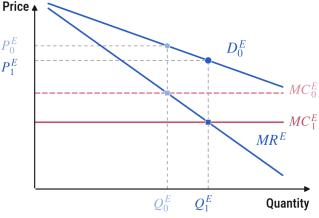
2. Lower ethanol marginal cost raises consumption and lowers price.



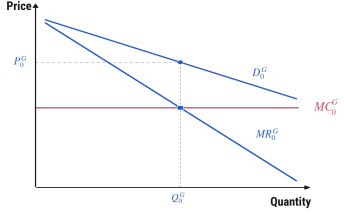
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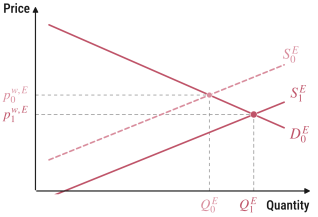


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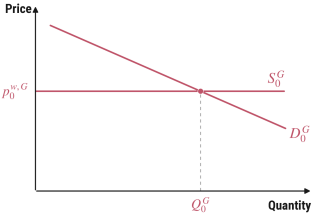


Gasoline Mix – Downstream

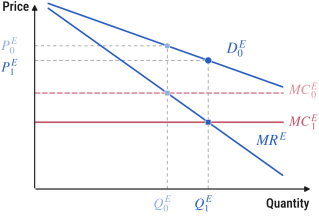
3. Cheaper ethanol shifts gasoline-mix demand downward.



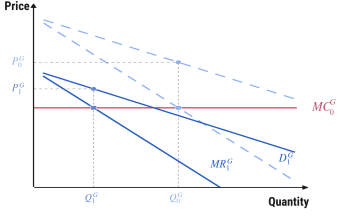
Ethanol – Upstream



Gasoline – Upstream

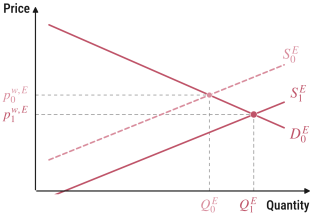


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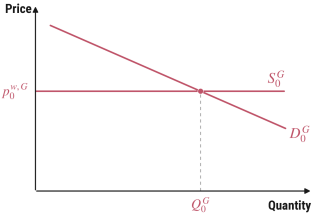


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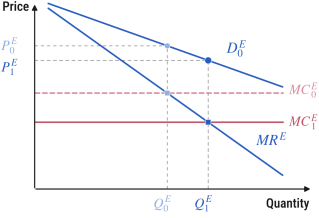
4. Ethanol blending lowers gasoline-mix marginal cost.



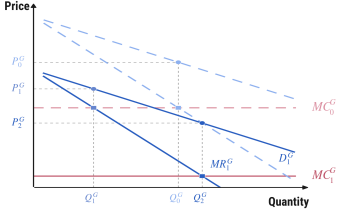
Ethanol – Upstream



Gasoline – Upstream

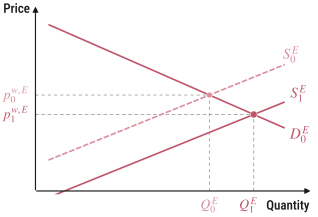


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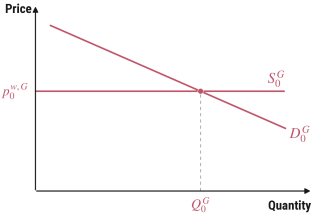


Gasoline Mix – Downstream

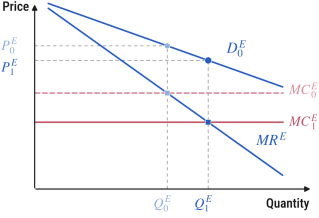
5. CBIO prices jointly determine the ethanol subsidy and gasoline-mix tax.



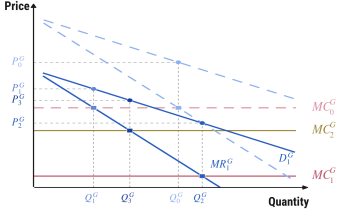
Ethanol – Upstream



Gasoline – Upstream

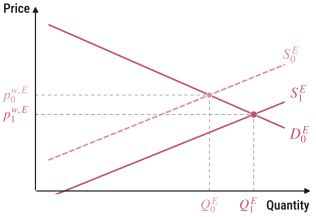


Ethanol – Downstream

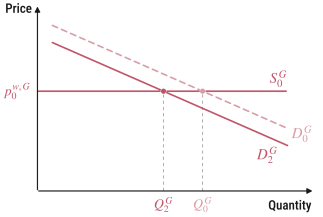


Gasoline Mix – Downstream

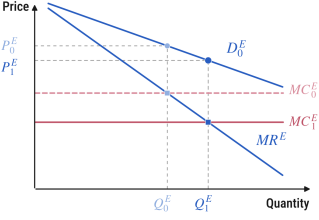
6. That tax shifts gasoline-mix marginal cost back up.



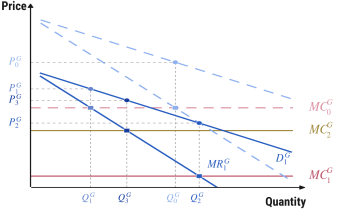
Ethanol – Upstream



Gasoline – Upstream

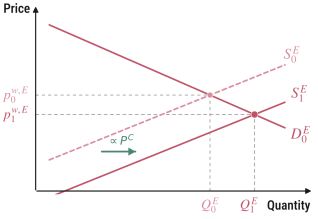


Ethanol – Downstream

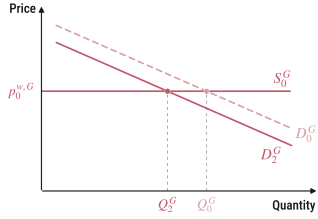


Gasoline Mix – Downstream

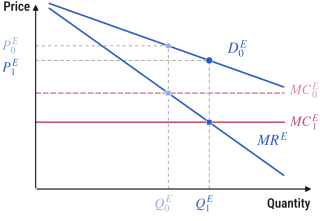
7. Both wedges are endogenous and proportional to the CBIO price.



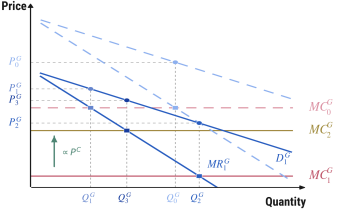
Ethanol – Upstream



Gasoline – Upstream

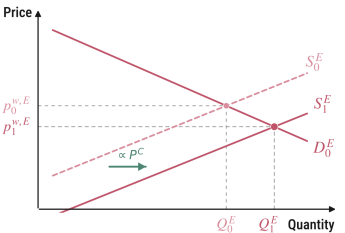


Ethanol – Downstream

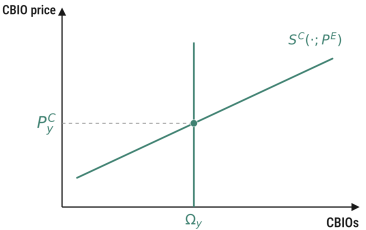


Gasoline Mix – Downstream

8. Supply and retirement targets set CBIO prices, linking ethanol subsidy to gasoline-mix tax.

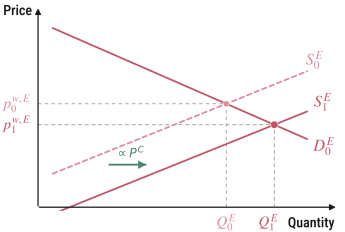


Ethanol – Upstream

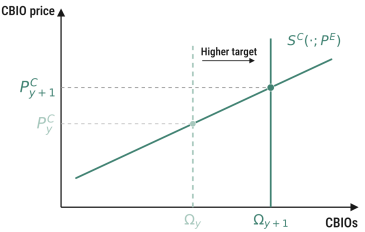


Carbon Market (Static)

9. Higher retirement targets raise future CBIO prices; no-arbitrage incentives credit banking.



Ethanol – Upstream



Carbon Market (Intertemporal)

Beyond the Simplified Model

- We estimate demand and supply jointly across vertically linked markets.
- The simplified framework misses:
  - Downstream: Consumer heterogeneity and multiproduct pricing.
  - Ethanol supply: Heterogeneous production technologies.
  - Carbon market: Financial frictions.

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Data

- **Retail fuel market:** 2010–2024
  - State × month × distributor brand × fuel.
  - Prices and sales; 62,901 product-market observations.

  Source: ANP (Brazilian petroleum regulator)

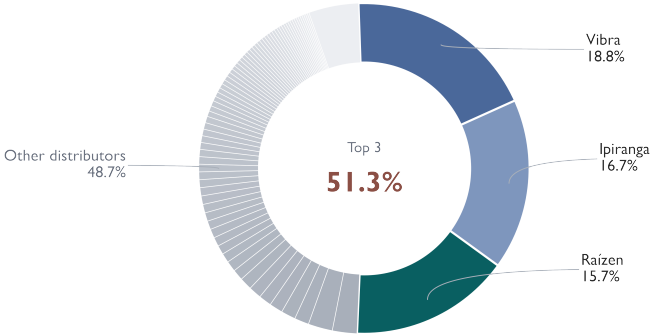
- **Ethanol production:** 2018–2024
  - State × month production and upstream prices.
  - 1,399 observations across 20 producing states.

  Sources: ANP & UNICA (Sugarcane industry association)

- **CBIO market:** 2020–2025
  - Daily prices, issuance, retirements, and inventories.
  - 1,621 market-level observations.

  Sources: B3 (Brazil's financial exchange), ANP

Fuel Distribution Market Shares (2024)



Three distributors accounted for 51.3% of national fuel sales:
44.2 billion liters of gasoline and **21.7 billion** liters of ethanol; ANP, 2024.

Ethanol Production (2025)



Brazil produces **27.3 billion** liters of sugarcane ethanol and **10.2 billion** liters of corn ethanol; 90% is consumed domestically.

Carbon Credit Price



CBIOs are worth about **4%** of ethanol's wholesale price.

The market channels about **US$620 million** annually to producers.

CBIO Scarcity and Banking Value

Credit availability is tight relative to targets, and banking may provide convenience value

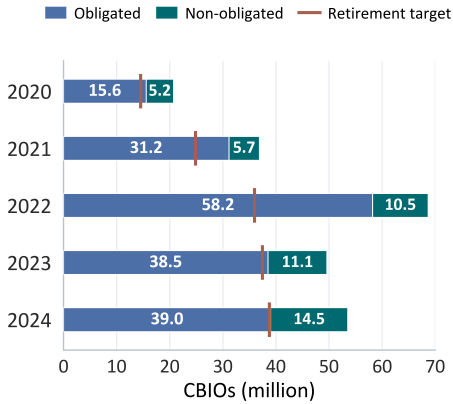


Figure 9: CBIO Market Holdings and Targets

Outline

1. Introduction

2. Industry and Policy Background

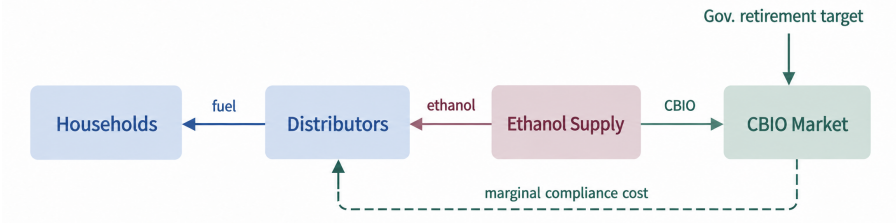
3. Data & Descriptive Statistics

4. Model and Estimation

- 4.1 Household Fuel Demand
- 4.2 Fuel Distribution and Marginal-Cost Recovery
- 4.3 Upstream Ethanol Supply
- 4.4 Carbon-Market Euler Equation

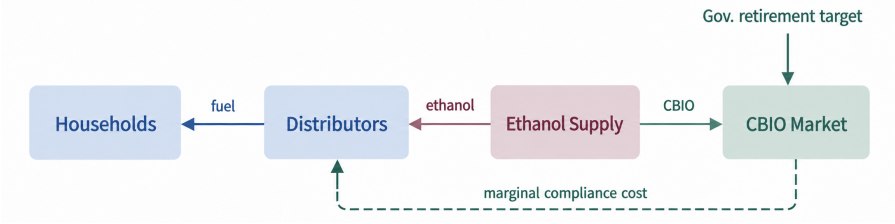
5. Counterfactuals

- **Downstream Fuel Market (D)**
  - Households choose gasoline (G), ethanol (E), or an outside good.
  - Distributors set retail prices based on upstream fuel prices and compliance costs.
    → Together, they determine demand for upstream ethanol.



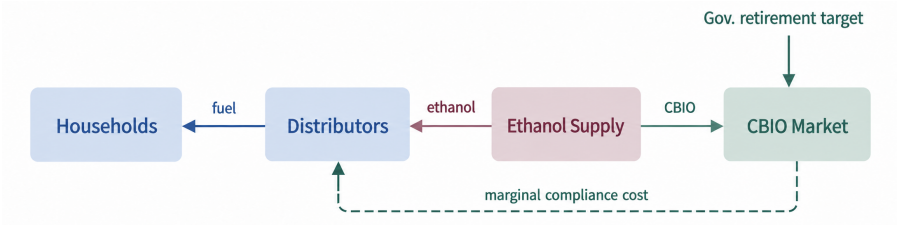
- **Downstream Fuel Market (D)**
- **Upstream Ethanol Market (U)**
  - Producers choose output based on ethanol and CBIO revenues.

    → Ethanol supply and CBIO issuance depend on the same production decision.



- **Downstream Fuel Market (D)**
- **Upstream Ethanol Market (U)**
- **Carbon Market (C)**
  - CBIO holders decide whether to purchase, retire, or bank CBIOs.

    → The CBIO price reflects current credit inventories and future compliance targets.



Household Fuel Demand

- Product (j): distributor (i) $\times$ fuel (f); market: state (s) $\times$ month (t).
- Downstream fuel markets clear in all states.

$$U_{hjst} = \underbrace{\delta_{jst}}_{\text{mean utility}} + \underbrace{(\alpha + \gamma \widetilde{Y}_{st}) p^D_{jst}}_{\text{income-proxy heterogeneity}} + \underbrace{\rho\, \zeta_{h,f(j),st} + (1-\rho)\varepsilon_{hjst}}_{\text{nested-logit shocks}}$$

  - δ_{jst}: Demand Shifters; Brand/seasonality FEs; unobserved quality.
  - $\widetilde{Y}_{st}$: standardized log retail sales per capita.
  - Market size: fleet $\times$ fuel use per km $\times$ monthly mileage.

Nested-logit shares δ specification

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- Market size: fleet $\times$ fuel use per km $\times$ monthly mileage.

Household fuel demand

$$q^D_{jst} = \text{MarketSize}_{st} \times s_{jst}(P^D_{st})$$

s_{jst} is the nested-logit choice probability for product j in state s.

Nested-logit shares δ specification

Household Fuel Demand: Estimation and Results

$$\xi_{jst} \equiv \tilde{U}_{jst} - \left(\alpha + \gamma \widetilde{Y}_{st}\right) p^D_{jst} - X^{D\prime}_{st} \beta_{f(j)} - \Lambda_{jst}$$

- **Endogeneity:** Demand shocks affect willingness to pay and prices.
- **Estimation:** Two-step IV-GMM.
- **Instruments:**
  - Oil and sugar prices $\times$ distributor group $\times$ fuel.
  - Oil and sugar prices $\times$ **Pre-sample firm-level supply-route distances.** Details
  - Oil and sugar prices $\times$ income proxy.
- **First-stage** *F*: price 107.2; price $\times$ income proxy 56.6; Month-clustered.

Household Fuel Demand: Estimation and Results

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- **First-stage** F**:** price 107.2; price $\times$ income proxy 56.6; Month-clustered.

Nested-logit estimates

Parameter	Estimate
Mean price effect, α	-0.192^{***}
Price $\times$ income proxy, γ	-0.045^{**}
Within-fuel correlation, ρ	0.850^{***}
Aggregate fuel elasticity	-0.54

$^{**}p < 0.05$, $^{***}p < 0.01$

Own-price elasticity distribution

Fuel distributor pricing Nash-Bertrand

- Given upstream fuel prices ($P^{G,u}$, $P^{E,u}$), the next-year CBIO target $\Omega_{y(t)+1}$, and CBIO price P_t^C,
- Distributor i in state s chooses downstream retail prices $p_{ist}^d = (p_{ist}^{G,d}, p_{ist}^{E,d})$.

$$\pi_{ist}^{fuel}\left(p_{ist}^d; p_{-i,st}^d, P^{G,u}, P_t^{E,u}, \Omega_y, P_t^C\right) = \underbrace{\left[p_{ist}^{G,d} - \left(0.73P_t^{G,u} + 0.27P_t^{E,u}\right)\right] q_{ist}^{G,d}(p_{st}^d)}_{\text{gasoline margin}}$$
$$+ \underbrace{\left(p_{ist}^{E,d} - P_t^{E,u}\right) q_{ist}^{E,d}(p_{st}^d)}_{\text{ethanol margin}} - \underbrace{C_{ist}^{dist}\left(\mathbf{q}_{ist}^d(p_{st}^d)\right)}_{\text{distribution cost}} - \underbrace{C_{it}^{compl}\left(q_{ist}^{G,d}(p_{st}^d); \Omega_y, P_t^C\right)}_{\text{RenovaBio compliance cost}}.$$

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Implied Upstream Ethanol Demand

$$Q_t^{E,u,D} = \sum_s \left[\sum_i q_{ist}^{E,d}(p_{st}^{d,*}) + 0.27 \sum_i q_{ist}^{G,d}(p_{st}^{d,*})\right]$$

Pricing FOC CBIO obligation

Recovered Retail Markups and Fuel Responses

- **Bertrand markup recovery**:

$$\underbrace{\mathbf{p}_t - \mathbf{mc}_t}_{\text{Retail markup}} = -\boldsymbol{\Delta}_t(\mathbf{p}_t)^{-1}\mathbf{s}_t(\mathbf{p}_t)$$

- Recovered markups are close to ANP's 17% accounting estimate (2024, including operating costs).

Recovered markups (2024)

Distributor	Ethanol	Gasoline mix
Vibra	14.98%	14.22%
Ipiranga	13.47%	12.85%
Raízen S.A.	14.12%	13.89%

Recovered Retail Markups and Fuel Responses

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- Recovered markups are close to ANP's 17% accounting estimate (2024, including operating costs).
- A 1% wholesale ethanol price cut also **increases gasoline-mix consumption by 0.032%**.

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Distributor	Ethanol	Gasoline mix
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Raízen S.A.	14.12%	13.89%

Elasticities with Respect to Wholesale Ethanol Price

Response	Ethanol	Gasoline mix
Retail price	+0.632	+0.117
Retail consumption	−0.402	−0.032

Ethanol Production

- Producer in each state (s) chooses monthly ethanol output $q_{st}^{E,U}$.
- Producers are price takers in the national ethanol and CBIO markets.

$$\pi_{st}^{E,U} = \underbrace{\left(P_t^{E,U} + \gamma_s P_t^{C}\right) q_{st}^{E,U}}_{\text{ethanol + CBIO revenue}} - \underbrace{\exp\left[-\left(X_{st}^{E,U\prime}\delta + \varepsilon_{st}^{E,U}\right)/\eta_s\right]\left(q_{st}^{E,U}\right)^{1+1/\eta_s} \Big/ \left(1+1/\eta_s\right)}_{\text{production cost}}$$

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- Supply elasticity varies with pre-policy corn ethanol exposure ($PreCorn_s$):

$$\eta_s = \eta + \eta^{corn} PreCorn_s$$

- $X_{st}^{E,U}$: sugar prices (ethanol's opportunity cost), corn prices, and FEs.

Seasonality Producer FOC

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- $X_{st}^{E,U}$: sugar prices (ethanol's opportunity cost), corn prices, and FEs.

Implied CBIO issuance

$$\sum_s \gamma_s q_{st}^{E,U}(P_t^{E,U}, P_t^C)$$

γ_s is a fixed, government-determined policy parameter.

Seasonality Producer FOC

Ethanol & Carbon Credit Supply Estimation

$$\log(1+q_{st}^{E,U}) = \eta \log P_{st}^{E,\text{eff}} + \eta^{corn}\left(\log P_{st}^{E,\text{eff}} \times PreCorn_s\right) + X_{st}^{E,U\prime}\delta + \varepsilon_{st}^{E,U}$$

$$P_{st}^{E,\text{eff}} \equiv P_t^{E,U} + \gamma_s P_t^{C}$$

- **Endogeneity:** Supply shocks affect ethanol and CBIO prices.
- **Estimation:** Linear IV/2SLS.
- **Instruments:** Oil-price level and 12-month shock, directly and $\times$ corn exposure.
  - KP rk Wald F = 8.00; rk LM = 8.45 (two-way clustered).

Estimation details

Ethanol & Carbon Credit Supply Estimation

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  - KP rk Wald $F = 8.00$; rk LM = 8.45 (two-way clustered).

Supply estimates

Parameter	Estimate
η	2.8779**
η^{corn}	11.5192***

***$p < 0.01$, **$p < 0.05$

Implied supply elasticities

Group	Elasticity
National average	3.09
Corn-exposed	3.58
No corn exposure	2.88

Estimation details

Carbon Credit Demand

- Given the CBIO price P_t^C, target path Ω, and market state (B_{t-1}^C, X_t^C).
- A representative holder chooses weekly net credit demand q_t^C.

$$V^C(B_{t-1}^C, P_t^C, X_t^C; \Omega) = \min_{q_t^C \geq 0} \left\{ P_t^C q_t^C + \Phi_t(B_t^C, q_t^C, X_t^C) + \beta \mathbb{E}_{P_{t+1}^C \sim f_P(\cdot | P_t^C, X_t^C)} \left[V^C(B_t^C, P_{t+1}^C, X_{t+1}^C; \Omega) \right] \right\}$$

$$B_t^C = B_{t-1}^C + q_t^C - \mathbf{1}\{t = \text{compliance}\}\Omega_{y(t)}$$

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$$B_t^C = B_{t-1}^C + q_t^C - \mathbf{1}\{t = \text{compliance}\}\Omega_{y(t)}$$

$$\Phi_t(B_t^C, q_t^C, X_t^C) = \underbrace{-\left(\phi_0 + X_t^{C\prime}\phi_X\right) B_t^C - \frac{\kappa_B}{2}\left(B_t^C\right)^2}_{\text{banking value}} + \underbrace{\frac{\kappa_q}{2}\left(q_t^C\right)^2}_{\text{adjustment cost}}$$

- X_t^C: Seasonality

CBIO Market Clearing

$$q_t^{C,*}(P_t^{C,*}; \Omega) = \underbrace{\sum_s \gamma_s q_{st}^{E,U,*}(P_t^{E,U,*}, P_t^{C,*})}_{\text{Ethanol CBIO}} + \underbrace{I_t^{C,\text{other}}}_{\text{Non-ethanol}}$$

CBIO Demand: Euler Equation Estimates

$$P_w^C - \beta_w P_{w+1}^C = \phi_0 + \kappa_B B_w^C + \kappa_q \left(\beta_w \Delta B_{w+1}^C - \Delta B_w^C\right) + X_w^{C\prime} \phi_X + \varepsilon_{w+1}^C$$

- **Endogeneity:** Shared innovations between ΔB_{w+1}^C and P_{w+1}^C bias OLS downward.
- **Estimation:** Weekly IV/2SLS.
- **Instrument:** Current bank change, ΔB_w^C; first-stage $F = 111.0$.

Estimation details

CBIO Demand: Euler Equation Estimates

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CBIO demand estimates

	OLS	IV
κ_B	0.056	0.097*
κ_q	−0.340*	0.782***
Observations	327	

*$p < 0.10$, ***$p < 0.01$; Newey–West (20 lags)

Estimation details

Solving the Dynamic Equilibrium

1. **Stable-Ω fixed point: three-level nested root-finding**
   1. *CBIO issuance:* $F^C(P_T^C) = \sum_{s,t} \gamma_{st} q_{st}^{E,S}(P_T^E(P_T^C), P_T^C) - \Omega_T \approx 0.$

Solving the Dynamic Equilibrium

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Solving the Dynamic Equilibrium

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3 *Retail pricing:* $\mathbf{F}^B(\mathbf{p}_T; P_T^E, P_T^C) = \mathbf{s}_T(\mathbf{p}_T) + \acute{}_T(\mathbf{p}_T)[\mathbf{p}_T - \mathbf{mc}_T(P_T^E, P_T^C)] \approx \mathbf{0}.$

Solving the Dynamic Equilibrium

1. Stable-Ω fixed point: three-level nested root-finding

1. *CBIO issuance:* $F^C(P_T^C) = \sum_{s,t} \gamma_{st} q_{st}^{E,S}(P_T^E(P_T^C), P_T^C) - \Omega_T \approx 0.$
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- *Stationary bank:* Recover B_T^C from the stationary Euler condition.

2. Transition: joint dynamic equilibrium

1. *CBIO path:* Guess $\{P_y^C\}$.
2. *Fuel-market roots:* $F_y^E(P_y^E; P_y^C) \approx 0$, $\mathbf{F}_y^B(\mathbf{p}_y; P_y^E, P_y^C) \approx \mathbf{0}$. Recover I_y^C.
3. *Forward banking:* $B_{y+1}^C(\{P_\tau^C\}_{\tau=0}^y) = B_y^C + I_y^C(P_y^C) - \Omega_y$, from observed B_0^C.
4. *Joint path root:* $\mathbf{F}^{C,\mathrm{dyn}}(\{P_y^C\}; B_0^C, P_T^C) \approx \mathbf{0}$.
   - Enforce Euler, banking, deadlines, and terminal continuation.

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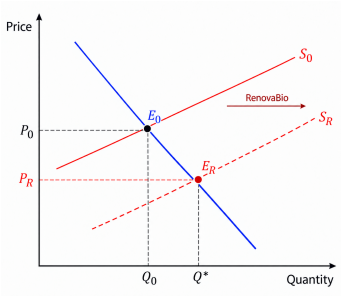
4. Model and Estimation

5. Counterfactuals

5.1 RenovaBio Removal
5.2 Counterfactual 2: Higher Ethanol Blend Mandate in Gasoline Mix
5.3 Reduced-Form Ethanol-Price Counterfactual

Counterfactual 1: RenovaBio Removal

1. **Remove the carbon market:**
   - Remove CBIO revenue for ethanol producers.
   - Remove distributors' CBIO compliance demand.
2. **Re-solve linked fuel markets:**
   - Re-solve the wholesale ethanol price (E_0).
   - Re-solve distributor pump prices.
   - Re-solve upstream and retail fuel quantities.
3. Compare surplus and welfare.



Wholesale ethanol market without RenovaBio.

Counterfactual 1: Producer Income

Supply is much more elastic than downstream demand ($\epsilon_S = 3.09 \gg |\epsilon_D| = 0.54$): Lower equilibrium ethanol prices offset 89% of producers' credit revenue.

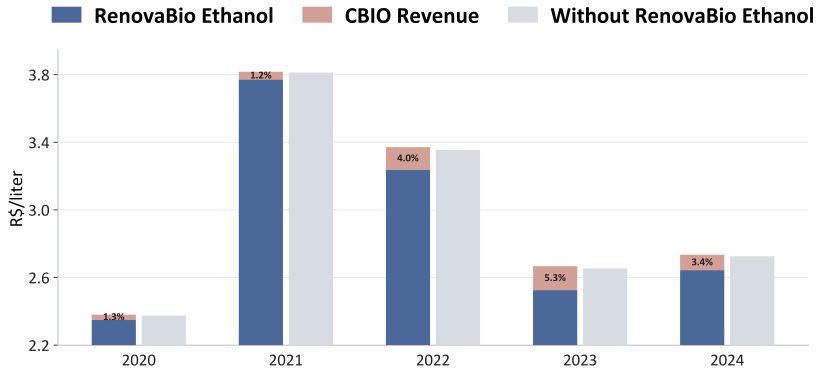


Figure 12: Upstream ethanol prices and CBIO income.

Counterfactual 1: Retail Fuel Prices

Ethanol consumption
+1.7 billion L (+2.3%)

Gasoline-mix consumption
+8.1 million L (+0.004%)

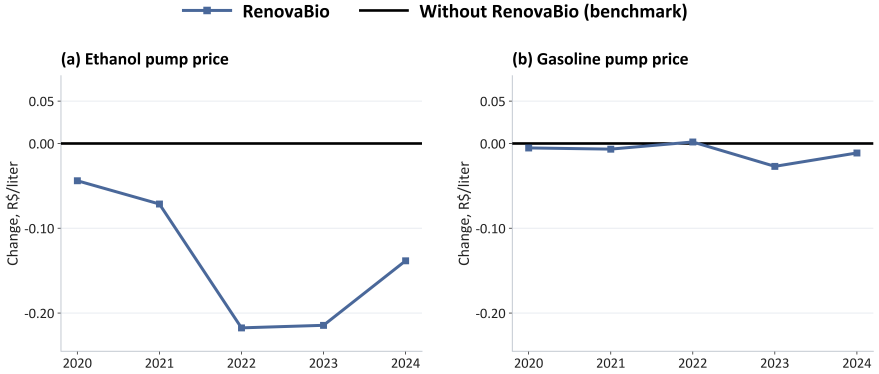
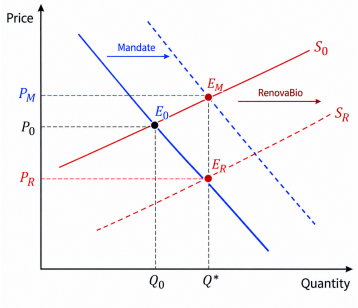


Figure 13: Changes in retail fuel prices.

Gasoline displacement details

Counterfactual 2: Higher Ethanol Blend Mandate

- Use RenovaBio removal counterfacutle (E_0) to assess a higher blend mandate:
  - RenovaBio shifts supply (E_R); mandates shift wholesale demand (E_M).
- **Calibrate and solve:**
  1. Interpolate a ∼1 pp mandate increase to match RenovaBio's ethanol output.
  2. Re-solve the fuel-market model.
- **Trade-off:** Mandate cuts emissions but lowers blend energy per liter.



Wholesale ethanol market under the higher mandate.

Counterfactual 2: Retail Fuel Prices

Ethanol consumption
−0.2 billion L (−0.27%)

Gasoline-mix consumption
+0.08 billion L (+0.05%)

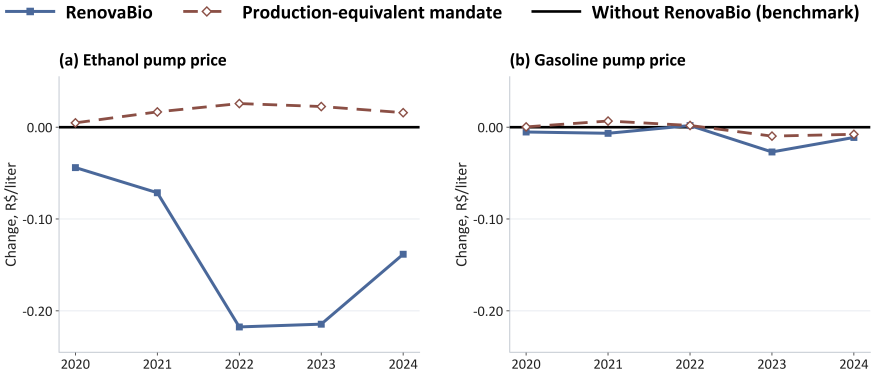


Figure 13: Changes in retail fuel prices.

Gasoline displacement details

Welfare Comparison: CF1 and CF2

Cheaper ethanol raises consumer welfare, but without reducing gasoline use, it increases ethanol consumption and total emissions.

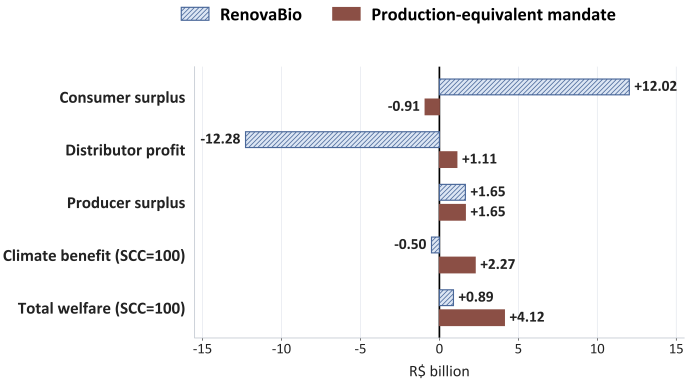


Figure 14: Welfare effects of RenovaBio.

Counterfactual 3: Why Joint Equilibrium?

- **Motivation:** Is joint supply-chain market clearing really necessary?

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Cumulative effect (2020–2024)	Export hub	Joint equilibrium
Production change	+6.25	+1.00
Emissions	−0.291	+0.122
Consumer surplus	+2.66	+6.42
Producer surplus	+5.86	+0.96
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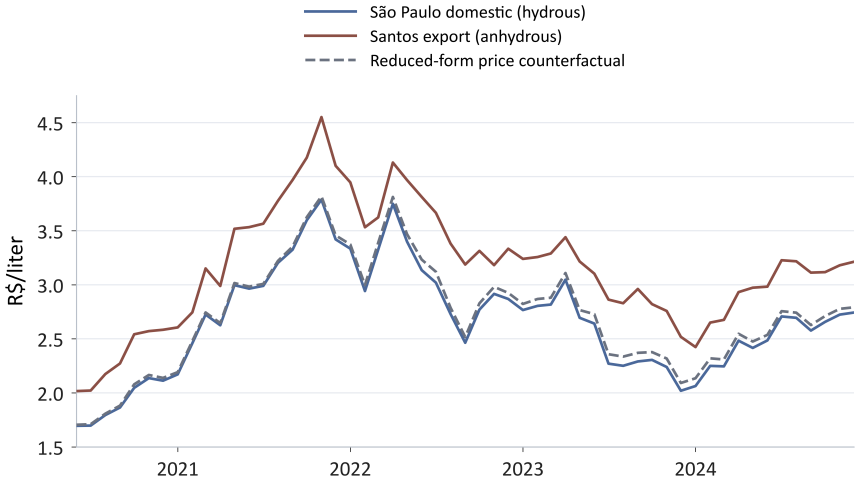
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- **Model implication:** Ignoring downstream equilibrium effects of ethanol prices significantly changes domestic outcomes.

Three Ethanol Prices



- **RenovaBio framework:**
  - A sectoral carbon market to self-finance its decarbonization.
- **Policy implication:**
  - Evaluation must account for equilibrium responses across the **supply chain**
  - Cleaner-supply incentives alone may not suffice without downstream demand policy.
- **Empirical finding:**
  - **Accounting:** 1 CBIO represents 1 tonne of CO_2 avoided.
  - **Outcome:** 1 CBIO represents almost no net CO_2 avoided.

- **Research interests:** Empirical IO, Environmental and Energy Economics, Econometrics.

Ongoing Projects

- *Euler Equations for Dynamic Games*
  With Victor Aguirregabiria
- *Who Benefits from Green Subsidies? Labor Standards and the Distribution of Gains*
  With Zahra Sedaghat
- *One Carbon market or Many? Optimal Integration of Sectoral Carbon Markets*

Prior Work

- *Empirical Bayes with Side Information: Incorporating Geographic Relevance into Neighborhood Impact Estimation*
  Sole-authored; revise and resubmit, Journal of Applied Econometrics
- *The Effects of Order Flow Imbalance on Stock Prices in Tehran Stock Exchange*
  Coauthored with Seyed Mahdi Barakchian; Financial Management Perspective, 2022

Thank you

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Supply Chain Responses to Lower Ethanol Prices

- **Experiment 1**
  - 1% retail ethanol price cut; retail gasoline price held fixed.

Monthly downstream fuel responses

Case	Ethanol	Gasoline	CO_2e
Exp 1	+9.51	−2.27	+0.13

Fuel quantities: million L/month; emissions: kt CO_2e/month.

Supply Chain Responses to Lower Ethanol Prices

- **Experiment 1**
  - 1% retail ethanol price cut; retail gasoline price held fixed.
- **Experiment 2**
  - 1% wholesale ethanol price cut; wholesale gasoline price held fixed.

Monthly downstream fuel responses

Case	Ethanol	Gasoline	CO_2e
Exp 1	+9.51	−2.27	+0.13
Exp 2	+5.54	+1.05	**+5.60**

Fuel quantities: million L/month; emissions: kt CO_2e/month.

- **Gasoline response reversal:**
  - Cross-pricing under imperfect competition.
  - Lower gasoline blending costs from mandated ethanol content.

Appendix

Additional evidence and robustness

Appendix: RCNL Market Shares

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Conditional utility and fuel-nest inclusive value

$$V_{hjst} = \delta_{jst} + (\alpha + \sigma_p \nu_h) p^D_{jst}, \qquad A_{hfst} = \sum_{k \in \mathcal{J}_{fst}} \exp\left(\frac{V_{hkst}}{1-\rho}\right)$$

Individual product share

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

Aggregate market share and demand

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

- $\mathcal{J}_{fst}$: products in fuel nest f.
- ρ: within-fuel correlation.
- $F(\nu_h)$: distribution of price heterogeneity.
- M_{st}: market size; denominator includes the outside good.

Appendix: Mean Utility Specification

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$$\delta_{jst} = X_{st}^{D\prime}\beta_{f(j)} + \Lambda_{jst} + \xi_{jst}$$

X_{st}^{D}: vector of observed demand shifters; Λ_{jst}: sum of the fixed effects listed below.

Observed demand shifters

- Electricity consumption per capita.
- Lagged flex-fleet share

$\beta_{f(j)}$: fuel-specific coefficients.

Fixed effects and unobservables

- Distributor-brand fixed effects.
- Fuel-specific calendar-month fixed effects.
- ξ_{jst}: unobserved product quality.

Appendix: Distributor Pricing FOC

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For $f \in \{G, E\}$:

$$
\begin{aligned}
0 = q_{ist}^{f,D} & \\
& + \left[p_{ist}^{G,D} - \left((1-e) P_t^{G,U} + e P_t^{E,U} \right) - \frac{\partial C_{ist}^{D}}{\partial q_{ist}^{G,D}} - P_t^{C} \frac{\partial O_{i,y+1}^{R}}{\partial q_{ist}^{G,D}} \right] \frac{\partial q_{ist}^{G,D}}{\partial p_{ist}^{f,D}} \\
& + \left[p_{ist}^{E,D} - P_t^{E,U} - \frac{\partial C_{ist}^{D}}{\partial q_{ist}^{E,D}} \right] \frac{\partial q_{ist}^{E,D}}{\partial p_{ist}^{f,D}}.
\end{aligned}
$$

$P_t^{C} \frac{\partial O_{i,y+1}^{R}}{\partial q_{ist}^{G,D}}$ is the marginal CBIO compliance cost of gasoline sales.

Appendix: Marginal CBIO Obligation

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$$O^R_{i,y+1} = \Omega_{y+1} \frac{a^G \sum_{\ell \in y} \sum_s q^{G,D}_{is\ell}}{\widehat{F}_y}$$

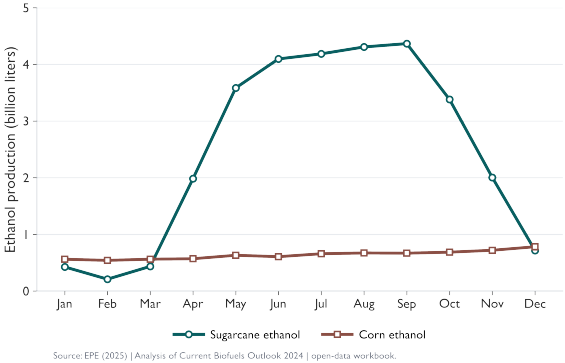
$$\frac{\partial O^R_{i,y+1}}{\partial q^{G,D}_{ist}} = \frac{\Omega_{y+1} a^G}{\widehat{F}_y} \quad \Longrightarrow \quad \underbrace{P^C_t \frac{\Omega_{y+1} a^G}{\widehat{F}_y}}_{\text{marginal compliance cost}}$$

- $O^R_{i,y+1}$: distributor i's next-year CBIO obligation.
- Ω_{y+1}: national CBIO retirement target.
- a^G: emissions weight per liter of gasoline.
- $\widehat{F}_y$: forecast national emissions-weighted fossil sales.
- P^C_t: current CBIO price.

Appendix: Ethanol Production Seasonality

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- Supply response to RenovaBio depends on when producers can expand output.



Sugarcane is seasonal; corn supports year-round production.

Appendix: Ethanol Producer FOC

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- **Effective producer return:**

$$P_{st}^{E,\text{eff}} \equiv P_t^{E,U} + \gamma_s P_t^C$$

- **FOC:** marginal production cost equals effective return.

$$\frac{\partial C_{st}^{E,U}}{\partial q_{st}^{E,U}} = P_{st}^{E,\text{eff}}$$

- **Isoelastic cost implies:**

$$q_{st}^{E,U} = \exp\left(X_{st}^{E,U\prime}\delta + \varepsilon_{st}^{E,U}\right)\left(P_{st}^{E,\text{eff}}\right)^{\eta_s}, \qquad \eta_s = \eta + \eta^{corn} PreCorn_s$$

Log supply equation

$$\boxed{\log q_{st}^{E,U} = \eta_s \log P_{st}^{E,\text{eff}} + X_{st}^{E,U\prime}\delta + \varepsilon_{st}^{E,U}}$$

Estimation uses $\log(1 + q_{st}^{E,U})$ to retain zero-production state-months.

Appendix: CBIO Euler Condition

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- For an interior acquisition and nonbinding banking constraint:

Intertemporal optimality

$$P_t^C + \frac{\partial \Phi_t(B_t^C, \chi_t)}{\partial B_t^C} = \beta E_t[P_{t+1}^C]$$

Marginal inventory value

$$\frac{\partial \Phi_t}{\partial B_t^C} = -\left(\phi_0 + X_t^{C\prime}\phi_X\right) - \phi_B B_t^C$$

Euler equation

$$\boxed{P_t^C - \beta E_t[P_{t+1}^C] = \phi_0 + \phi_B B_t^C + X_t^{C\prime}\phi_X}$$

- P_t^C: current CBIO price; B_t^C: bank after current acquisition and retirement.
- X_t^C: portfolio-state controls; β: monthly discount factor.

Appendix: Household Fuel Demand Estimation

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Two-way clustered diagnostics

Statistic	Value
Wald F	2.71
MOP effective F	27.4
MOP CV_{10}	17.6
MOP CV_5	30.0

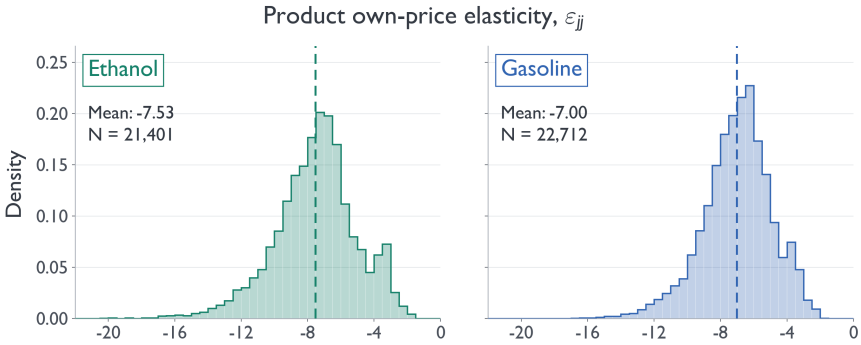
State $\times$ month-year clustered covariance

- The two-way clustered Wald F is low, but it is a joint-significance statistic rather than a weak-IV-specific diagnostic.
- The MOP effective F uses the same two-way covariance and is designed for weak-IV assessment.
  - $27.4 > 17.6$: passes the 10% relative-bias criterion.

Appendix: Own-Price Elasticity Distribution

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- Comparable median own-price elasticities:
  - Lopez (2025, Argentina: -3.5).
  - Chaves et al. (2025, Quebec: -9.1).



Appendix: Supply-Route Distance Instrument

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- Construct each distributor's average sourcing distance by fuel and destination state, using 2007–2009 shipment shares and distances between state capitals.
- Interact this fixed distance with monthly oil prices: longer supply routes imply greater exposure to transportation-cost changes.

$$Z_{bfst} \propto \text{OilPrice}_t \times \underbrace{\sum_o w_{bfso}^{2007\text{–}2009} \, d_{os}}_{\text{historical shipment-weighted distance}}$$

Appendix: Ethanol Supply Estimation

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Second-stage specification

	Included
Sugar-price control	Yes
Corn-price control	Yes
$PreCorn_s \times$ linear trend	Yes
State fixed effects	Yes
Month fixed effects	Yes
Year fixed effects	Yes
Observations	1,114
Adjusted R^2	0.6845

Equation-specific first stages

Endogenous term	SW F
$\log P_{st}^{E,\text{eff}}$	17.09
$\log P_{st}^{E,\text{eff}} \times PreCorn_s$	30.30

Month-year-clustered SW statistics

- $PreCorn_s$ is pre-policy state exposure to corn ethanol production.
- National oil-price time variation and mainly cross-sectional $PreCorn_s$ (nonzero in few states) destabilized separate first-stage Wald F inference. Hence, final diagnostics use Kleibergen–Paap with two-way state and month-year clustering.
- KP rk LM rejects underidentification at the 5% level.
- KP rk Wald $F = 8.00$ indicates moderate, borderline weak-IV strength.
- Robustness check using month-year-clustered SW first-stage statistics.

Appendix: CBIO Demand Estimation

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Specification

	Included
Calendar-month seasonality	Yes
Lagged early retirement	Yes
Non-obligated holder share	Yes
Observations	48

Estimation

- Linear IV/2SLS.
- Newey–West standard errors with 3 monthly lags.
- Discount factor: $\beta = (1.10)^{-1/12} \simeq 0.9921$.
- One instrument and one endogenous regressor: exactly identified.

Identification

- Sugar prices shift ethanol's opportunity cost, changing ethanol production, CBIO issuance, and the aggregate bank.
- Conditional on controls, sugar prices are assumed to affect the Euler condition only through CBIO availability.

Appendix: Market Clearing

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Fuel-market clearing

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

$$\sum_{s} q_{st}^{E,U} = \sum_{s} \left[\sum_{i} q_{ist}^{E,D} + e \sum_{i} q_{ist}^{G,D} \right] + D_{t}^{stor}$$

- $D_t^{stor} > 0$: storage; $D_t^{stor} < 0$: release; $\sum_{t \in \mathcal{T}_y} D_t^{stor} = 0$ annually.
- April baseline: inventories are low, roughly one month of consumption.
- Annual clearing pins down $P_y^{E,U}$; state-month supply functions generate monthly output.

CBIO-market clearing

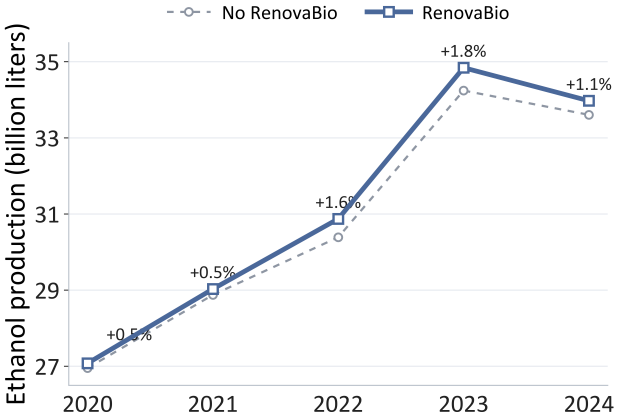
$$B_{t+1}^{C} = B_{t}^{C} + \sum_{s} \gamma_s q_{st}^{E,U} - R_t$$

- Monthly ethanol output generates monthly variation in CBIO supply.
- Banking smooths this variation across months and future retirement needs.
- In the stabilized compliance-year cycle, annual CBIO additions equal annual retirement.

→ Upstream ethanol, retail fuel, and CBIO prices adjust jointly to clear the fuel and credit markets.

RenovaBio Expands Ethanol Production

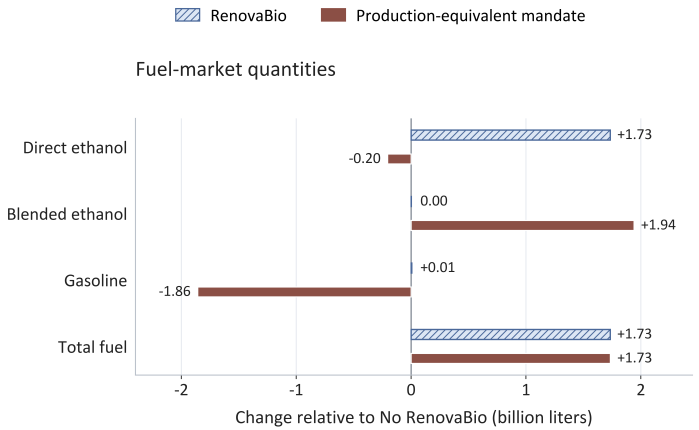
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Production rises by 0.5–1.8% annually under RenovaBio.

Appendix: Gasoline Displacement

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Only 5.2% of additional ethanol demand under RenovaBio displaces gasoline.