Aggregate and distributional effects of a carbon tax

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Motivation

Economists agree that **carbon taxes** are a powerful tool

But: Concerns about their impact on output and inequality

Little known about their **general equilibrium effects**

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This paper:
Develop **multi-sector energy model** to evaluate aggregate and distributional consequences of a **\$100-per-ton carbon tax**

What do we know so far?

Expenditure channel is regressive (Hassett et al., 2009; Grainger and Kolstad, 2010; Mathur and Morris, 2014; Fremstad and Paul, 2017; Feindt et al., 2021)

Comparison with Känzig (2021)

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- ...that households work in different sectors

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But studies so far ignore...

- ...the low short-run price elasticity of energy demand and the strong complementarity between capital and energy
- ...that households work in different sectors
- ...the feedback of household heterogeneity into aggregate dynamics

Comparison with Känzig (2021)

Main results

Aggregate effects:

- Carbon emissions fall by 25% after 5 years, 50% in long run
- **GDP drops by 3%** upon impact (4% long run)
- Large **drop in investment**; consumption initially goes up

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- Substantial **dispersion** in consumption response across households
- Carbon tax initially **progressive**, but regressive over time

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Tax progressivity driven by energy-capital complementarity

- Capital income falls more than labor income ("**stranded assets**")
- Fall in wages in capital-producing sectors (well-paying jobs)
- Limited pass-through into consumer prices

Model

Capital supply: putty-clay approach

Capital funds manage capital stocks on behalf of households

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Each machine defined by 2 technical features:

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Capital capacity of a machine:

$$k = z^{\chi_i} e^{1-\chi_i} = z^{\chi_i}$$

Capital supply: putty-clay approach

Each period t, capital funds decide

- how many new machines to buy, $x_{i,t}$
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$$X_{i,t+1} = (1 - \delta_{i,t})X_{i,t} + x_{i,t}$$

Capital capacity K

$$K_{i,t+1} = (1 - \delta_{i,t})K_{i,t} + x_{i,t}k_{i,t}$$

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$\rightarrow$ Energy requirement of capital stock is pre-determined!

Utilization margin

Running time for machines: $u_{i,t}$

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Energy consumption: $E_{i,t} = u_{i,t} X_{i,t}$

Capital services: $u_{i,t} K_{i,t}$

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Cost of utilizing machines:

- Cost of energy: $p_{E_i,t} + \tau_{E_i,t} \rightarrow$ **energy tax**
- Higher depreciation: $\delta_{i,t}(u_{i,t})$ with $\delta'_{i,t}, \delta''_{i,t} > 0$

Embedding in a multi-sector model

Roundabout production: 404 sectors of BEA IO tables + car services

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Carbon tax: on energy + on output for firms producing cement, ...
→ reflects carbon intensity of each sector (data from U.S. EPA)

		Carbon intensity (kg/$)			Emissions
		Non-energy	Energy	Total	(%)
1	Cement manufacturing	6.17	2.21	8.38	0.9
2	State and local government electric utilities	0.00	4.72	4.72	5.3
3	Federal electric utilities	0.00	4.71	4.72	1.2
4	Electric power generation and transmission	0.00	4.62	4.62	31.5
5	Lime and gypsum product manufacturing	2.36	1.46	3.82	0.4
6	Copper, nickel, lead, and zinc mining	0.00	1.30	1.30	0.3
7	Motor vehicle services	0.00	1.20	1.20	16.8
8	Truck transportation	0.00	1.17	1.18	6.4

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Carbon tax **rebated via consumption tax**

Households

Continuum of households holding jobs $\iota \in [0, 1]$

Inelastic labor supply with sticky wages

Work in one out of J sectors (gradual re-allocation)

Non-homothetic preferences

Differ in labor productivity and their holdings of capital fund shares

Details

Households

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Work in one out of J sectors (gradual re-allocation)
→**Labor income channel (CPS)**

Non-homothetic preferences
→**Expenditure channel (CEX)**

Differ in labor productivity and their holdings of capital fund shares
→**Factor income channel (DINA)**

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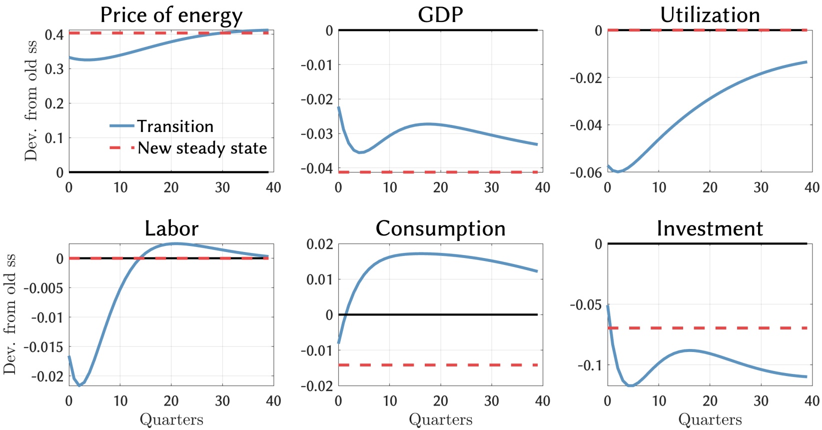
NB: Stochastic discount factor puts larger weight on households with high capital income (similar to **TANK / HANK**)

Details

Results

Response to unexpected tax of $100 per ton of carbon



More IRFs

Calibration

Linking energy consumption to GDP

$$\widetilde{GDP}_t = \underbrace{\phi^K}_{\text{capital share}=1/3} \tilde{E}_t + \left(1 - \phi^K\right) \tilde{L}_t +$$

Short run, one sector:
Elasticity of GDP to E exceeds its share in GDP!

Linking energy consumption to GDP

$$\widetilde{GDP}_t = \phi^K \tilde{E}_t + \left(1 - \phi^K\right) \tilde{L}_t + \sum_i \frac{E_i}{GDP} \underbrace{\left[\frac{\phi_i^K}{\phi_i^E} - \frac{\phi^K}{\phi^E}\right] \tilde{E}_{i,t}}_{>0} +$$

Short run, multiple sectors:

Cross-sector substitution lowers elasticity: energy-intensive sectors contract more

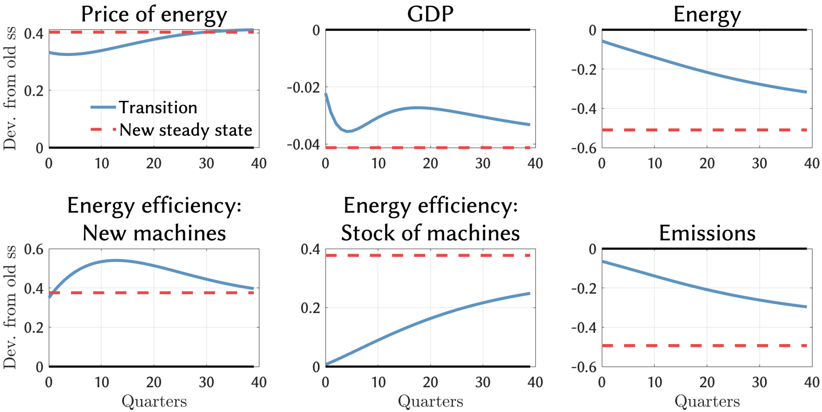
Linking energy consumption to GDP

$$\widetilde{GDP}_t = \phi^K \tilde{E}_t + \left(1 - \phi^K\right) \tilde{L}_t + \sum_i \frac{E_i}{GDP} \left[\frac{\phi_i^K}{\phi_i^E} - \frac{\phi^K}{\phi^E}\right] \tilde{u}_{i,t} + \left(\phi^K + \phi^E\right) \tilde{Z}_t$$

Long run, multiple sectors:

Higher energy efficiency $\tilde{Z}_t$ decouples GDP from energy use

Response to unexpected tax of $100 per ton of carbon



More IRFs

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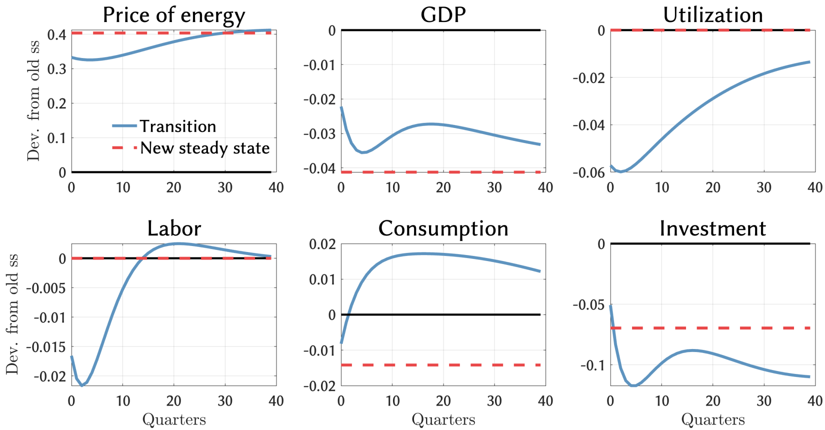
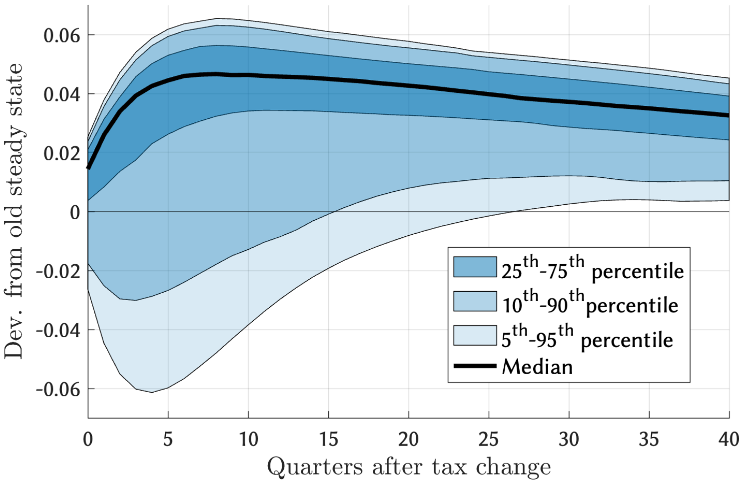


More IRFs

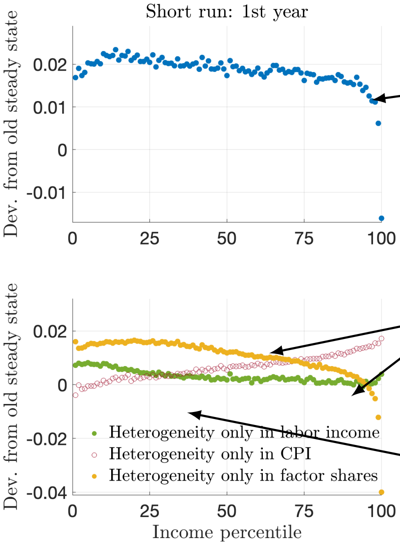
Calibration

Variation in consumption growth across households



Distribution of consumption changes across households

Carbon tax is progressive in short run...

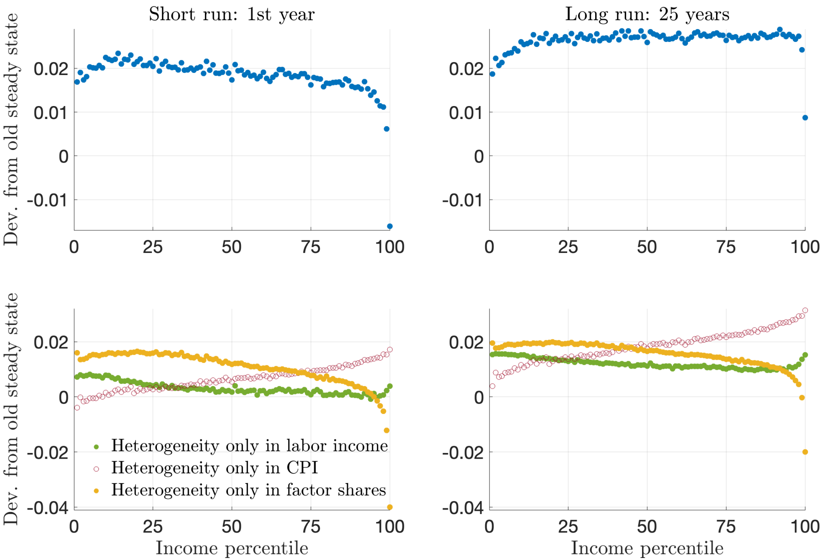


Carbon tax progressive

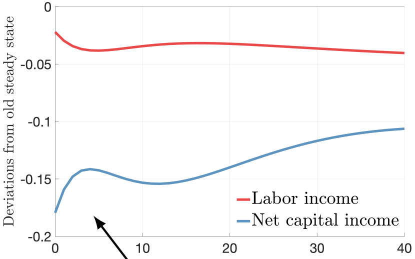
Income channels progressive

Expenditure channel regressive

... but becomes more regressive over time



Why the factor income channel hurts the rich



Response of factor income

Energy-capital complementarity
strongly reduces capital income

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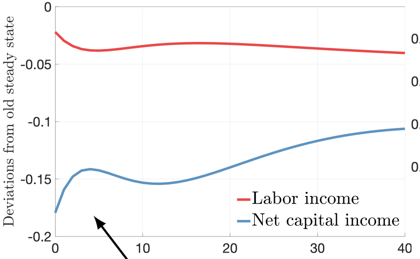

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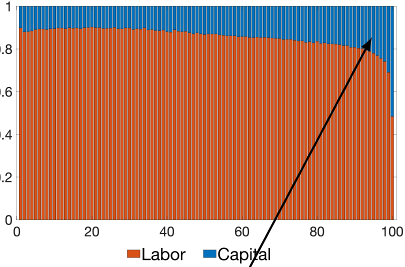


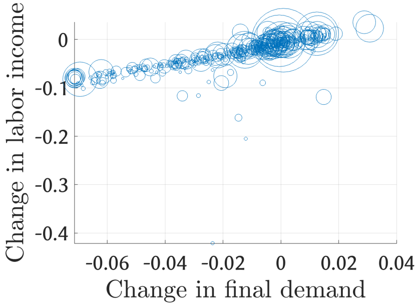
Income shares by income percentile

Energy-capital complementarity strongly reduces capital income

Capital income more important for high-income earners

Why the labor income channel hurts the rich

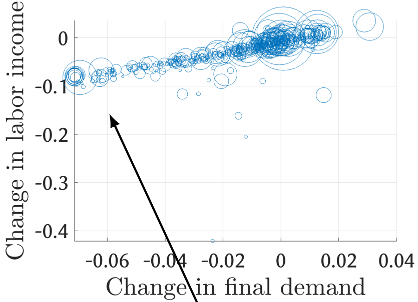
What drives differences in labor income across sectors and workers?



Response across sectors in 1st year

Why the labor income channel hurts the rich

What drives differences in labor income across sectors and workers?



Response across sectors in 1st year

Sectors that experience drop in **demand** reduce labor payments

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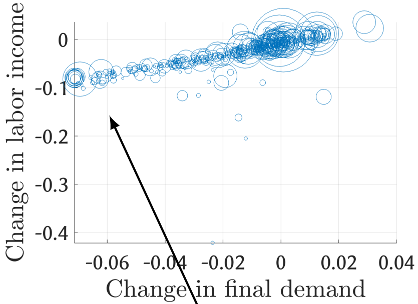

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Drop in demand driven by **fall in investment**

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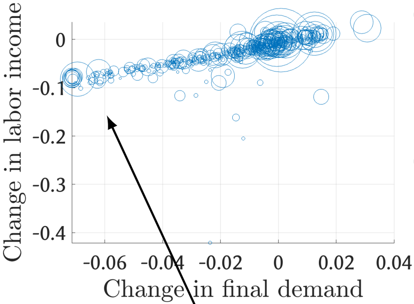

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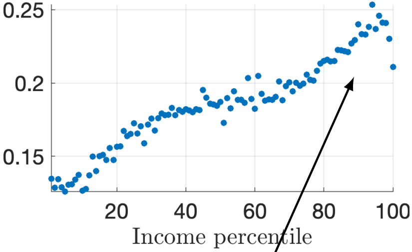


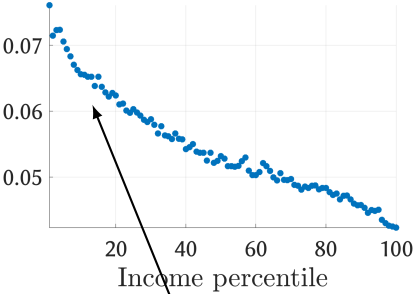
Share of income induced by investment

Sectors that experience drop in **demand** reduce labor payments

High-income earners over-represented in capital-good sectors

Drop in demand driven by **fall in investment**

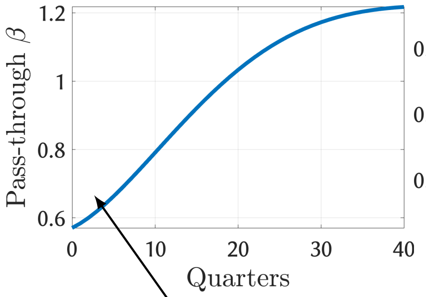
Why the expenditure channel hurts the poor a little



Implied tax on consumption

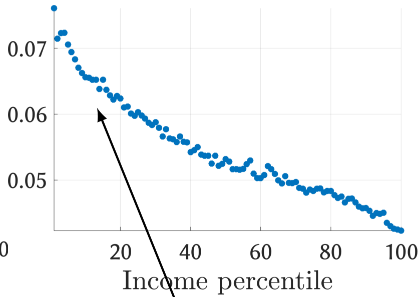
Low-income consumers
more exposed to carbon tax

Why the expenditure channel hurts the poor a little



Tax pass-through into consumer prices

Sectors hit by tax raise prices but initially not 1 for 1



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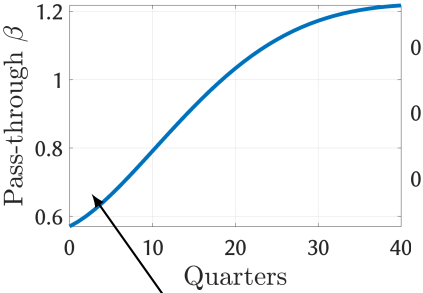
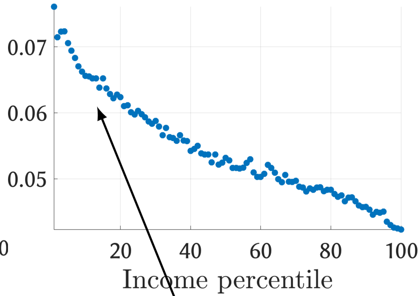


TAX PASS-THROUGH INTO CONSUMER PRICES



IMPLIED TAX ON CONSUMPTION

Sectors hit by tax raise prices but initially not 1 for 1

Low-income consumers more exposed to carbon tax

Due to energy-capital complementarity, higher taxes are passed on to capital owners rather than consumers

First-year response across model variations

	Model	ΔGDP	Δc^{B50}	Δc^{T5}	Δc^{T5-B50}
(1)	Baseline	-2.96	1.83	-0.51	-2.34

First-year response across model variations

	Model	ΔGDP	Δc^{B50}	Δc^{T5}	Δc^{T5-B50}
(1)	Baseline	-2.96	1.83	-0.51	-2.34
(2)	No utilization	-2.17	2.91	-0.20	-3.11

Inelastic capital supply:

- Smaller fall in GDP
- Stronger incidence on capital $\rightarrow$ more progressive

First-year response across model variations

	Model	ΔGDP	Δc^{B50}	Δc^{T5}	Δc^{T5-B50}
(1)	Baseline	−2.96	1.83	−0.51	−2.34
(2)	No utilization	−2.17	2.91	−0.20	−3.11
(3)	Cobb-Douglas	−2.70	0.38	1.47	1.09

Cobb-Douglas:

- Large drop in energy
- Both labor and capital suffer: Tax becomes regressive

First-year response across model variations

	Model	ΔGDP	Δc^{B50}	Δc^{T5}	Δc^{T5-B50}
(1)	Baseline	−2.96	1.83	−0.51	−2.34
(2)	No utilization	−2.17	2.91	−0.20	−3.11
(3)	Cobb-Douglas	−2.70	0.38	1.47	1.09
(4)	Lump-sum rebate	−3.11	14.15	−4.38	−18.53

Lump-sum:

- Tax very progressive
- GDP drops more (permanent shock & non-homothetic preferences)

Conclusion

Quantitative multi-sector energy model to evaluate carbon tax

Complementarity of capital and energy...

...amplifies the effects of energy consumption on GDP

...makes carbon tax more progressive in the short run

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Känzig (2021): Effects of carbon pricing shocks

Empirical findings:

- Strong GDP response: Drop of 5% for 10% increase in energy prices
- Bottom 25% with slightly stronger fall in income and stronger expenditure response after 2-3 years
- Argues that poor work in demand-sensitive sectors

Theoretical model:

- Highly transitory carbon tax shock
- Hand-to-mouth households vs. savers
- Cobb-Douglas production function + revenue redistributed to savers $\rightarrow$ tax regressive $\rightarrow$ demand amplification

Back

Household preferences

Utility for household working job ι in sector i at time t

$$c_{i,t}(\iota) = \left(\sum_{j=1}^{J} \left(\boldsymbol{\omega_c^j(c_{i,t}(\iota))} \right)^{\frac{1}{\sigma}} \left(y^j_{c_i,t}(\iota) \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Household ι's preference weight for good j

Household preferences

Utility for household working job ι in sector i at time t

$$c_{i,t}(\iota) = \left(\sum_{j=1}^{J} \left(\boldsymbol{\omega_c^j(c_{i,t}(\iota))} \right)^{\frac{1}{\sigma}} \left(y^j_{c_i,t}(\iota) \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Household ι's preference weight for good j

Budget constraint

$$(1 + \tau_t^C) p_{c_i,t}(\iota) c_{i,t}(\iota) = \boldsymbol{a_l(\iota)} w_{i,t} l_{i,t} + \boldsymbol{a_{k,t}(\iota)} div_t$$

- $a_l(\iota)$: heterogeneity in labor productivity
- $a_{k,t}(\iota)$: heterogeneity in ownership shares

Labor supply

Labor supply by household type ι in sector i

$$L_{i,t}(\iota) = n_{i,t}(\iota) \times a_l(\iota) l_{i,t}$$

Labor supply within sectors (l):
Sticky wage model (Erceg et al., 2000) extended to allow for inelastic labor supply (House et al., 2018)

Wage Phillips curve

$$\tilde{\pi}^w_{i,t} = \frac{(1-\theta_w\beta)(1-\theta_w)}{\theta_w}\tilde{l}_{i,t} + \beta\mathbb{E}_t\left[\tilde{\pi}^w_{i,t+1}\right],$$

Labor supply

Labor supply across sectors (*n*):

Perpetual youth model: each period cohort of size ψ is born / dies

Households born in t choose sector to maximize

$$\max_i \left\{ \left(\sum_{s=0}^{\infty} [\beta(1-\psi)]^s \, \mathbb{E}_t \left(\mathcal{U}_{i,t+s} \right) \right) + \frac{1}{\gamma} \varepsilon_{i,t} - \kappa_i \right\}.$$

Law of motion for number of households in sector i:

$$n_{i,t} = (1-\psi) n_{i,t-1} + \psi \mu_{i,t}.$$

$\mu_{i,t}$: Share of households choosing i

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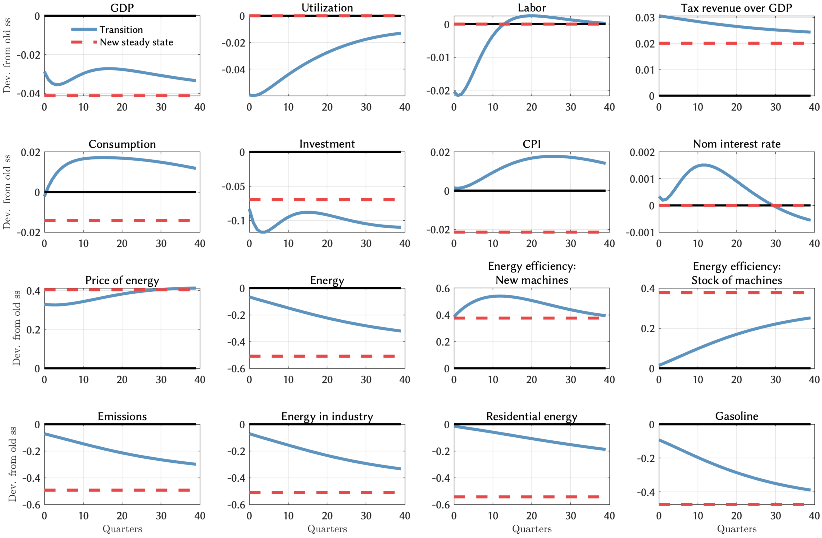
Response to $100 carbon tax



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Calibration Table

Description	Parameter	Value	Source / Target
Production			
Curvature of capital in production function	α_i	sec. sp.	I-O tables, 2012, **(alias?)**, Karabarbounis and Neiman (2013)
Weight on intermediate goods	ϕ_i	sec. sp.	I-O tables, 2012
Weight on energy goods	χ_i	sec. sp.	I-O tables, 2012
Input weights for final goods	ω_s^i	sec. sp.	I-O tables, 2012
Elast. of subst. value added and intermediates	ξ	0.1	Boehm et al. (2019)
Elast. of subst. across goods	σ	2	Hobijn and Nechio (2019)
Consumption preferences			
Discount factor	β	0.99	Standard value
Consumption basket weights	$\omega_c^j(\iota)$	sec. & inc. sp.	Estimated from CEX (U.S. Department of Labor, 2021) (see text)
Consumption elasticity	$\frac{\partial \ln \omega_c^j(\iota)}{\partial \ln c(\iota)}$	sec. sp.	Estimated from CEX (U.S. Department of Labor, 2021) (see text)
Income			
Share of capital fund per income percentile	$a_k(\iota)$	perc. sp.	Derived from DINA (Piketty et al., 2018)
Labor productivity per income percentile	$a_l(\iota)$	perc. sp.	Derived from DINA (Piketty et al., 2018)
Labor			
Wage stickiness	θ_w	0.85	Grigsby et al. (2021)
Share of workers leaving workforce	ψ_L	0.025	Working life of 40 years
Propensity to change sectors	γ	0.2	Artuç et al. (2010), Caliendo et al. (2019)
Average wage per sector	w_i	sec. sp.	Estimated from CPS data (Flood et al., 2021)
Distribution of income percentiles per sector	$\omega_i^l(\iota)$	sec. & inc. sp.	Estimated from CPS data (Flood et al., 2021)
Capital			
Depreciation rate non-residential capital (p.a.)	δ	0.07	Share non-residential investment in GDP (17%), 2000 - 2019
Depreciation rate housing (p.a.)	δ_h	0.03	Share residential investment in GDP (3%), 2000 - 2019
Depreciation rate motor vehicles (p.a.)	δ_d	0.16	Rates for motor vehicles (Fraumeni, 1997)
Investment adjustment cost	f''	2.50	House and Shapiro (2008)
Utilization adjustment cost	δ''	$\frac{1}{30}$	Short-run energy demand elasticity of 0.15-0.20 (Labandeira et al., 2017)
Fiscal and monetary policy			
Share government consumption	G	0.15	Share government consumption in GDP (15%), 2000 - 2019
Taylor rule persistence coefficient	φ	0.75	Clarida et al. (1997)
Taylor rule inflation coefficient	φ_π	1.5	Clarida et al. (1997)

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