Commuting, Home Utilities, and Production: The Distributional Effects of Energy Price Shocks

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Introduction

- Energy price experiences sharp and persistent changes relative to other prices
  ▶ Energy vs. Non-Energy CPI ▶ Energy Corr

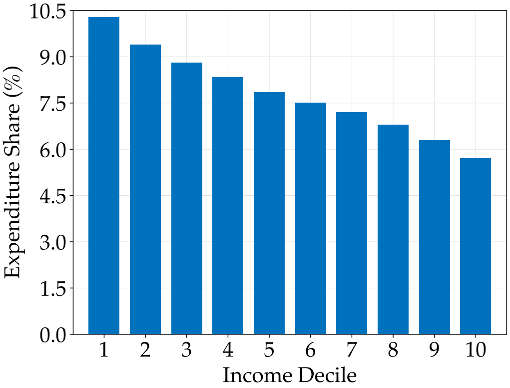
- Literature has studied aggregate effects of energy price shocks (e.g., Kim and Loungani, 1992; Hamilton, 2003; Kilian, 2009)

- **This paper:** Distributional consequences of energy price shocks

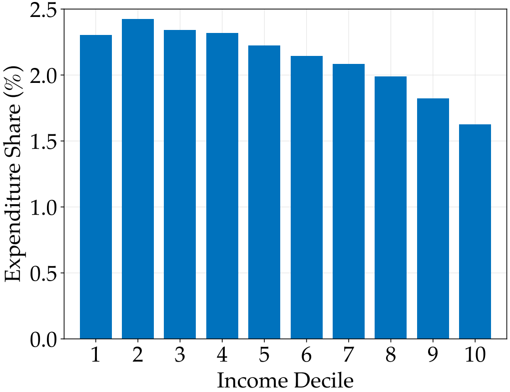
Facts

- **Fact 1:** Low-income households (HHs) spend larger budget share on (residential & commuting) energy than high-income HHs
- **Fact 2:** Demand for energy is inelastic (e.g., Havranek and Kokes, 2015; Labandeira, Labeaga, and Lopez-Otero, 2017)
  - Demand for commuting energy is more inelastic than demand for residential energy ▶ Evidence
- **Fact 3:** Production sectors use two-thirds of total energy ▶ Figure

Low-Income HHs Spend Larger Budget Share on (Residential & Commuting) Energy than High-Income HHs



Exp. Share on Residential Energy



Exp. Share on Commuting Energy

Source: CEX

▶ Calculation of E_T ▶ Electricity vs. Gasoline

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Research Question

- **Q:** How does an energy price shock affect the consumption and welfare of HHs in different income groups?
- **Why do we care?**
  - To design government transfer programs aimed at reducing negative impact of high energy prices
  - To design energy pricing policies (e.g., energy taxation/subsidies)

Approach

- Develop a dynamic heterogeneous-agent incomplete market model
- Calibrate the model to US data
- Use calibrated model for welfare and policy analysis

Key Model Features and Contribution

- Non-homothetic consumption preferences to capture variations in expenditure share on energy across income groups

- Extensive & intensive margin labor supply choices + Commuting costs (commuting is energy intensive and can influence labor supply)

- Energy as a factor of production for non-energy goods & services

- Exogenous energy price shock (typically energy price fluctuations are common worldwide and caused by factors external to the U.S. economy)

Key contribution: Derive distributional effects of energy price shocks in a unified framework of energy use in commuting, home utilities, and production

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Model

Economic Environment

- **Time:**
  - Discrete with an infinite horizon: $t = 1, 2, 3, \cdots, \infty$
- **Households:**
  - Continuum of HHs heterogeneous in productivity (z)
  - Derive utility from consumption (energy (E_R), non-energy (C)) + leisure
  - Employed HHs face commuting costs ($p_E E_T(zwh)$) ▶ Functional Form
- **Government:**
  - Collects taxes on assets and labor income
  - Finances transfers to ensure minimum consumption expenditure
- **Firms:**
  - Representative
  - *Factor inputs:* Labor (L), capital (K), and energy (E_F)
  - *Output:* Non-energy goods
- **Aggregate Shock:**
  - Exogenous energy price shock

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Household's Problem

$$V_t(a,z) = \max\{V_t^E(a,z), V_t^U(a,z)\}$$

- **when HH decides to work:**

$$V_t^E(a,z) = \max_{\{E_{Rt}, C_t, h_t, a'\}} \left\{ u_{xt}(E_{Rt}, C_t) - u_{ht}(h_t) + \beta \mathbb{E}_t \left[V(a', z') | z \right] \right\}$$

s.t.

$$p_{Et} \left(E_{Rt} + E_T(zw_t h_t) \right) + C_t + a' = zw_t h_t - \mathcal{T}\left(zw_t h_t \right) + [1 + (1 - \tau^a) r_t] a$$

$$a' \geq \underline{a}, \ \ \underline{a} \leq 0$$

$$E_{Rt} \geq 0, \ \ E_{Tt} \geq 0, \ \ C_t \geq 0, \ \ h_t \in [0,1]$$

▶ Functional Form

Household's Problem

- **when HH decides not to work:**

$$V_t^U(a,z) = \max_{\{E_{Rt}, C_t, a'\}} \left\{ u_{xt}(E_{Rt}, C_t) + \beta \mathbb{E}_t \left[V(a', z') | z \right] \right\}$$

s.t.

$$p_{Et} E_{Rt} + C_t + a' = [1 + (1 - \tau^a) r_t] a + T(a)$$

$$a' \geq \underline{a}, \ \underline{a} \leq 0$$

$$E_{Rt} \geq 0, \ C_t \geq 0$$

▶ Functional Form

Household's Period Utility Function

$$u(E_R, C, h) \equiv u(\boldsymbol{x}, h) = \frac{\boldsymbol{x}^{1-\gamma} - 1}{1-\gamma} - \varphi_1 \frac{h^{1+\frac{1}{\nu}}}{1+\frac{1}{\nu}} - \varphi_2 \cdot \mathbf{1}_{\{h>0\}}$$

where $\boldsymbol{x}$ is implicitly aggregated as

$$1 = \left[\Omega_{E_R}^{\frac{1}{\sigma}} \left(\frac{E_R}{\boldsymbol{x}^{\boldsymbol{\epsilon_{E_R}}}} \right)^{\frac{\sigma-1}{\sigma}} + \Omega_C^{\frac{1}{\sigma}} \left(\frac{C}{\boldsymbol{x}^{\boldsymbol{\epsilon_C}}} \right)^{\frac{\sigma-1}{\sigma}} \right]$$

where

- $\boldsymbol{\gamma}$: relative risk aversion
- $\boldsymbol{\nu}$: Frisch elasticity
- $\boldsymbol{\varphi_1}$: disutility of labor hours
- $\boldsymbol{\varphi_2}$: fixed disutility of work
- $\boldsymbol{\sigma}$: elasticity of substitution between E_R and C
- $\boldsymbol{\epsilon_j}$: non-homotheticity parameter of good $j = \{E_R, C\}$
- $\boldsymbol{\Omega_j}$: weight of good $j = \{E_R, C\}$ in consumption basket

▶ Exp. Share of Energy ▶ Shape

Firm's Problem

- Representative firm operates in a perfectly competitive market:

$$\max_{\{K_t, L_t, E_{Ft}\}} \Pi_t \equiv Y_t - (r_t + \delta)K_t - w_t L_t - p_{Et} E_{Ft}$$
$$\text{s.t. } Y_t = F\left(G\left(K_t, L_t\right), E_{Ft}\right)$$

- All energy imported & balanced trade
- Output = HHs' non-energy consumption + Export
- Constant returns-to-scale Leontief production technology: ▶ Emp. Evidence

$$Y_t = \min\left[K_t^{\alpha} L_t^{1-\alpha}, \kappa A_{Et} E_{Ft}\right]$$
$$\text{s.t. } \kappa A_{Et} E_{Ft} \leq K_t^{\alpha} L_t^{1-\alpha}$$

- Evolution of capital:

$$K_{t+1} = (1-\delta)K_t + I_t$$

Calibration

Summary of Calibration

- Model is calibrated to **quarterly** frequency
- Overall **twenty-five** parameters:
  - **three** related to technology: $\{\alpha, \kappa, \delta\}$
  - **five** related to labor productivity: $\{\rho_z, \sigma_z, z_{\max}, \pi_{\text{up}}, \pi_{\text{stay}}\}$
  - **ten** related to preference: $\{\beta, \gamma, \sigma, \epsilon_C, \epsilon_{E_R}, \Omega_{E_R}, \Omega_C, \nu, \varphi_1, \varphi_2\}$
  - **four** related to tax and transfers: $\{\tau^a, \tau^l, \lambda, \bar{e}\}$
  - **two** related to commuting costs: $\{\iota_0, \iota_1\}$
  - **one** related to borrowing: $\underline{a}$
- $\{\Omega_C, \epsilon_C\}$ normalized to 1
- $\{\sigma, \epsilon_{E_R}\}$ estimated using CEX data
- $\{\alpha, \delta, \rho_z, \sigma_z, \gamma, \nu, \tau^a, \tau^l\}$ assigned directly from literature
- $\{\kappa, z_{\max}, \pi_{\text{up}}, \pi_{\text{stay}}, \beta, \Omega_{E_R}, \varphi_1, \varphi_2, \lambda, \bar{e}, \iota_0, \iota_1, \underline{a}\}$ calibrated jointly in a steady state equilibrium to match equal number of moments from US Data

▶ Externally Set Params

Calibration of σ and ϵ_{E_R} Using CEX

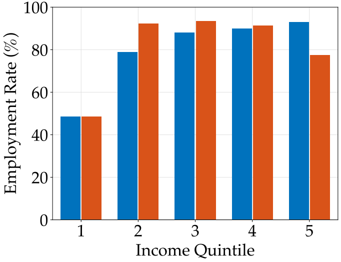
Model consumption allocation: $j_{it} = \Omega_j \left(\frac{p_{jt}}{Exp_{it}} \right)^{-\sigma} \boldsymbol{x}_{it}^{\epsilon_j(1-\sigma)}, \;\; j = \{E_R, C\}$

Parameter	Description	Value
$\boldsymbol{\sigma}$	Elasticity of substitution between E_R and C	0.248
$\boldsymbol{\epsilon_{E_R}}$	Non-homotheticity of E_R	0.346

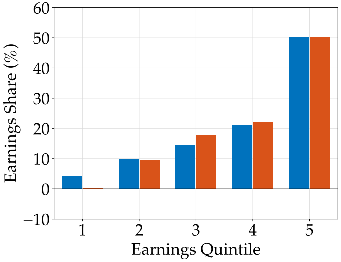
▶ Full-Table ▶ Exp. Elasticity ▶ Other Energy-Related Params ▶ Other Internally Calibrated Params

Model Validation

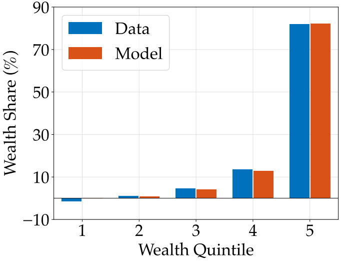
Cross-Sectional Distributions – Data vs. Model



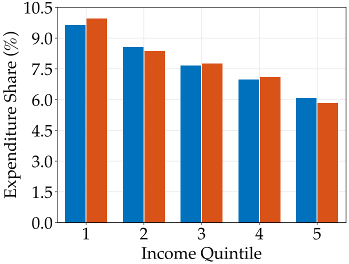
Employment Distribution



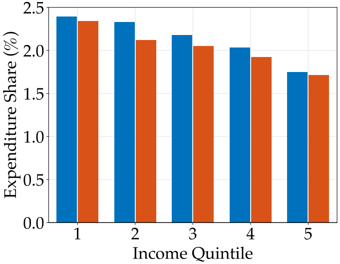
Earnings Distribution



Wealth Distribution



Residential Energy Expenditure Share Distribution

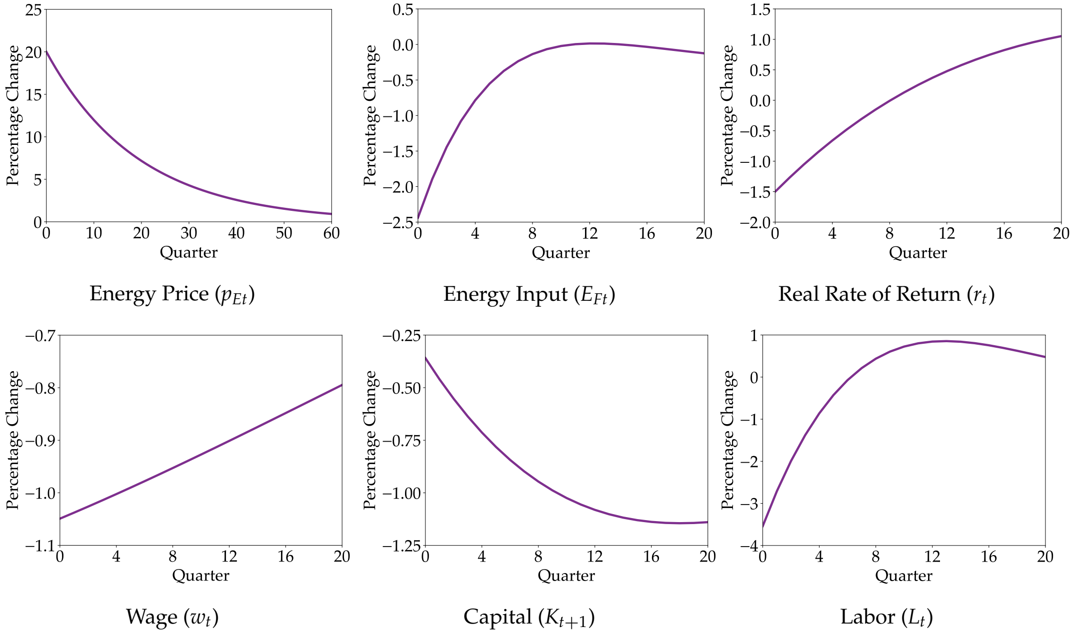


Commuting Energy Expenditure Share Distribution

Quantitative Analysis:

Distributional Effects of an Inflationary Energy Price Shock Similar to the One in 2021 ($\approx 20\% \uparrow$ of p_E)

Aggregate Responses to a 20% Inflationary p_E Shock



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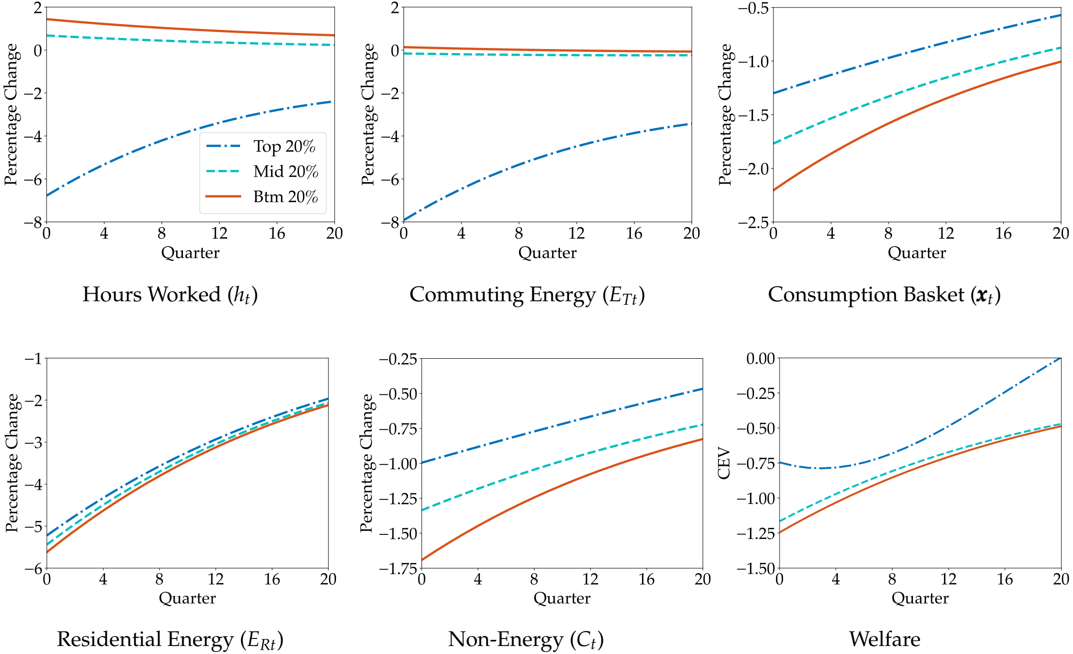
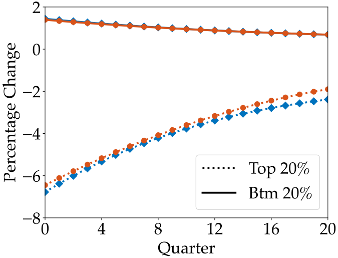


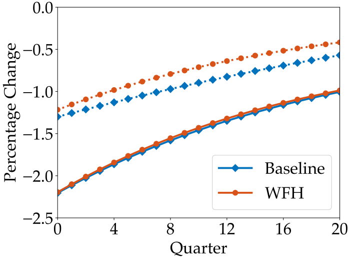
Policy Analysis:

(i) Work from Home (WFH) Opportunity
(ii) Targeted Lump-Sum Transfer

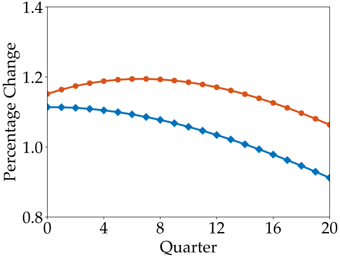
Influence of WFH Opportunity on the p_E Shock Effects



Hours Worked (h_t)

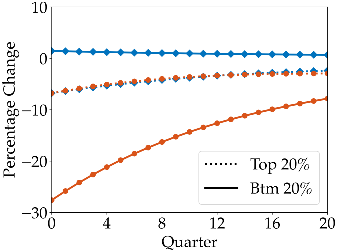


Consumption Basket ($\boldsymbol{x}_t$)



Consumption Gini

Influence of Targeted Transfer on the p_E Shock Effects



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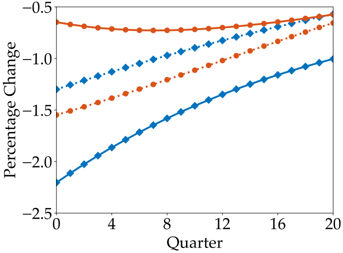

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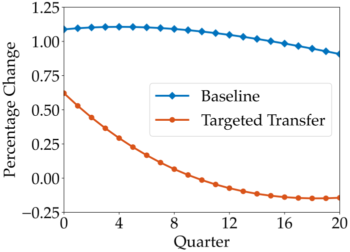

Consumption Gini

Concluding Remarks

- Develop and solve a heterogeneous agent incomplete market model with three different types of energy use
- Energy price shocks unevenly impact HHs across different income groups with low-income HHs being impacted the most
- WFH mainly benefits high-income households due to their disproportionate access to it thus worsening inequality
- A lump-sum transfer to low-income HHs, financed by higher earnings tax, mitigates shock's impact on consumption inequality

Thank You!

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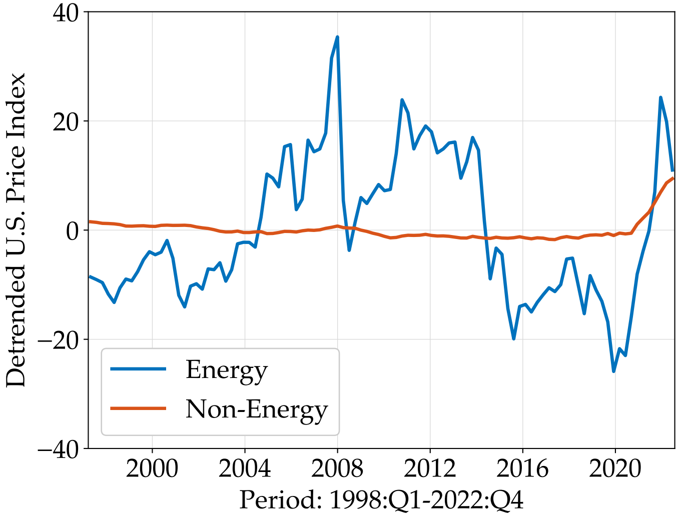
Appendix

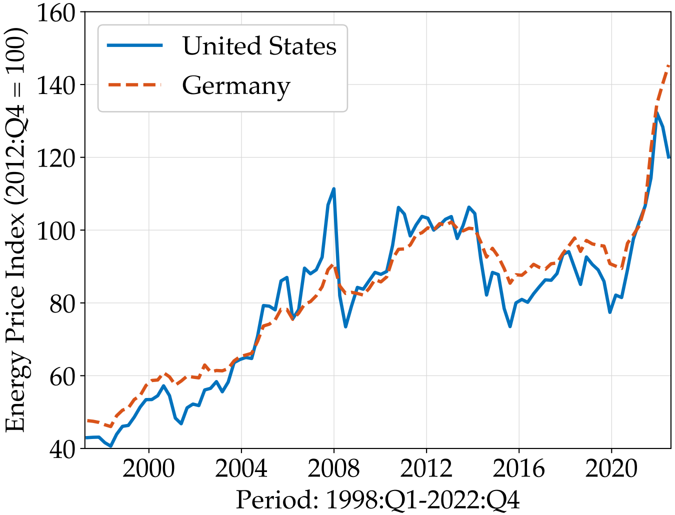
Energy vs. Non-Energy (Consumer) Price Index



Source: CPI

◀ Introduction

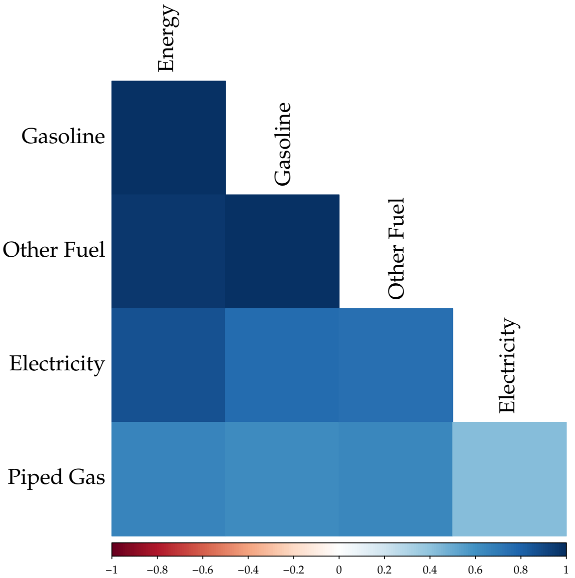
Energy Price Index: US vs. Germany



Source: CPI & Eurostat

◀ Introduction

Correlation Matrix of CPIs of Different Energy Goods



◀ Introduction

Expenditure on Energy to Commute to Work from CEX

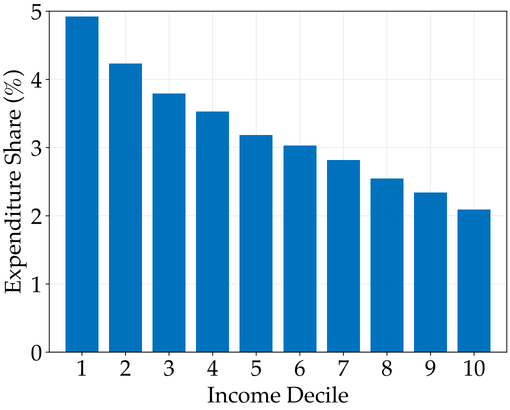
- **First step:** Exp. on gasoline for regular use = Total exp. on gasoline −
  Exp. on gasoline for trips & vacations

- **Second step:**

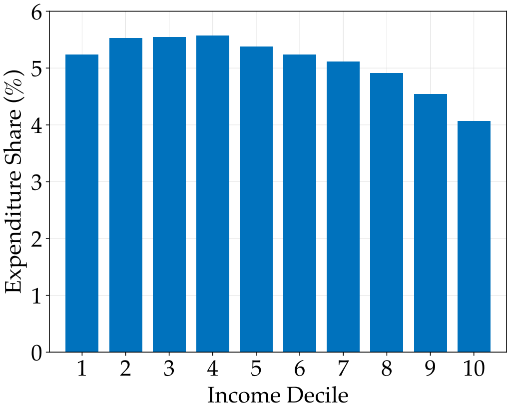
$$
\begin{aligned}
\log(\text{exp. on gasoline for regular use}) = \beta_0 &+ \beta_1 \log(\text{after-tax income}) \\
&+ \beta_2 \log(\text{total expenditure}) \\
&+ \beta_3 (\text{time}^2) \\
&+ \beta_4 (\text{unemployed} = 1, \text{otherwise } 0) \\
&+ \epsilon
\end{aligned}
$$

◀ Facts ◀ Calibration

Electricity and Gasoline Expenditure Shares by Income Decile



Electricity Expenditure Share Distribution



Gasoline Expenditure Share Distribution

Source: CEX

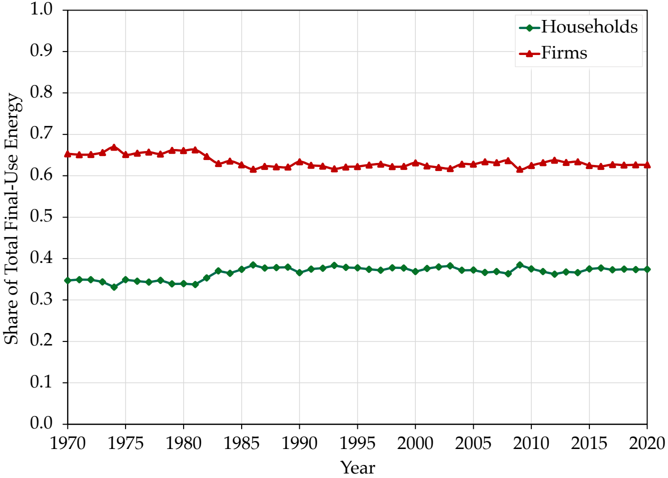
◀ Facts

2021 Energy Price Shock and Changes in Consumption across Income Groups

	Income Groups (Percentiles)		
	≤ 33	34-67	> 67
	Percentage Change: Q1 to Q4		
Quarterly Expenditure	−11.66	−13.59	−9.50
Energy	−6.22	−1.93	0.22
Commuting	**−3.29**	**4.58**	**2.69**
Residential	**−6.94**	**−3.78**	**−0.50**
Non-Energy	−12.22	−14.62	−10.18

◀ Facts

Historical Patterns of Energy Consumption



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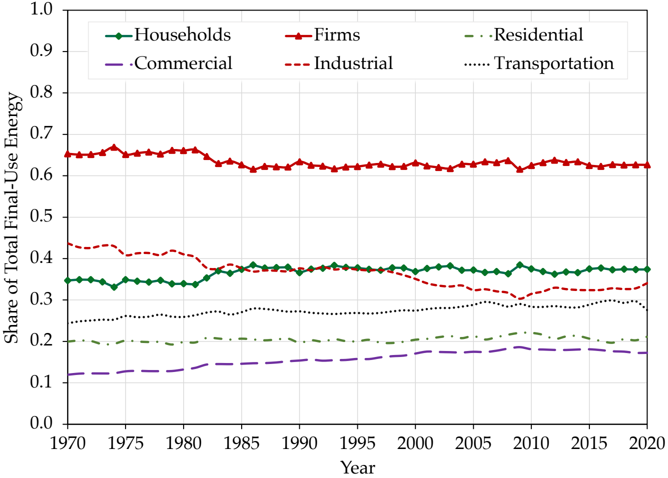
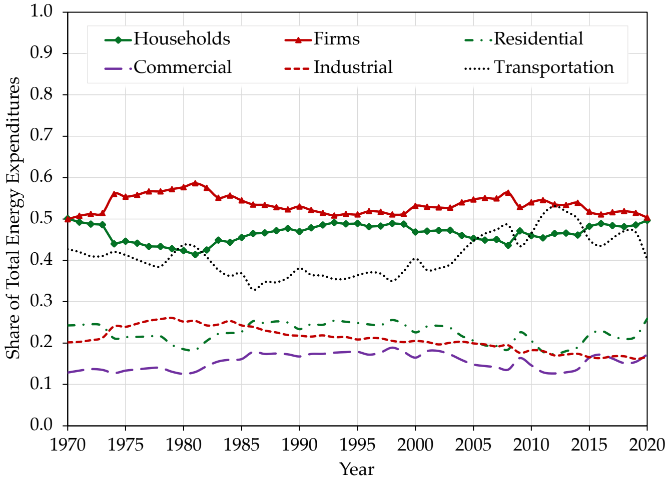


◀ Facts

Historical Patterns of Energy Expenditures



◀ Facts

Functional Form of Energy Use for Commuting, Labor Income Tax, and Means-Tested Transfers

- Energy use for commuting to work:

$$E_T(zwh) = \boldsymbol{\iota_0} \left[\log(1 + zwh)\right]^{\boldsymbol{\iota_1}}$$

- Labor income tax function:

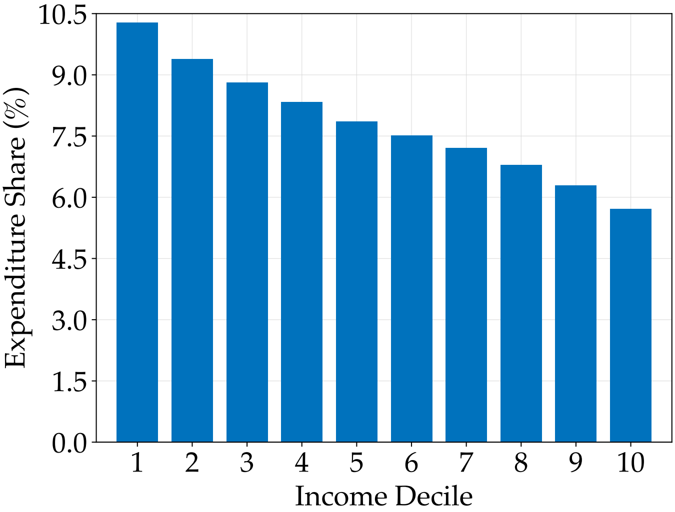
$$\mathcal{T}(y) = y - \lambda y^{1-\tau^l}$$

- Transfers:

$$T(a) = \max\left\{0, \bar{e} - [1 + (1 - \tau^a)r]a \cdot \mathbf{1}_{\{a>0\}}\right\}$$

◀ Model Blocks ◀ HH Problem ▶ Exp. Share Dist. of E_T ▶ Exp. Share Dist. of E_T by No. of Earners ◀ Calibration

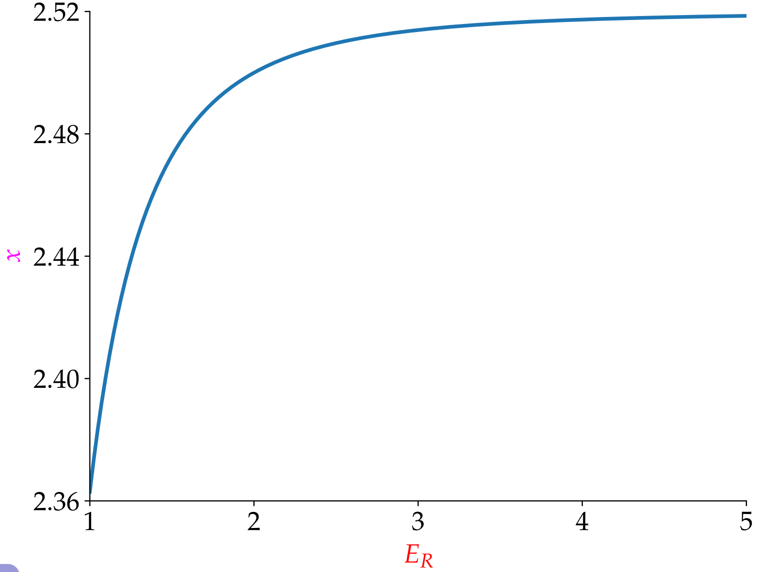
Distribution of HH Exp. Share on Residential Energy



Source: CEX

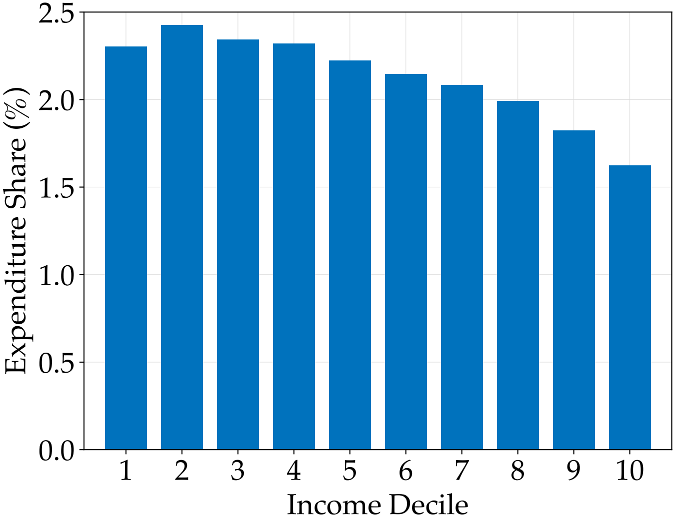
◀ Preferences

Non-Homothetic CES Aggregator



◀ Preferences

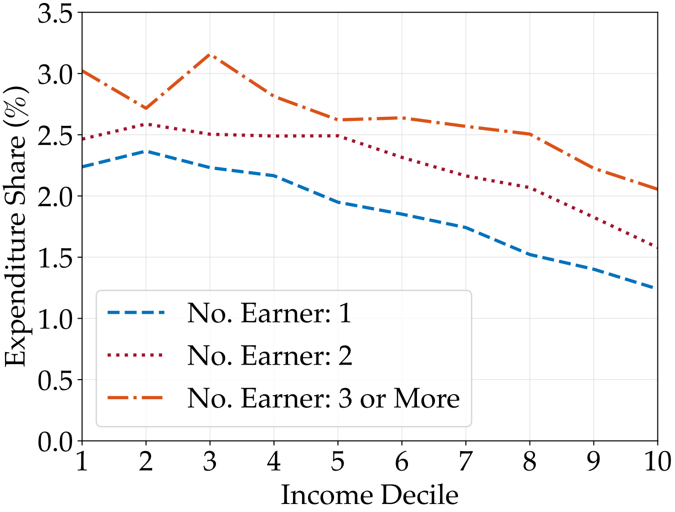
Distribution of HH Exp. Share on Commuting Energy



Source: CEX

◀ Functional Form ◀ Calibration

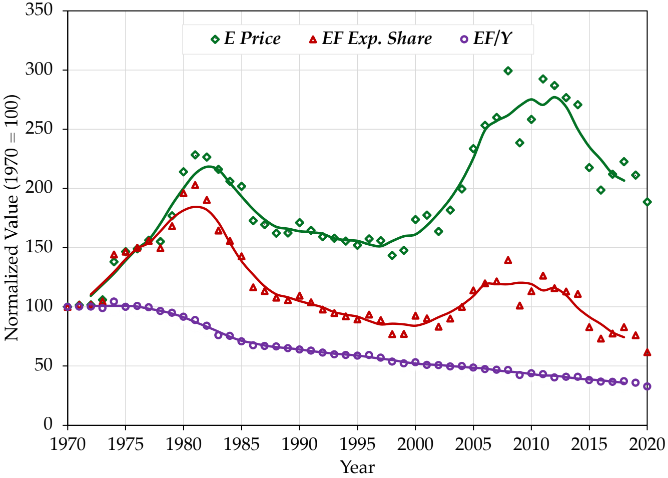
Distribution of HH Exp. Share on Commuting Energy by Number of Earners



Source: CEX

◀ Functional Form ◀ Calibration

Energy Intensity of Output



- Energy intensity of output does not react to short-run energy price fluctuations

◀ Firm Problem

Rental Rate and Wage

$$R_t = \alpha \left(1 - \frac{p_{Et}}{\kappa A_{Et}}\right) \left(\frac{K_t}{L_t}\right)^{\alpha - 1}$$

$$w_t = (1 - \alpha) \left(1 - \frac{p_{Et}}{\kappa A_{Et}}\right) \left(\frac{K_t}{L_t}\right)^{\alpha}$$

◀ Firm's Problem

Demand Estimation Using CEX

$$\ln \mathbb{X}_{iEt} = (1-\sigma)\ln p_{iEt} + \sigma(1-\epsilon_{E_R})\ln Exp_{it} - \epsilon_{E_R}(1-\sigma)\ln p_{iCt} + \epsilon_{E_R}\ln \mathbb{X}_{iCt} + \zeta_{iE} + \xi_{iEt}$$

where $\mathbb{X}_{ijt} \equiv j_{it}\, p_{ijt}$: exp. on good j by HH i at time t with $j = \{E_R, C\}$

Parameter	(1)	(2)	(3)
σ	0.251***	0.303***	0.248***
	(0.015)	(0.014)	(0.021)
ϵ_{E_R}	0.328***	0.301***	0.346***
	(0.017)	(0.017)	(0.020)
Region FE	✗	✓	✓
Year × Quarter FE	✗	✗	✓

Notes. *** indicates significance at the 1% level.

◀ Calibration ▶ Exp. Elasticity

Expenditure Elasticity: Structural vs. Reduced-Form

Structural (Non-Homothetic CES): $\eta_j = \sigma + (1-\sigma)\frac{\epsilon_j}{\sum_j \omega_j \epsilon_j}, \quad j = \{E_R, C\}$

Reduced-Form: $\log\left(\frac{\mathbb{X}^i_{jt}}{\overline{\mathbb{X}}_{jt}}\right) = \alpha_{jtr} + \eta_j \ln Exp^i_t + \boldsymbol{\Gamma}_j \mathbf{Z}^i + u^i_{jt}, \quad j = \{E_R, C\}$

where $\mathbb{X}^i_{jt}$: expenditure on good j by HH i at time t

$\overline{\mathbb{X}}_{jt}$: average expenditure on good j across HHs at time t

Consumption Category	CE Share (in Percentage)	Non-Homothetic CES		Reduced-Form
		ϵ_j	η_j	η_j
Energy	7.94	0.346*** (0.020)	0.522	0.466*** (0.007)
Non-Energy	92.06	1.00 (-)	1.041	0.989*** (0.005)

Notes. $\sigma = 0.248$. *** indicates significance at the 1% level.

◀ Calibration

Externally Set Parameters

Parameter	Value	Source
α	**0.36**	Literature
δ	**0.015**	Literature
ρ_z	**0.975**	Floden and Lindé (2001)
σ_z	**0.165**	Floden and Lindé (2001)
γ	**2.0**	Within the range of values in literature
ν	**0.50**	Literature
τ^a	**0.36**	Trabandt and Uhlig (2011)
τ^l	**0.09**	Heathcote, Storesletten, and Violante (2020)

◀ Calibration

Calibration of Other Energy-Related Parameters

Parameter	Value	Target	Data	Model
κ	**20.0**	Firms' expenditure on energy as a share of GDP	4.1%	4.1%
Ω_{E_R}	**0.08**	HHs' average E_R expenditure share	7.94%	7.93%
ι_0	**0.03**	Employed households' average E_T expenditure share	2.0%	2.0%
ι_1	**0.58**	Bottom-to-top income quintile working HHs' E_T expenditure share	1.37	1.37

◀ Calibration ▶ Exp. Share Dist. of E_T ▶ Calculation of E_T ▶ Functional Form ▶ Other Internally Calibrated Parameters

Other Internally Calibrated Parameters

Parameter	Value	Target	Data	Model
β	**0.981**	After-tax rate of return	4.1%	4.1%
$z_{\max}$	**20.85**	Wealth share of top wealth decile	66.44%	64.88%
π_{up}	$\mathbf{7.03 \times 10^{-4}}$	Earnings share of top earnings decile	35.04%	35.12%
π_{stay}	**0.978**	Earnings share of top 1% of the earnings	11.62%	14.32%
φ_1	**38.84**	Average hours worked as a share of total time endowment	33.33%	33.34%
φ_2	**0.52**	Employment rate	79.63%	80.64%
λ	**0.789**	Govt. purchases as a share of output	20.0%	20.0%
$\bar{e}$	**0.24**	Average transfers-to-income ratio of the lowest wealth quintile	14.72%	15.97%
$\underline{a}$	**−0.07**	Share of HHs with negative wealth	12.58%	10.49%

◀ Calibration