Towards Hybrid Economy-Wide Frameworks for the Distributional Assessment of Climate Policies

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Introduction

- Climate policy affects households through **multiple channels at once**: consumer prices, intermediate input costs, wages, capital income, and demand feedbacks [Fullerton, 2011].
- Standard **input-output (IO)** models are transparent about sectoral propagation, but usually separate **price** and **quantity** modules.
- Standard microsimulation models capture rich household heterogeneity, but they often take economy-wide price shocks as **given** [Böhringer et al., 2022].
- **How do we preserve household-level heterogeneity while still tracing economy-wide propagation inside one model?**

Working question

How can we assess the **distributional incidence** of climate policy when:

- sectoral cost shocks propagate through production networks,
- households differ in both **income sources** and **consumption baskets**,
- and these channels feed back on one another?

Main contribution of the paper

1. **Combines two existing strands**: price–quantity IO modeling [Cardenete et al., 2024] and household-level microsimulation.
2. **Embeds households directly**: about 3,233 households enter the model individually, preserving micro-level heterogeneity.
3. **Builds a transparent household bridge**: a reproducible mapping from **COICOP purchaser-price survey data** to **NACE basic-price industry demand** [Cazcarro et al., 2022].
4. Solves incidence channels jointly: Policy shocks propagate through production networks, prices, factor incomes, and demand.
5. **Applies the framework to the Czech case**: to our knowledge, it is the first household-rich simultaneous price-quantity IO framework for climate-policy in this setting.

This is a **methodological paper first**. The policy scenarios are illustrative applications used to demonstrate what the framework can distinguish, not a true policy assessment exercise:

- average burden,
- sectoral origin of the burden,
- regressivity across the distribution,
- and heterogeneity *within* standard household groups.

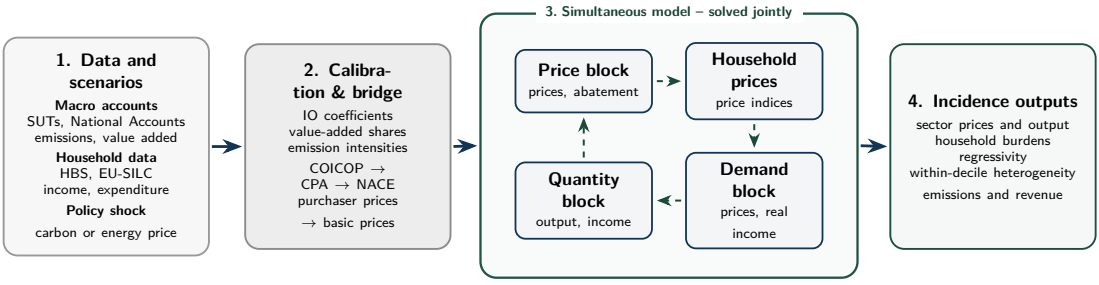
Data structure and calibration

- **Supply and Use Tables (SUTs)**: Eurostat, 89-industry detail, benchmark economy-wide backbone.
- **Household Budget Survey (HBS)**: expenditure microdata in **COICOP** categories.
- **EU-SILC**: income decomposition, industry assignment for labor, capital income, demographics, etc.
- **National Accounts**: household consumption totals, valuation tables, consistency targets.
- **Air Emissions Accounts**: industry emission intensities by pollutant.
- **Elasticities**: current implementation uses literature-based values; Czech **QUAIDS** estimation is ongoing.

Quick terminology

- **COICOP**: household consumption purpose classification.
- **CPA**: product classification used in national accounts.
- **NACE**: industry classification.
- **Purchaser prices**: what households pay.
- **Basic prices**: producer-side valuation used in IO accounting.
- **DAS**: Demand system product categories.

IO-DASMOD architecture



The bridge is calibrated first; the central block is solved as one simultaneous price–quantity–household system.

Household consumption bridge: from HBS records to IO demand



What each step does

- **Annualization and scaling:** converts raw HBS expenditures into annual household spending and aligns category totals with National Accounts.
- **COICOP → CPA bridge:** translates survey consumption categories into product categories used in national accounts. The bridge is derived using constrained cross-entropy with National Accounts row and column totals.
- **Purchaser prices → basic prices:** removes product taxes and reallocates trade and transport margins:

$$PP_c = BP_c + TTM_c + TLS_c.$$

- **Domestic share and industry transformation:** keeps the domestic component of consumption and maps products to NACE industries using the Make matrix.

Household income treatment

- The household microdata combine **HBS expenditure records** with **EU-SILC income and socio-demographic information**.
- In the Czech data, this **linkage is built into the survey design**: households observed in HBS are connected to the EU-SILC panel.
- This avoids a separate statistical matching step and preserves a coherent household profile: income sources, demographics, and consumption baskets refer to the same household unit.

Labor income

- The household reference person is assigned to a **NACE industry** using EU-SILC information.
- For inactive / retired households with positive labor income, sectoral allocation uses observed sector weights plus small seeds where needed.
- Sector totals are then **rescaled to National Accounts compensation of employees**.

Capital side

- Capital income is distributed proportionally to each household's share of total observed capital income.
- This implies a **diversified capital ownership** assumption across industries.

What is endogenous in IO-DASMOD?

Benchmark DAS purchaser prices are formed by chaining NACE basic prices through five linear transformations:

$$\underset{\text{NACE BP}}{p_i^0} \xrightarrow{T_{p,i}^{(2)}} \underset{\text{CPA BP}}{p_p^{\text{CPA}}} \xrightarrow{M_{p',p}^{BP\to PP}} \underset{\text{CPA PP}}{p_{p'}^{\text{CPA,PP}}} \xrightarrow{B_{c,p'}^{P\to C}} \underset{\text{COICOP}}{p_c^{\text{COICOP}}} \xrightarrow{\Phi_{c,k}} \underset{\text{DAS PP}}{\tilde{p}_k^0}.$$

Simultaneously determined

- Industry output: x_i
- Industry prices: p_i
- Aggregate wage and rental rate: $w,\ r$
- Household disposable income: m_h^d
- Household demand: $d_{h,k}$
- Household-specific price indices: P_h^{HH}
- Abatement rates: $\mu_{i,e}$
- Policy revenue: R^E

Important closure choices

- Comparative-static, **price-endogenous IO**, not CGE.
- Production remains **Leontief**.
- Demand responds to **real disposable income**, not nominal income.
- In the four application scenarios shown today, **revenue recycling is switched off** to isolate gross incidence.

Quantity block: how household demand feeds back into production

$$x_i = \sum_{j \in I} a_{i,j} x_j + \sigma_i \sum_{j \in I} \Theta_j^K x_j + \bar{f}_i + G_i^{pol} + \sum_{h \in H} \sum_{k \in K} \Gamma_{h,k,i} d_{h,k}$$

Interpretation

- Intermediate demand from other industries.
- Investment demand.
- Exogenous final demand.
- Policy-financed investment (inactive in today's scenarios).
- **Household demand mapped into industry space**.
- The bridge parameter $\Gamma_{h,k,i}$ means that **each household's expenditure basket** enters the production system with its own product–industry composition.

Price block and abatement: two cost channels of carbon pricing

$$p_i = \sum_{j \in I} a_{j,i} p_j + \Theta_i^L w + \Theta_i^K r + u_i + \bar{s}_i + \sum_{e \in E} \left[\tau_{i,e}^E \epsilon_{i,e} (1 - \mu_{i,e}) + \frac{1}{2} \phi_{i,e} \mu_{i,e}^2 \right]$$

Two margins

1. **Residual emissions charge**
   higher effective costs for emissions-intensive sectors.
2. **Resource cost of abatement**
   emission intensity can fall endogenously:

$$\phi_{i,e} \mu_{i,e} = \tau_{i,e}^E \epsilon_{i,e}$$

3. Emissions can fall through:
   - lower output,
   - and lower emissions intensity.

Household demand, factor prices, and incidence

Primary factor prices: the quantity–price link

- The aggregate wage and rental rate respond to changes in economy-wide labor and capital use.
- Policy-induced factor-price changes feed back into industry costs through labor and capital cost shares.
- They also affect household disposable income, depending on each household's labor and capital income sources.

$$d_{h,k} = d^0_{h,k} \left(\frac{\tilde{p}_k}{\tilde{p}^0_k} \right)^{1+\eta^{own}_{h,k}} \prod_{k' \neq k} \left(\frac{\tilde{p}_{k'}}{\tilde{p}^0_{k'}} \right)^{\eta^{cross}_{h,k,k'}} \left(\frac{m^d_h}{P^{HH}_h \cdot m^{d,0}_h} \right)^{\eta^{inc}_{h,k}}, \quad P^{HH}_h = \sum_{k \in K} \omega^c_{h,k} \frac{\tilde{p}_k}{\tilde{p}^0_k}$$

- Households face different effective inflation because their expenditure shares differ.
- Demand responds to **real purchasing power**, not just nominal income.
- Incidence therefore reflects both **consumer-price effects** and **factor-income effects**.

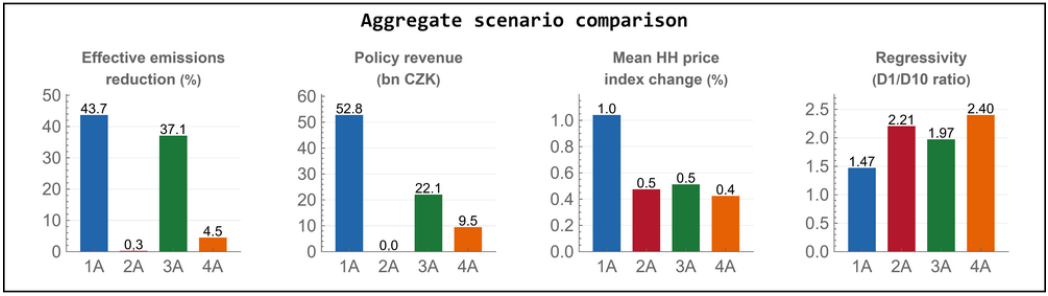
Policy scenarios used to illustrate the framework

ID	Label	Sectors / channel	Instrument
1A	Uniform economy-wide CO_2 price	All 89 NACE industries; CO_2 account; endogenous abatement	60 EUR/tCO_2
2A	Household energy price shock	Electricity, gas, steam, air conditioning (D35); no abatement	5% ad valorem price shock
3A	ETS2-style proxy	Refined petroleum (C19), electricity & gas (D35), land transport (H49); CO_2 account	60 EUR/tCO_2
4A	Agri-food GHG price	Agriculture, forestry, fishing, food, beverages; CO_2-equivalent account	60 EUR/tCO_2e

Common design choice

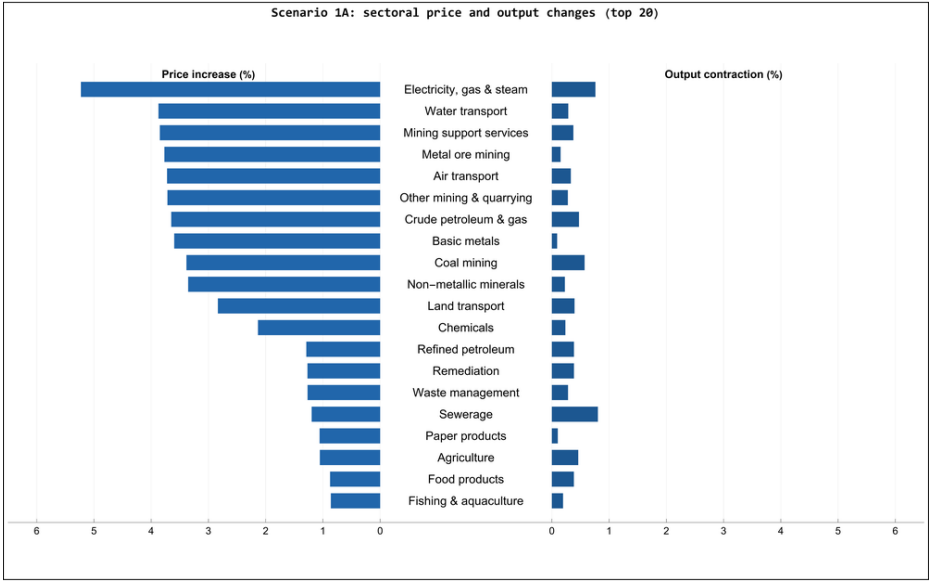
No revenue recycling is shown in these four runs. That makes them useful as **gross-incidence** scenarios.

Aggregate comparison: broad burden and regressivity do not move together

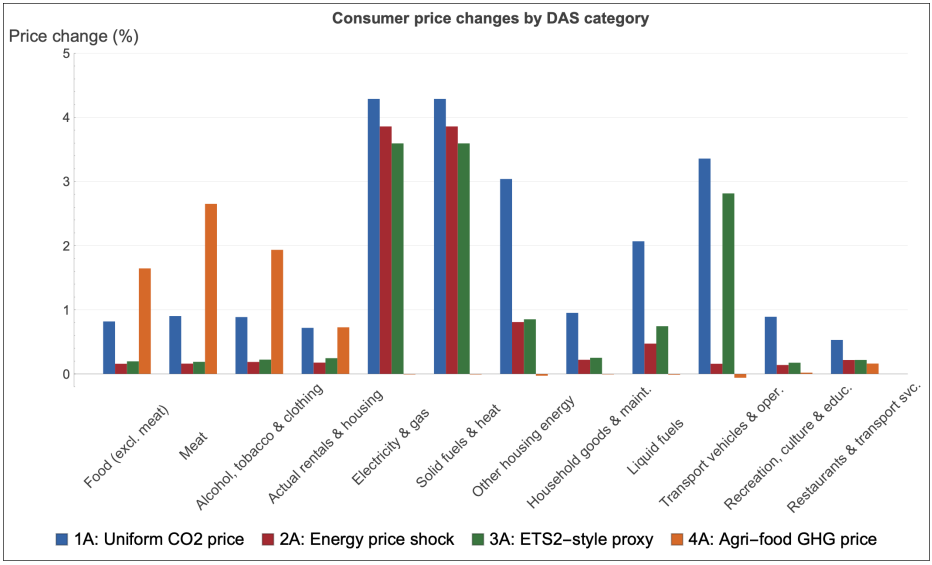


Scen.	Main household channels	Mechanism / interpretation
1A	Energy, transport, fuels, broad upstream effects	**Economy-wide** carbon price → key intermediate inputs revalued → network-wide pass-through
2A	Electricity, gas, household energy bills, indirect effects	D35 energy shock → key intermediate input → economy-wide spillovers
3A	Household energy, transport fuels, transport services	Carbon price → concentrated in highly visible, frequently purchased items
4A	Food-at-home, meat, agri-food categories	Smaller aggregate shock → concentrated in a necessity good

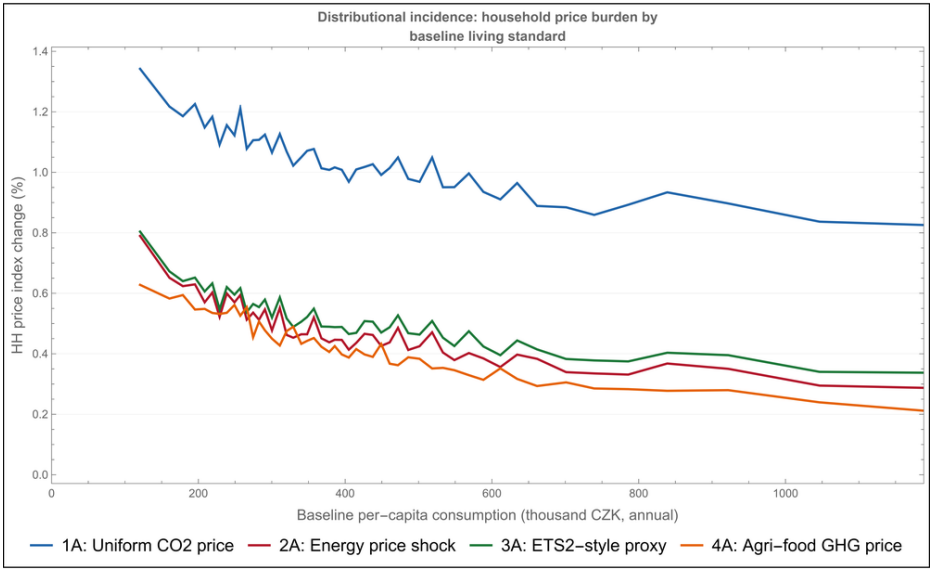
Scenario 1A: upstream sectors drive economy-wide pass-through



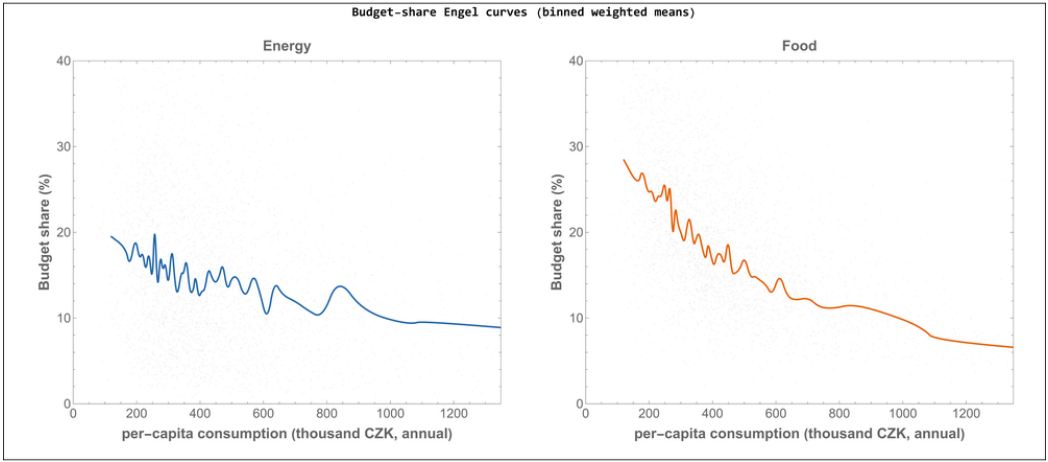
Consumer price impacts



All scenarios are regressive, but not equally so



Food budget shares fall more steeply than energy shares



Why is the agri-food scenario more regressive?

Mechanism in the paper's Engel-curve evidence

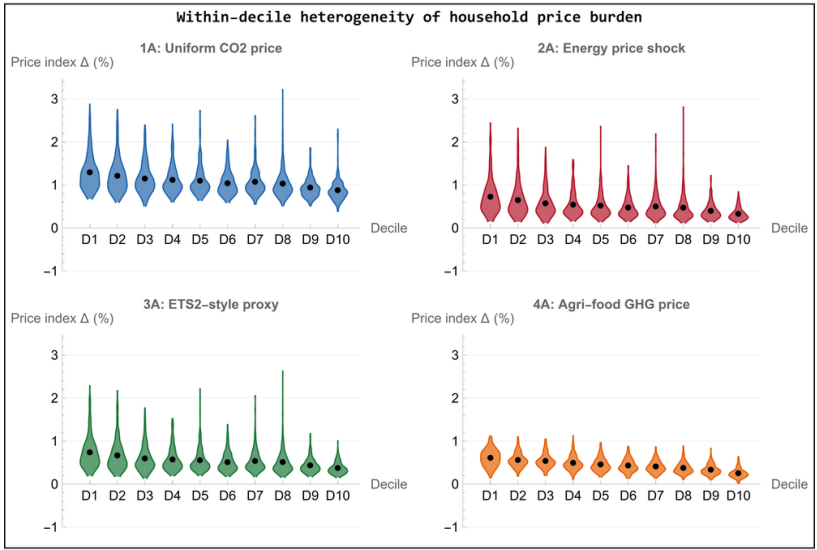
- The **food budget share** declines more steeply with living standard than the **energy budget share**.
- Therefore, a food-system price shock can be:
  - modest in aggregate terms,
  - yet strongly concentrated on lower-consumption households.
- This is why Scenario 4A has the **highest D1/D10 burden ratio** despite a relatively small mean price-index effect.

Interpretation for microsimulation

Representative-household approaches can identify average decile patterns, but they are less well suited to preserving:

- detailed basket composition,
- within-group variation,
- and the interaction between basket composition and economy-wide pass-through.

Household-level modeling reveals dispersion hidden by decile averages



1. **Households remain individual observations**: no need to collapse immediately into representative groups.
2. **Within-decile dispersion varies systematically by scenario**: largest under energy shocks, tightest under the agri-food price.
3. **Price indices are household-specific**: inflation is endogenous and heterogeneous.
4. **Income and expenditure feedbacks interact**: the framework is simultaneous rather than one-way.

Limits of interpretation

Structural limits

- Production is **Leontief**: firms do not substitute among inputs in the CGE sense.
- Factor markets are represented by **aggregate scarcity conditions**, not full Walrasian market clearing.
- Abatement is **reduced-form** and stylized.

Current empirical limits

- Elasticities are still **provisional** (demand system being estimated).
- Revenue recycling is already in the model structure, but currently introduces strong nonlinearities and solver instability.
- Results shown today should therefore be read as **framework demonstration**, not final policy calibration.

Thank you for your attention!

Questions and comments are very welcome.

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Bridge details

1. **Support set construction**: admissible COICOP–CPA links based on correspondence tables.
2. **Feasibility pruning**: LP-based removal of cells whose maximum feasible value is essentially zero.
3. **Two normalizations from the same joint table**:
   - row-normalized bridge: CPA shares *given* a COICOP category;
   - column-normalized reverse bridge: COICOP shares *given* a CPA product.
4. **Margins matter**: PP–BP conversion creates off-diagonal effects because margins are reallocated to wholesale, retail, and transport services.

Policy revenue and recycling logic

$$R^E = \sum_{i \in I} \sum_{e \in E} \tau^E_{i,e} \epsilon_{i,e} (1 - \mu_{i,e}) x_i$$

$$R^E = \sum_{h \in H} \alpha^{hh}_h R^E + \sum_{i \in I} \alpha^{inv}_i R^E + R^{sink}$$

Why not in the main results yet?

- The model structure already allows equal per-capita dividends, targeted transfers, policy-financed investment, or partial recycling.
- In the current implementation, these choices add strong nonlinearities and can make the solver unstable.
- So the paper first isolates **gross burden before compensation**. [Banks et al., 1997]

PP to BP conversion

For household final consumption,

$$\mathsf{PP} = \mathsf{BP} + \mathsf{TLS} + \mathsf{TTM}$$

where TLS denotes taxes less subsidies on products and TTM denotes trade and transport margins.
Define

- $\mathcal{P}^+ = \{i : \mathsf{TTM}_i^{\mathsf{HH}} > 0\}$ (products with embedded margins)
- $\mathcal{P}^- = \{i : \mathsf{TTM}_i^{\mathsf{HH}} < 0\}$ (margin-providing products).

Implicit rates and shares:
For $i \in \mathcal{P}^+$, the margin rate is

$$m_i = \mathsf{TTM}_i^{\mathsf{HH}} / \mathsf{BP}_i^{\mathsf{HH}}$$

. For $i \in \mathcal{P}^-$, the redistribution share is

$$s_i = \mathsf{TTM}_i^{\mathsf{HH}} / \sum_{k \in \mathcal{P}^+} \mathsf{TTM}_k^{\mathsf{HH}}$$

(negative, summing to -1). The tax rate is $t_i = \mathsf{TLS}_i^{\mathsf{HH}} / (\mathsf{PP}_i^{\mathsf{HH}} - \mathsf{TLS}_i^{\mathsf{HH}})$.

- Remove taxes: $\mathsf{TLS}_{ih} = \mathsf{PP}_{ih}\, t_i/(1+t_i)$.
- Extract positive margins: $\mathsf{TTM}_{ih}^{+} = \mathsf{PP}_{ih}\, m_i/[(1+m_i)(1+t_i)]$ for $i \in \mathcal{P}^+$.
- Reallocate to margin-providing products: $\mathsf{TTM}_{ih} = s_i \cdot M_h$ for $i \in \mathcal{P}^-$, where $M_h = \sum_{i \in \mathcal{P}^+} \mathsf{TTM}_{ih}^{+}$.

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