When Pigouvian waste taxes (cannot) implement the first-best in general equilibrium

A CGE integrating material stocks and flows

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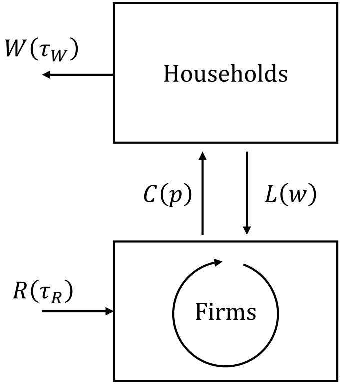
Environmental problems and economics

Macroeconomics thrived under different environmental problems:

- 1970s: a resource problem
  - 1971 GR, 1972 Club of Rome and ecological econ
  - Stiglitz, Solow, Heal...
- 1990s: a climate problem
  - 1993 Nordhaus DICE approach
  - Further critics and refinements (2008 Stern review, 2014 Golosov et al)
- now: a generic waste problem, connected to the resource and climate problems
  - Waste accumulation and dispersion (material and emissions)
  - Circular Economy

$\Rightarrow$ We need a coherent framework for economic analysis:
with material balance and consistency

Our paper



- A most simple economy (labor and consumption)

- Material consistency and balance $R = W$

$\Rightarrow$ Material content inherited in intermediary input X

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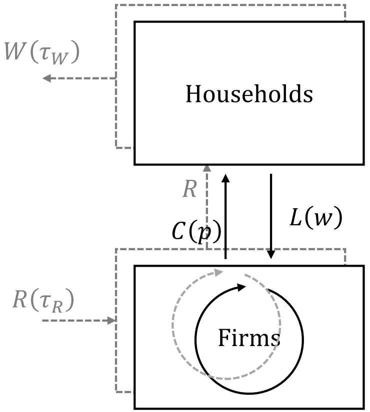

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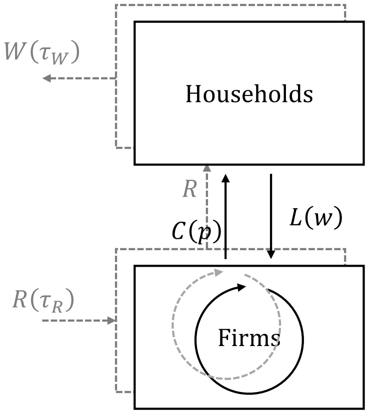


- A most simple economy (labor and consumption)

- Material **consistency** and **balance** $R = W$

$\Rightarrow$ Material content inherited in intermediary input X

(1) Taxing waste τ_W or resource τ_R is usually not equivalent

(2) We define an extended General Equilibrium, with endogenous balanced material flows

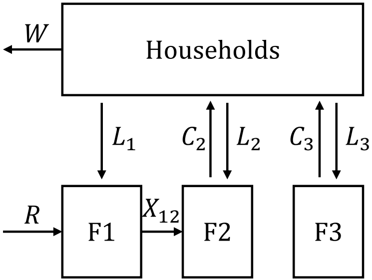
Overview this presentation

Literature

- Criticism addressed to (macro)economics regarding physical representation (Daly 1997 EcolEcon, Couix 2020 EJHET)
- Early work on material constraints in GE (Ayres and Kneese 1969 AER, Noll and Trijonis 1971 AER, Converse 1974 JET)
- Strict material balance in GE (Krysiak and Krysiak 2003 JEEM, Baumgärtner 2004 ERE)
  $\rightarrow$ Leontief economy + indus ecol approach (Ibenholt 2003 ERE, Masui 2005 EJOR)
- Material content as a product characteristic $\rightarrow$ hedonic pricing of products (Rosen 1974 JPE, Leland 1977 AER, Drèze and Hagen 1978 Econometrica)
- Debate on the efficiency of upstream/downstream instruments for waste (Sigman 1995 RAND, Palmer and Walls 1997 JPE, Calcott and Walls 2000 AER Walls and Palmer 2001 JEEM,...)
- Recent representation of material flows: exogenous material intensities and soft coupling of CGE and IE models (e.g. GTAP-Exiobase)

A simple economy

We draw a 3-sector economy (mining, manufacturing, services), with material balance



$$Y_1 = \min\{L_1, R\} \tag{1}$$

$$Y_2 = Y_1^{\frac{1}{2}} L_2^{\frac{1}{2}} \tag{2}$$

$$Y_3 = L_3 \tag{3}$$

$$U = C - \alpha W = Y_2^{\frac{2}{3}} Y_3^{\frac{1}{3}} - \alpha W \tag{4}$$

$$\bar{L} = L_1 + L_2 + L_3 \tag{5}$$

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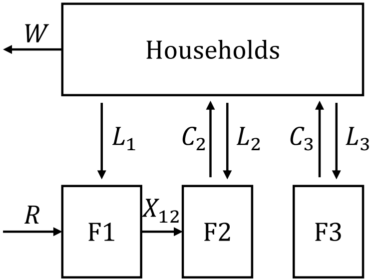

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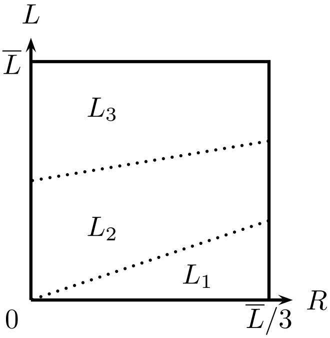
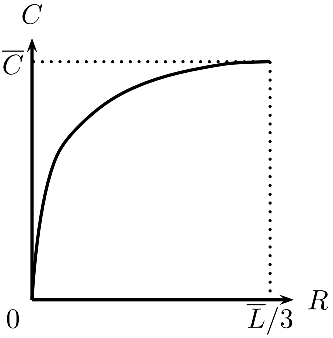
Leontief production in mining industries: material content is key.
CD in manufacturing industries: substitution of labour for material allowed

Optimal allocation



Labour shares, dependence on resource



Consumption good, dependence on resource

$$L_2 = L_3 = \frac{1}{2}(\overline{L} - R) \Rightarrow C(R) = R^{\frac{1}{3}} \left(\frac{1}{2}\overline{L} - \frac{1}{2}R\right)^{\frac{2}{3}} \quad (6)$$

Competitive equilibrium

Define material intensity for good 2 (kg/€): $\theta = R/Y_2$.
Profit maximization and household utility maximization.
Upstream and downstream taxation of material τ_R and τ_W.

Proposition

In a competitive equilibrium, upstream taxes τ_R implement the social optimum (same labor shares and consumption).

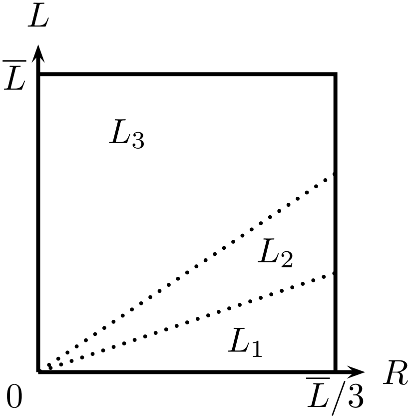
$$L_2 = L_3 = \frac{1}{2}(\overline{L} - R) \Rightarrow C_{up}(R) = R^{\frac{1}{3}} \left(\frac{1}{2}\overline{L} - \frac{1}{2}R\right)^{\frac{2}{3}}$$

Proposition

Downstream taxes τ_W give strictly lower consumption for the same resource use: $C_{down}(R) < C_{up}(R)$.

$$R = L_1 = L_2, L_3 = (\overline{L} - 2R) \Rightarrow C_{down}(R) = R^{\frac{2}{3}}(\overline{L} - 2R)^{\frac{1}{3}}$$

Waste taxes allocation: market failure



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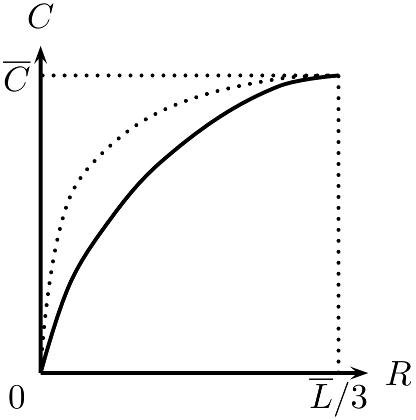
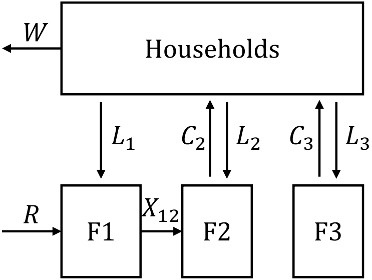


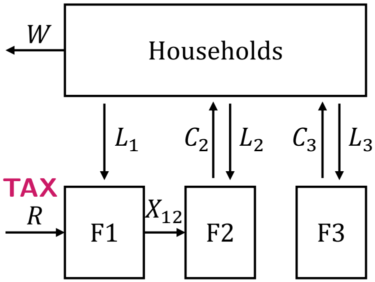
Consumption good, dependence on resource (FB=dotted line)

Market failure with a waste tax



Resource tax: efficient,
Waste tax: not efficient
→ for the same tax level, more material flow reduction with resource tax.

Market failure with a waste tax



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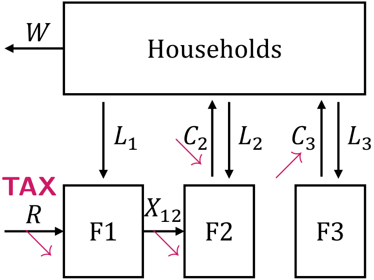

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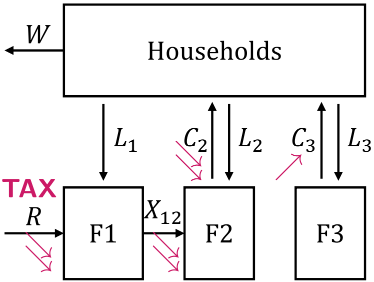

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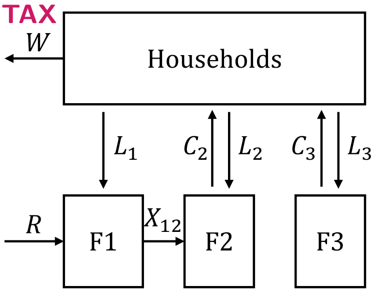
Resource tax: prices + material content adjust ; consumption basket adjusts = 2 mechanisms

Market failure with a waste tax



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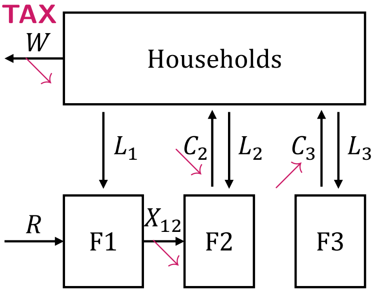

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→ for the same tax level, more material flow reduction with resource tax.

Resource tax: prices + material content adjust ; consumption basket adjusts = 2 mechanisms

Waste tax: consumption basket adjusts = 1 mechanism
→ *Households do not transfer information on their preferences for material intensity to Firm 2.*

Restoring waste/resource equivalence

Theorem

Equivalence between waste and resource taxation is restored under one of these conditions:
- The economy is fully Leontief
- There is a sufficiently ***fine grid of goods*** *with complete price information also for goods not produced*
- There is ***complete hedonic information*** *on goods price variation with material intensity, also for material intensity levels not produced.*
Otherwise, only an upstream resource tax can implement the first-best.

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Leontief economy: end consumption C is linear in resource R

$\rightarrow$ Krysiak & Krysiak JEEM 2005

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Fine grid, firms doubled indexed $\{2, \theta\}$, with $\theta = X_{12,\theta}/Y_{2\theta}$

$$U = \left(\int_0^\infty Y_{2,\theta} d\theta \right)^{\frac{2}{3}} C_3^{\frac{1}{3}} - \alpha W \quad \text{and} \quad Y_{2,\theta} = \min\{\frac{X_{12\theta}}{\theta}, \theta \cdot L_{2,\theta}\} \quad (7)$$

$\rightarrow \theta$ chosen to minimize costs: $p_2(\theta)$ (cf. Jones 2005 QJE)

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The consumer transfers information on its preference on material content of goods: add hedonic pricing of material goods (Rosen JPE 1974): $p_2(\theta)$

Discussion

Are the equivalence conditions realistic?

- Leontief economy: very constraining for economics
- A fine grid of goods: means that every single type of good with all material intensities can be produced... (think: cars)
- Complete hedonic information: information on quantities, prices and **price derivatives** need to be available

Discussion

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What about **carbon taxation**?

- Economists argue they work
- One might view carbon taxes as waste taxes on carbon exiting the economy (and being released in the atmosphere)

▶ One could also argue that they are implemented as resource taxes: fuels are bought as the sole purpose of burning it, not embedded in goods (except when buying ff for cars/residential heating).

One step further: addition to macro models

We generalize the analysis to a Computable General Equilibrium (CGE).
Objective(s):

- Used for **climate** policies ;
- To be used for **circular economy** analysis ;

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Objective(s):

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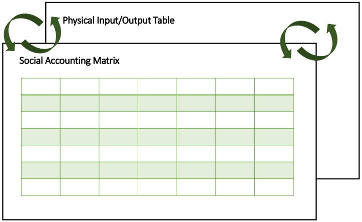
- To be used for **circular economy** analysis ;

But macro models mostly neglect physical consistency, CGE and material flows: soft link or rudimentary (e.g. exogenous material intensities)

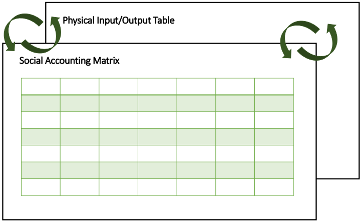
- Precise **sectoral** representation and dependencies ;
- Social Accounting Matrix (SAM) structure relates to Input/Output (IO) and Material Flow Analysis (MFA) in **industrial ecology**.

Setup of CGE+CE



- I industrial sectors, intermediary X_{IJ}, output Y_I
- H Consumer types, $C_{I,H}$
- Factors: capital and labor
- Transfers to the government, and government consumption $C_{I,G}$

Setup of CGE+CE



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We match SAM + PIOT structures.
Material intensity of output and intermediate deliveries: $(\theta_{..})$:

$$Y_{m,i} = \theta^{Y}_{m,i} Y_i \; ; \quad X_{m,i,j} = \theta^{X}_{m,i,j} X_{i,j} \; ; \quad C_{m,i,h} = \theta^{C}_{m,i,h} C_{i,h} \tag{7}$$

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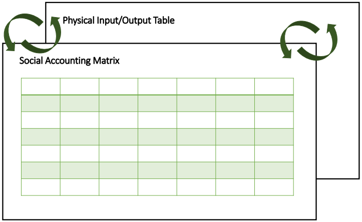

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The previous small economy is a specific case of this general model
What is the rule for endogenously adjusting the $\theta_{..}$?

Physical Input Output Table (PIOT), assumptions 0

	Firms (I)	Factors (F)	Cons (H_A)	Inv	Instit (G)	Environment	Capital	Outflows
I	X^M	0	$C^M_{I,H}$	$C^M_{I,inv}$	$C^M_{I,G}$	W^M_I	0	Outflow by I
F	0	0	0	0	0	0	0	Outflow by F
H	0	0	0	0	0	W^M_H	0	Waste by H
Inv	0	0	0	0	0	0	$\Delta^+ K^M$	Capital increase
G	0	0	0	0	0	W^M_G	0	Waste by G
Env	R^M	0	0	0	0	0	0	Extraction
Cap	0	0	0	0	0	$\Delta^- K^M$	0	Depreciation
	Inflow by I	Inflow by F	Inflow by H	Inflow by inv	Inflow by G	Sink	Gross accum.	

The PIOT is fully balanced (row sum = col sum)

Assumption: Mining sector has fixed ratio of material content per unit of output (cf Leontief sector 1 in simple economy), and fixed ratio for industrial waste:

$$\rho_{m,i} = \frac{R_{m,i}}{Y_i} \quad \text{and} \quad \epsilon_{m,i} = \frac{W_{m,i}}{\sum_j X_{m,j,i} + R_{m,i}}$$

PIOT adjustement, which assumption ?

Assumption 1a: material intensities are independent of the use of a good: $\theta^X_{m,i,j} = \theta^C_{m,i,g/h} = \theta_{m,i}$:

- Relaxes Krysiak and Krysiak 2003 assumption with non-constant intensities
- But not coherent with real observation (cf McCarthy et al 2018): e.g. light and heavy cars

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- But not coherent with real observation (cf McCarthy et al 2018): e.g. light and heavy cars

Assumption 1b: rows scale proportionally to keep balance (rowsum=colsum) for all m, i, $\theta_{m,i,j/g/h} = \lambda_{m,i}\bar{\theta}_{m,i,j/g/h}$ (with $\bar{\theta}$ the benchmark):

$$\theta_{m,i} Y_i = \sum_j \lambda_{m,i}\bar{\theta}_{m,i,j} X_{i,j} + \sum_{g,h} \lambda_{m,i}\bar{\theta}_{m,i,g/h} C_{i,g/h} \tag{8}$$

Eg: if steel in private cars is reduced by $x\%$, then also in trucks used by firms (if produced by same sector).

Material balance for input/output of products

	Firms (I)	Factors (F)	Cons (H_A)	Inv	Instit (G)	Environment	Capital	
I	X^M	0	$C^M_{I,H}$	$C^M_{I,inv}$	$C^M_{I,G}$	W^M_I	0	Outflow by I
F	0	0	0	0	0	0	0	Outflow by F
H	0	0	0	0	0	W^M_H	0	Waste by H
Inv	0	0	0	0	0	0	$\Delta^+ K^M$	Capital increase
G	0	0	0	0	0	W^M_G	0	Waste by G
Env	R^M	0	0	0	0	0	0	Extraction
Cap	0	0	0	0	0	$\Delta^- K^M$	0	
	Inflow by I	Inflow by F	Inflow by H	Inflow by inv	Inflow by G	Sink and accumulation		

$$\sum_j X^M_{j,i} + R^M_i = \underbrace{\sum_j X^M_{i,j} + \sum_h C^M_{i,h} + \sum_g C^M_{i,g}}_{Y^M_i} + \underbrace{W^M_i}_{\epsilon_i \sum_j X^M_{ji} + R^M_i} \tag{9}$$

I equations: consistent vector for (relative) material intensity of production (**Asm. 1a**: $\theta_{m,i}$ or **Asm. 1b**: $\lambda_{m,i}$).

Competitive equilibrium with material balance

	Firms (I)	Factors (F)	Cons (H_A)	Inv	Instit (G)	Environment	Capital	Outflows
I	X^M	0	$C^M_{I,H}$	$C^M_{I,inv}$	$C^M_{I,G}$	W^M_I	0	Outflow by I
F	0	0	0	0	0	0	0	Outflow by F
H	0	0	0	0	0	W^M_H	0	Waste by H
Inv	0	0	0	0	0	0	$\Delta^+ K^M$	Capital increase
G	0	0	0	0	0	W^M_G	0	Waste by G
Env	R^M	0	0	0	0	0	0	Extraction
Cap	0	0	0	0	0	$\Delta^- K^M$	0	Depreciation
	Inflow by I	Inflow by F	Inflow by H	Inflow by inv	Inflow by G	Sink	Gross accum.	

Lemma

Under assumptions 0 and 1b (the weaker one), given a competitive equilibrium, a unique vector λ exists so that material balance holds.

Theorem

A competitive equilibrium with material balance with resource taxes implements a cost-efficient allocation. With a waste tax, it is generally not cost-efficient (cf Simple economy).

Set up

- We calibrate with GTAP data and material data
  - 1 region
  - 2 materials (iron + carbon)
  - 8 sectors
  - Cobb Douglas
  - fill in data: economic + iron + fossil fuel
- Scenarios
  - BAU + (iron ore tax + iron waste tax) + (fossil fuel extraction tax + GHG tax)
  - ore/waste/ff/GHG taxes are on material flows
  - VAT adjusted so that government as a consumption as constant share of GDP
  - Static scenarios, sensitivity on tax levels

Upstream vs Downstream taxation

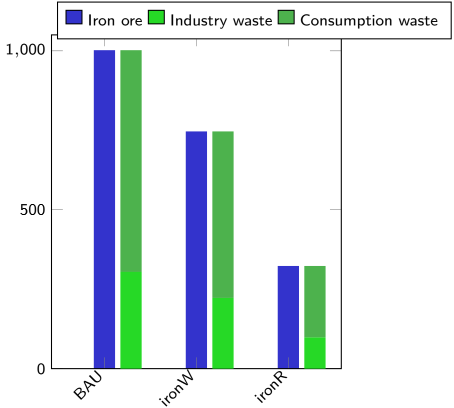


Figure: Input/Output material balance Iron (Mt)

- Material flows adjust endogenously
- But we keep material balance
- Balances can also be observed at sector level, etc
- Upstream vs downstream (ironR VS ironW) at 2000$/t.

Upstream vs Downstream taxation

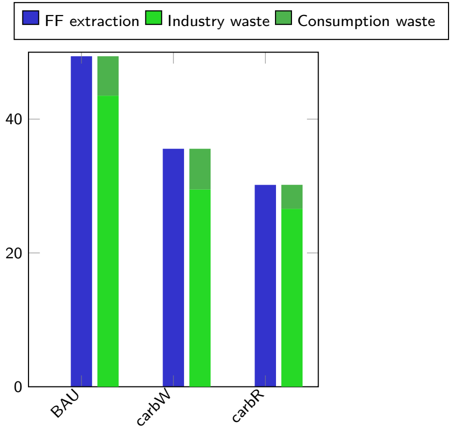
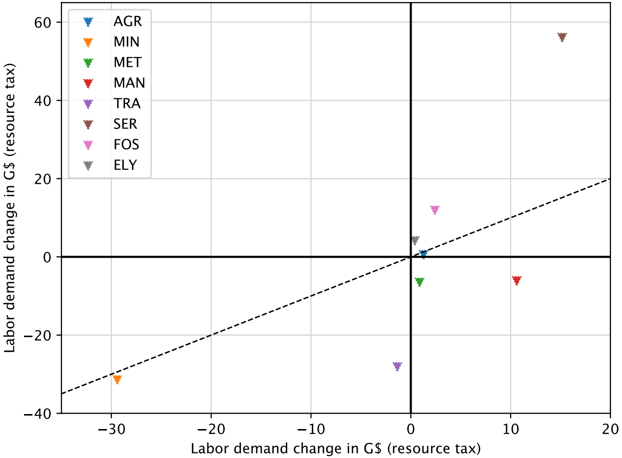


Figure: Input/Output material balance carbon ($GtCO_2e$)

- Material flows adjust endogenously
- But we keep material balance
- Balances can also be observed at sector level, etc
- Upstream vs downstream (carbR VS carbW) at 50$/t.
- Less up/down difference than with iron

Labor adjustments



With a a 200Mt iron reduction: from mining to services: sectors substitution + material reduction (when resource is taxed)

Conclusion and further work

- Importance of endogenous mapping of constrained/balanced material flows (common criticism of macroeconomics)
- Market failure: consumers do not transmit their preferences on material intensities
- Resource taxation is efficient, waste taxation is second best
- Restored optimum with either: (i) Leontief economy, (ii) fine grid of goods, (iii) hedonic pricing of material intensity
- Consistent CGE framework: economic + material equilibrium is defined

Upcoming work:

- Work on PIOT data (EXIOBASE, PIOLab?) for consistency with GTAP
- More realistic econ (CES...)
- Vintages and circular economy in a CGE

Thank you !

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