Source taxes versus end-of-chain taxes in General Equilibrium

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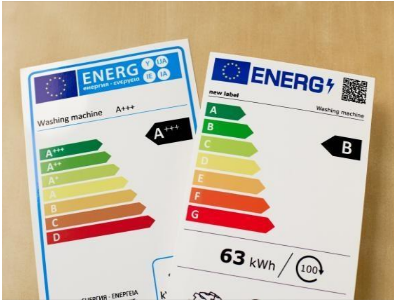
15th Toulouse Conference
on the Economics of Energy and Climate
June 4-5th, 2026

Motivations



Motivations

There is a by-product of the good that the government may wish to regulate (externality) e.g. material content with waste and extraction, or carbon content with greenhouse gas emissions.

The rationale behind the end-of-chain tax:

- In the emissions interpretation, the government taxes the carbon footprint of the goods finally consumed.
- In the physical interpretation, consumption represents the end of the life cycle of a product and thus its material content becomes waste and this waste is taxed by the government.

- Strong advocates of end-of-chain taxation:
  - "Carbones sur Factures" / "Compte carbone"
  - Thomas Wiedman, Edgar Hertwich, Glen Peters, Diana Ivanova, Kate Raworth

- But why should source and end-of chain taxation differ?
  - Assumptions?
  - Market mechanisms?

What people do

- Steckel et al. (2010): *"the way of accounting has neither efficiency nor distributive effects in the presence of a global cap-and-trade regime".*
  BUT emissions intensities are fixed and thus emissions are proportional to output (same for Jakob et al. 2013).

- Jakob et al. (2014): work related to the discussion between production-based and consumption-based policies:
  - source taxation is a production-based policy
  - end-of-chain taxation is a consumption-based policy.

  $\rightarrow$ as above, no incentive for upstream firms to change production decisions

On the contrary, we are (also) interested in the incentives given to the producers to modify the carbon contents of their output.

More recently

- Baqaee and Farhi (2024): highly flexible generic approach to assess how shocks (e.g. policies) transmit through GE.

- Farrokhi and Lashkaripour (2025): assess CBAM but treat it as ad-valorem tax. Producers do no vary product features based on downstream demand.

$\rightarrow$ we consider formation of prices as schedules transmitting essential information

- Clausing et al. (2025): downstream CBAM transmits to upstream decisions through demand shifts between metal production plants. But partial equilibrium analysis.

$\rightarrow$ we consider general equilibrium

What we do

- Producers can substitute between inputs and thus vary the carbon/material content of their product.
- There is an externality balance at every stage of production
  - accounting as legal requirement for consistent footprinting of embodied externalities
  - alternative application: material physical balance
- Consumers do not explicitly care about a good's attributes, but rather care about them implicitly through their budget constraints and any taxes imposed on them.

In this more complex setting, we show conditions under which consumption-based and production-based carbon taxation are equivalent and can decentralize the optimal solution.
Prices become schedules.

Contribution to literature on externality pricing

- Taxation in GE : from Arrow-Debreu to Bovenberg and Goulder (1996) or Schubert et al., (2025)
- Absorbing uncertainty through Quantity vs Prices (Weitzman 1972)
- General equilibrium effects of taxation (Anderson and Duanmu, 2025)
- Point of taxation: upstream versus downstream taxation (Harstadt, 2012, Green and Dennis, 2018 or Asheim et al., 2019)
- Study of carbon and/or resource use along the supply chain: production network (Sager, 2023 or Campligio et al., 2024) or industrial ecology (Pauliuk et al, 2017)

Further contributions

- To identify the assumptions and market mechanisms under which the point of taxation, at the source or at the end of the value chain, does not affect allocation outcomes.
- To rethinking the formation of prices $\rightarrow$ theoretical contribution to the use of price schedules in general equilibrium.
- Can be applied to various domains: carbon emissions, resource use etc. $\rightarrow$ understandable to both general and environmental economists.

Outline

- The economy
- Properties
- Propositions and corollaries on the equivalence
- Conclusion (discussion)

The economy

- Finite set of consumers: $h \in \mathcal{H} = \{1, \dots, H\}$.
- Finite set of production factors that cannot be produced: $k \in \mathcal{K} = \{1, \dots, K\}$.
- Finite set of produced goods $i \in \mathcal{I} = \{1, \dots, I\}$.
- Firms are specialized, i.e. a given firm produces only one commodity.
- Production set $F_j \subset \mathbb{R}^{\mathcal{K} \cup \mathcal{I}}$, convex;
  notation: $z_j = (-l_j, -x_j, y_j)$ for factor use l_{jk}, intermediate deliveries x_{ji} from i to j, output y_j

The intensity of embodied externality

- At each stage of production, an externality can be produced.
- Each firm has an externality function (possibly null) $G_j : (l_j, x_j) \in \mathbb{R}^{\mathcal{K}} \times \mathbb{R}^{\mathcal{I}} \mapsto r_j = G_j(l_j, x_j) \in \mathbb{R}$, with CRS.
  - G_j does not represent damages which might be convex but the material footprint or extraction from the environment, which naturally scales with production.
  - The externality embodied in a good is both
    - inherited from the embodied externality of inputs
    - added at the production stage.
- Consider firm j with inputs x_{ij} of intensity θ_i. Thus good j produced by firm j has intensity θ_j such that:

$$\theta_j y_j = G_j(l_j, x_j) + \sum_{i \in \mathcal{I}} \theta_i x_{ij} \tag{1}$$

because θ_j appears on both side of equation (1), it is not obvious that there exist a vector of intensities that satisfies the equations (1) for every j. We set out conditions for a unique θ in a Lemma.

Government

- The government can raise taxes and rebate tax revenues to consumer.
- The government introduces a taxation system in order to act on the aggregate quantity of the externality in the economy: $R = \sum_{j \in \mathcal{I}} r_j = \sum_{j \in \mathcal{I}} G_j(l_j, x_j)$.
- It can use two different taxes:
  - a source tax t that taxes at the firm level the externality added by the firm
  - and an end-of-chain tax τ that taxes at the consumer level the embodied externality in the goods consumed.

If consumers are taxed on the externality embodied in the good they consume, firms can compete on embodied externality by changing their production choices (l_j, x_j, y_j).

Justification of price schedules 1

Consider a good i directly consumed.

- The consumer derives utility independently of the intensity: $u(c_h)$).
- Yet demand depends on the intensity as it affects the effective price the consumer pays: $d_h((p_i^c)_i)$ with $p_i^c = p_i + \tau\theta_i$.
- Between all possible varieties of the product with their individual intensities, she will consume the good with the lowest effective price $p_i^c \Rightarrow$ producers will compete to offer the good at the lowest consumer price.
- Let the equilibrium consumer price be denoted by p_i^{c*}.
- Rational producers then face a price schedule for their demand
    - Demand is zero for a firm that supplies the good with variety θ_i and price $p_i > p_i^{c*} - \tau\theta_i$,
    - the firm can win the entire market if she can offer the good at $p_i < p_i^{c*} - \tau\theta_i$.

Justification of price schedules 2

- Price schedules support an equilibrium condition: buyers and suppliers agree on the equilibrium intensity.
- The above mechanism applies recursively to intermediate demand.
- The price schedule $P_i : \theta_i \mapsto p_i$ maps θ_i, the externality embodied in the commodity i, to the price $p_i = P_i(\theta_i)$ of good i with intensity θ_i.
- Prices for factors of production are standard prices, and we note $q \in \mathbb{R}^{\mathcal{K}}$ the vector of factor prices (i.e. q_k is price of factor k). We assume factors have no embodied externality.

Firms: maximization behavior

- When firm j uses production factors l, and inputs x of intensity θ, its profits are:

$$\pi_j(z, \theta; q, P, t) = P_j(\hat{\theta}_j) y_j(l, x) - q \cdot l - P(\theta) \cdot x - t G_j(l, x) \quad (2)$$

  where the $\hat{\theta}_j$ denotes the intensity computed from the balance at the firm level, e.g.

$$\hat{\theta}_j F_j(l, x) = G_j(l, x) + \theta \cdot x; \quad (3)$$

- Externality produced at the firm level is directly taxed by the government through t.
- In a competitive setting, firms take factor prices and goods price schedules as given, and maximize their profits as defined in (2).

$$\mathcal{P}_j(q, P, t) := \arg\max_{z,\theta} \pi_j(z, \theta; q, P, t) \quad (4)$$

Consumers

- Individuals consume only goods and not production factors. Individual h's consumption is $c_h = (c_{ih})_{i \in \mathcal{I}} \in \mathbb{R}^{\mathcal{I}}$.
- Her preferences are represented by a utility function $u_h : c_h \in \mathbb{R}^{\mathcal{I}}_{++} \mapsto u_h(c_h) \in \mathbb{R}$: it does not depend on the intensity of the externality embodied in the goods consumed.
- She is endowed with a vector of production factors $\omega_h \in \mathbb{R}^{\mathcal{K}}_{+}$, has a contractual claim to the share $\alpha_{hj} \geq 0$ of the profit π_j of the firm j and receives a lump sum income transfer from the government $T_h \Rightarrow$ her income is $I_h = P(\theta) \cdot \omega_h + \alpha_h \cdot \pi + T_h$
- The government raises the end-of-chain tax at the consumer level $\Rightarrow$ the consumer price per unit of goods is $P_i(\theta_i) + \tau\theta_i$.

$$\mathcal{C}_h(P, \tau, I_h) := \arg\max_{c_h, \theta} u_h(c_h) \text{ subject to } (P(\theta) + \tau\theta) \cdot c_h \leq I_h \quad (5)$$

Definitions

- A **production economy**

$$\mathfrak{E} = ((u_h, \omega_h)_{h \in \mathcal{H}}, (F_j, G_j)_{j \in \mathcal{I}})$$

is the list of a set of consumers $\mathcal{H}$ with their utility functions u_h and endowments ω_h; and, a set of producing firms $\mathcal{I}$, one for each commodity, with their production functions F_j and externality functions G_j.

- A **production economy with source and end-of-chain taxation**

$$\mathfrak{E}^T = ((u_h, \omega_h, \lambda_h)_{h \in \mathcal{H}}, (F_j, G_j)_{j \in \mathcal{I}}, t, \tau)$$

is a production economy as above plus a government with $t \geq 0$, $\tau > 0$ and a rebate scheme $(\lambda_h)_{h \in \mathcal{H}}$.

Properties 1: Feasibility and consistency

- An allocation $\mathfrak{a} = ((c_h)_{h\in\mathcal{H}}, (z_j)_{j\in\mathcal{I}})$ of a production economy $\mathfrak{E}$ is **feasible** when:

$$\sum_{h\in\mathcal{H}} \omega_h = \sum_{j\in\mathcal{I}} l_j \tag{6}$$

$$\sum_{j\in\mathcal{I}} y_j = \sum_{h\in\mathcal{H}} c_h + \sum_{j\in\mathcal{I}} x_j \tag{7}$$

- Intensities $\theta \in \mathbb{R}^{\mathcal{I}}$ are **consistent** with an allocation $\mathfrak{a} = ((c_h)_{h\in\mathcal{H}}, z_j)_{j\in\mathcal{I}})$ when they satisfy the embodied externality balances (1):

$$\forall j \in I : \quad \theta_j y_j = G_j(l_j, x_j) + \theta \cdot x_j$$

Properties 2: Nothing is lost, nothing is created

Source taxation and end-of-chain taxation have the same tax base.

Lemma (Aggregate level of externality)

Given a feasible allocation $\mathfrak{a}$ and consistent intensities θ, the aggregate level of externality $R(\mathfrak{a})$ produced by firms is the same as the aggregate level of externality embodied in consumption:

$$R(\mathfrak{a}) := \sum_{j \in \mathcal{I}} r_j = \theta \cdot \sum_{h \in \mathcal{H}} c_h \tag{8}$$

where $r_j = G_j(l_j, x_j)$.

Intuition: No free disposal of goods! Feasibility requires output=input+consumption.

Equilibrium with end-of-chain taxation

An equilibrium $\mathfrak{e} = ((c_h)_{h\in\mathcal{H}}, (z_j, \theta_j)_{j\in\mathcal{I}}, q, P)$ of an economy $\mathfrak{E}^T$ with end-of-chain taxation $\tau > 0$ is a list of an allocation $\mathfrak{a}(\mathfrak{e}) = ((c_h)_{h\in\mathcal{H}}, (z_j)_{j\in\mathcal{I}})$, intensities θ, factor prices q and price schedules P, such that :

1. the allocation $\mathfrak{a}(\mathfrak{e})$ follows (6) and (7) (feasibility);
2. intensities θ follow (1) (consistency);
3. $\forall h \in \mathcal{H} : (c_h, \theta) \in \mathcal{C}_h(P, \tau, I_h)$ with $I_h = q \cdot \omega_h + \alpha_h \cdot \pi^E(P, t) + \lambda_h(t + \tau)R(\mathfrak{a})$ (consumer's maximisation);
4. $\forall j \in \mathcal{I} : (z_j, \theta) \in \mathcal{P}_j(q, P, t)$ (producer's maximisation).

Pure source tax economy

A pure source tax economy $\mathfrak{E}^S = ((u_h, \omega_h, \alpha_h, \lambda_h)_{h \in \mathcal{H}}, (F_j, G_j)_{j \in \mathcal{I}}, t)$ is a production economy $((u_h, \omega_h)_{h \in \mathcal{H}}, (F_j, G_j)_{j \in \mathcal{I}})$ plus a government with a source tax $t > 0$ and a rebate scheme $(\lambda_h)_{h \in \mathcal{H}}$.
$\rightarrow$ The use of Pigovian taxes is classic; there is no need for specifying intensities as the externalities are covered at the source.
$\rightarrow$ The behavior of producers and consumers is simplified.

An equilibrium $\mathfrak{e} = ((c_h)_{h \in \mathcal{H}}, (z_j)_{j \in \mathcal{I}}, q, p)$ of an economy $\mathfrak{E}^S$ with source taxation is a list of an allocation $\mathfrak{a}(\mathfrak{e}) = ((c_h)_{h \in \mathcal{H}}, (z_j)_{j \in \mathcal{I}})$, factor prices q and good prices p (no price schedules), such that

- the allocation is feasible,
- consumption maximizes utility,
- production maximizes profits,
- tax revenues are rebated according to λ.

Existence and efficiency

- **Proposition 1: an equilibrium of an economy with source taxation can be mapped to an equilibrium of an economy with source and end-of-chain taxation.**
  Hint: even though the economy does not have intensities playing any role in equilibrium, they will endogenously evolve and replicate the same allocation as with end-of-chain taxation.

- **Proposition 2: an equilibrium for an economy with end-of-chain taxation can be mapped to an equilibrium of an economy with source taxation.**
  Hint for the proof: competition ensures that (prices+tax) are the smallest possible under end-of-chain taxation → unique. Then check that the conditions for a source tax equilibrium are satisfied.

Propositions

Proposition 1: Let $\mathfrak{e} = ((c_h)_{h\in\mathcal{H}}, (z_j)_{j\in\mathcal{J}}, p)$ be an equilibrium for an economy with source taxation $\mathfrak{E}^S = ((u_h, \omega_h, \alpha_h, \lambda_h)_{h\in\mathcal{H}}, (F_j, G_j)_{j\in\mathcal{J}}, t)$ and $\theta(\mathfrak{e})$ the consistent intensities defined in the lemma. Take any end-of-chain tax level $0 < \tau' \leq t$. Then $\mathfrak{e}' = ((c_h)_{h\in\mathcal{H}}, (z_j,)_{j\in\mathcal{J}}, \theta(\mathfrak{e}), P)$, where $P_j(\theta) = \max(p_j - \tau'\theta_j, 0)$, is an equilibrium for an economy with end-of-chain taxation $\mathfrak{E}^E = ((u_h, \omega_h, \alpha_h, \lambda_h)_{h\in\mathcal{H}}, (F_j, G_j)_{j\in\mathcal{I}}, t', \tau')$ with $t' = t - \tau'$.

Property: Let $\mathfrak{e}'$ be the equilibrium constructed in the proposition above. Then $P_j(\theta(\mathfrak{e})) = p_j - \tau'\theta_j(\mathfrak{e})$, and $P_j'(\theta(\mathfrak{e})) = -\tau_j'$.

Proposition 2: Let $\mathfrak{e} = ((c_h)_{h\in\mathcal{H}}, (z_j)_{j\in\mathcal{J}}, \theta, P)$ be an equilibrium for an economy with end-of-chain taxation $\mathfrak{E}^E = ((u_h, \omega_h, \alpha_h, \lambda_h)_{h\in\mathcal{H}}, (F_j, G_j)_{j\in\mathcal{J}}, t, \tau)$. Then $\mathfrak{e}' = ((c_h)_{h\in\mathcal{H}}, (z_j)_{j\in\mathcal{J}}, p')$ where $p' = P(\theta) + \tau\theta$ is an equilibrium of the economy with source taxation $\mathfrak{E}^S = ((u_h, \omega_h, \alpha_h, \lambda_h)_{h\in\mathcal{H}}, (F_j, G_j)_{j\in\mathcal{J}}, t')$ with $t' = t + \tau$.

Corollary 1

The above 2 propositions imply:

1. There is equivalence between any equilibrium with a mix of source and end-of-chain taxes and a unique well-defined (Pigovian) pure source tax equilibrium.

2. What only matters for the allocation and aggregate externality is the sum of $t + \tau$.

3. Any equilibrium allocation with $\tau > 0$ is equivalent to an equilibrium allocation with linear price schedules.

Corollary 2

- If, under assumptions A on the economy with source taxation, there is a general equilibrium of this economy that has property P,
- then under the corresponding assumptions A on the economy with end-of-chain taxation, there is also a general equilibrium of that economy that has property P.

Intuition : Since our framework places only minimal structure on preferences, technologies, and the externality, any assumption A and any property P formulated in terms of the allocation transfer between the two regimes.

Illutration. A: Feasibility

One production factor 'labor', $\mathcal{K} = \{0\}$ and two commodities 'metal', and 'manufactured goods', labeled by the subscript $i \in \mathcal{I} = \{1, 2\}$. Production of metal emits CO_2.

1. Household h is endowed with one unit of labor only, $\omega_h = (1, 0, 0)$ and: $u_h(c_h) = c_{h,2}$.
2. Metal-producing firm $j = 1$: $F_1 = \{(-l_1, y_1, 0) | l_1, y_1 \geq 0,\ y_1 \leq l_1\}$. CO_2 emissions: $G_1((-l_1, y_1, 0)) = y$.
3. Manufacturing firm $j = 2$: $F_2 = \{(-l_2, -x_{21}, y_2) | l_2, x_{21}, y_2 \geq 0, y_2 \leq 2\sqrt{l_2 x_{21}}\}$. No CO_2 emissions: $G_2 = 0$.

We restrict to "efficient" allocations ($l_2 = 1 - l_1$ and firms operate at their production frontiers).

An allocation $\mathfrak{a} = (c_h, z_1, z_2)$ of the production economy is feasible, when for any labor used in the metal-producing sector $l_1 \in (0, 1)$,
$c_h = (0, 0, 2\sqrt{l_1(1 - l_1)}$, $z_1 = (-l_1, l_1, 0)$,
$z_2 = (-(1 - l_1), -l_1, 2\sqrt{l_1(1 - l_1)})$.
The aggregate externality generated by this allocation is l_1.

Illutration. B: Consistent intensities

- The balance (1) for firm 1: $\theta_1 l_1 = l_1$: externality embodied in metal is equal to externality emitted directly by the firm, since there is no good input.
- For firm 2: $\theta_2 2\sqrt{l_1(1-l_1)} = \theta_1 l_1$: externality embodied in manufactured good is equal to externality embodied in metal input, since no externality is directly emitted.
- This gives

$$\theta_1 = 1 \; ; \; \theta_2 = \sqrt{l_1/(4-4l_1)} \tag{9}$$

Aggregate externality is $R = l_1$ and we verify that the externality embodied in final consumption $\theta_2 2\sqrt{l_1(1-l_1)} = l_1$ is equal to aggregate externality (lemma).

Illutration. C: Equilibrium with end-of-chain taxation 1

1. Consumer h:

$$\max_{c_{2,h},\theta_3} c_{2,h} \text{ subject to} \left(P_2(\theta_2)+\tau\theta_2\right)c_{2,h} \leq q+T_h$$

2. Metal production $i=1$ solves

$$\max_{l_1} P_1(\theta_1)l_1 - ql_1$$

3. Production of firm 2 satisfies $y_2 = 2\sqrt{l_2 x_{21}}$ and $\theta_2 y_2 = \theta_1 x_{21}$, so that:

$$\max_{l_2;x_{21};\theta_1} P_2\left(\frac{1}{2}\theta_1\sqrt{x_{21}/l_2}\right)2\sqrt{l_2 x_{21}} - ql_2 - P_1(\theta_1)x_{21}$$

Illutration. C: Equilibrium with end-of-chain taxation 2

- Consumer's FOCs transmit the end-of-chain taxation τ into a local property of the manufacturing good price schedule: $P_2'(\theta_2) = -\tau$.
- The manufacturing firm's FOCs then transmit this information into the metal price schedule $P_1'(\theta_1) = -\tau$.
- Metal production technology imposes $\theta_1 = 1$ and prices $P_1(\theta_1) = q$ and manufacturing FOCs then provide the inputs and intensity $\theta_2 = 1/(2\sqrt{1 + \tau/q})$ with price level $P_2(\theta_2) = (q + \tau/2)/\sqrt{1 + \tau/q}$.
- The factor and goods balances then provide the input and output levels $l_1 = 2q/(2q + \tau)$, $l_2 = 2(q + \tau)/(2q + \tau)$, $y_2 = c = 4q\sqrt{(1 + \tau/q)}/(2q + \tau)$.

The equilibrium has money neutrality: the allocation is not affected if taxes and prices rise by the same factor.

Illutration. D: Equilibrium with source taxation 1

We consider a source tax $t \geq 0$ with redistributed revenues $T_h = tR$.

- Consumer h:

$$\max_{c_{2,h},\theta_3} c_{2,h} \text{ subject to } p_2 c_{2,h} \leq q + T_h$$

FOCs result in:

$$\mathcal{C}_h^E(p,t,\tau,T_h) = \left\{ \; c_{2,h} = \frac{q+T_h}{p_2} \; \right\} \tag{10}$$

- Metal production $i = 1$ solves

$$\max_{l_1} p_1 l_1 - (q+t) l_1$$

after substituting $r_1 = y_1 = l_1$. FOCs result in $x_{11} = x_{12} = 0$ and:

$$\mathcal{P}_1(p,t) = \left\{ \; p_1 \leq q + t \perp y_1 \geq 0 \; \right\} \tag{11}$$

- Production of firm 2 satisfies $y_2 = 2\sqrt{l_2 x_{21}}$, so that profits it maximizes can be rewritten as follows:

$$\max_{l_2;x_{21};\theta_1} 2p_2\sqrt{l_2 x_{21}} - q l_2 - p_1 x_{21}$$

Illutration. D: Equilibrium with source taxation 2

We normalize prices to $q = 1$. The resulting equilibrium allocation is:

$$p_1 = 1 + t; p_2 = \sqrt{1+t} \tag{13}$$

$$l_1 = \frac{2}{2+t} \tag{14}$$

$$l_2 = \frac{2(1+t)}{2+t} \tag{15}$$

$$y_2 = \frac{4\sqrt{1+t}}{2+t} \tag{16}$$

$$c_h = \frac{1}{\sqrt{1+t}} + \lambda_h \frac{2t}{(2+t)\sqrt{1+t}} \tag{17}$$

Note that the solution satisfies $c_{12} + c_{22} = y_2$.
More specifically, the source and end-of-chain taxes are interchangeable for their effect on the allocation l_i, x_i, y_i, c_h. Yet, they have different effects on prices p_i and $P_i(.)$

Conclusion 1

- Formally determine the conditions for having source taxation equivalent to end-of-chain taxation.
- Footprint taxes require support by price schedules throughout economy
- Conditions for equivalence (e.g. no perfect circular flows between firms)
- Provide some illustrations.
- multiple firms / non-additive externalities / ...

Conclusion 2

→ Our propositions provide freedom for policies to implement a material reduction policy, or a reduction of the impact-footprint, through either resource taxes or through consumption externality taxes (footprint taxes)...or a mix
CBAM: can be interpreted as in-between source and end-of-chain regulation through intermediate-chain implementation.

→ The formal equivalence does not mean that both equilibria are equally demanding in terms of implementation.
Informational or institutional requirements differ.
The tax might have to be paid after the sale, for instance at the time of disposal (rationality burden)

→ Additional complexity is brought by uncertainty, distributional considerations, market imperfections

→ Strategic considerations play a role at the international macro level.
Downstream instruments have been criticized for creating free-riding incentives in open economies (Harstad, 2012; Asheim, 2013).

Illutration. C: Equilibrium with end-of-chain taxation 1

1. Consumer h:

$$\max_{c_{2,h},\theta_3} c_{2,h} \text{ subject to } (P_2(\theta_2) + \tau\theta_2)c_{2,h} \leq q + T_h$$

FOCs result in:

$$\mathcal{C}_h^E(P, \tau, I_h) = \left\{ \begin{array}{c} c_{2,h} = \frac{I_h}{P_2(\theta_2)+\tau\theta_2} \\ P_2'(\theta_2) = -\tau \end{array} \right\} \tag{18}$$

2. Metal production $i = 1$ solves

$$\max_{l_1} P_1(\theta_1)l_1 - ql_1$$

FOCs result in $x_{11} = x_{12} = 0$ and:

$$\mathcal{P}_1^E(P, t) = \left\{ \begin{array}{c} \theta_1 = 1 \\ P_1(\theta_1) \leq q \perp y_1 \geq 0 \end{array} \right\} \tag{19}$$

Illutration. C: Equilibrium with end-of-chain taxation 2

Production of firm 2 satisfies $y_2 = 2\sqrt{l_2 x_{21}}$ and $\theta_2 y_2 = \theta_1 x_{21}$, so that profits it maximizes can be rewritten as follows:

$$\max_{l_2;x_{21};\theta_1} P_2\left(\frac{1}{2}\theta_1\sqrt{x_{21}/l_2}\right)2\sqrt{l_2 x_{21}} - ql_2 - P_1(\theta_1)x_{21}$$

The FOCs result in:

$$\mathcal{P}_2^E(P,t) = \begin{cases} l_2 = \sqrt{\frac{P_1(\theta_1)-P_2'(\theta_2)\theta_1}{q}}\frac{y_2}{2} \\ x_{21} = \sqrt{\frac{q}{P_1(\theta_1)-P_2'(\theta_2)\theta_1}}\frac{y_2}{2} \\ P_2 \leq \sqrt{q/(P_1(\theta_1)-P_1'(\theta_1)\theta_1)}(P_1(\theta_1)-P_1'(\theta_1)\theta_1/2) \perp y \\ P_1'(\theta_1) = P_2'(\theta_2) \end{cases} \tag{20}$$

References

Anderson, R. M. and Duanmu, H. (2025). Cap-and-Trade and Carbon Tax Meet Arrow–Debreu. Econometrica, 93(2):357–393. Publisher: The Econometric Society.

Asheim, G. B. (2013). A Distributional Argument for Supply-Side Climate Policies. Environmental and Resource Economics, 56(2):239–254.

Baqaee, D. R. and Farhi, E. (2024). Networks, barriers, and trade. Econometrica, 92(2):505–541.

Clausing, K. A., Colmer, J. M., Hsiao, A., and Wolfram, C. (2025). The global effects of carbon border adjustment mechanisms. Technical report, National Bureau of Economic Research.

Farrokhi, F. and Lashkaripour, A. (2025). Can trade policy mitigate climate change? Econometrica, 93(5):1561–1599.

Harstad, B. (2012). Buy Coal! A Case for Supply-Side Environmental Policy. Journal of Political Economy, 120(1):77–115.

Jakob, M., Marschinski, R., and Hübler, M. (2013). Between a Rock and a Hard Place: A Trade-Theory Analysis of Leakage Under Production- and Consumption-Based Policies. Environmental and Resource Economics, 56(1):47–72.

Jakob, M., Steckel, J. C., and Edenhofer, O. (2014). Consumption- Versus Production-Based Emission Policies. Annual Review of Resource Economics, 6(1):297–318.

Steckel, J. C., Kalkuhl, M., and Marschinski, R. (2010). Should