The Good, the Bad and the Ugly

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Production or Disposal into Air, Water, or Land

We assume MEDs are $0 < \mu_{\mathrm{G}} < \mu_{\mathrm{B}} < \mu_{U}$







Pigou: If all activities taxable, then FBO tax = MED

- But illegal dumping is often hidden and difficult to penalize.
- Suppose monitoring is too costly, and enforcement is not feasible.
- What then is the SBO tax or subsidy rate on "good" cleaner methods (τ_{G}^{*}) and "bad" dirtier-but-legal methods (τ_{B}^{*})?
- Enforcement is well covered already (Slemrod, 2019 JEL).
- We could model optimal audits, penalties, and imperfect enforcement. Low tax rates encourage compliance. But too many tradeoffs for analytical solutions.
- Complicated solutions are complex and difficult to interpret. But it would still include cross-price terms like the ones we find here.

Table 1: A Few Examples from Empirical or Numerical Economics Literature

Example	Production or Disposal Methods	Result suggesting a subsidy to a dirty (*i.e.*, "bad") form of disposal
Toxic chemical waste	Good: recycling Bad: legal disposal Ugly: dumping	Sullivan (1987): Optimal subsidy for legal disposal, 34.9% of price, "is more efficient than the optimum enforcement program" (p.65).
Household solid waste	Good: recycling Bad: garbage Ugly: dumping	Fullerton and Kinnaman (1996): An 80-cent price per bag reduces garbage but increases dumping by a third of that amount.
Informal sector brick oven fuels (Mexico)	Good: renewables Bad: propane Ugly: used tires	Blackman and Bannister (1998): Encouraging propane can avoid "cheap, highly polluting fuels such as used tires and scrap wood" (p.1).
Used motor oil	Good: re-refining Bad: legal disposal Ugly: dumping	Sigman (1998): Illegal dumping of used motor oil rises in response to higher costs of legal waste disposal or higher costs of re-refining for reuse.
Industrial waste (Japan)	Good: recycling Bad: legal disposal Ugly: dumping	Ichinose and Yamamoto (2011): Funding the provision of additional legal waste treatment facilities would reduce illegal dumping.
Shale gas wells affect surface water	Good: reuse, recycling Bad: treated discharge Ugly: direct discharge	Olmstead *et al* (2013): "Direct discharge of fluids from well sites is illegal [but could be collected for] reuse, recycling, treatment, and disposal." (p. 4962)
Methane from oil and gas supply chain	Good: capture Bad: flaring Ugly: venting/leaking	Agerton *et al* (2023): Capture can produce energy, while "leaked volumes often are either not known or not reported" (p.267).
Vehicle emissions	Good: electric vehicle Bad: tested emissions Ugly: non-compliant	Bradt and Dorsey (2026): A new method to estimate the fraction of cars being driven with fraudulent emission test results.

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Five Contributions

- **First**, use logic of Corlett and Hague (CH,1953 REStud), about tax rates on two goods in utility when leisure cannot be taxed.
  - The SBO tax on bad disposal τ_B^* can be < τ_{G}^*, or even less than zero.
- **Second**, we build and linearize a new AGE model to find changes in all outcomes from a small change in each tax (& two special cases)
- **Third**, a new method to find *level* of each SBO tax rate: differentiate welfare, insert eq's for *changes*, get closed-form solution for each τ^*
- **Fourth**, we interpret results for pollution changes and SBO tax levels.
  - Identify marginal damage term, a CH term, and a cross-price term.
- **Fifth**, we calibrate the model for numerical illustrations.

Some relevant prior literature

- **Early SBO tax lit**: Corlett and Hague (1953) with 951 cites. Diamond (1973), Atkinson and Stiglitz (1976), Green and Sheshinski (1976), Sandmo (1976), Auerbach and Hines (2002).
- **SBO pollution tax with untaxed leisure**: Bovenberg and Goulder (1996). West and Williams (2007) estimate cross-price elasticity between gasoline and leisure and find they are complements.
- ***Everything* on garbage, recycling, dumping**: NASEM (2025 book)
- **None find SBO pollution taxes with an untaxable waste, …**
- **Except Sallee (2025),** which we show to be a special case.

Key Results

- **First**, PE elasticities with production, shares, resource constraints → very different GE elasticities for each outcome w.r.t. each tax price.
- **Second**, actual changes are what matter for setting SBO tax rates.
- **Third**, elasticities combine with share parameters and all three MEDs to determine SBO tax rates on good and bad disposal.
- **Fourth**, if $e_{UB} > 1$, and μ_U is 3 x μ_B, then $\tau_B^* < \tau_G^*$ (or even negative).
- **Thus**, optimal policy *subsidizes bad behavior* when even-worse ugly disposal (a) is highly damaging, (b) cannot be reduced directly, and (c) can be reduced by subsidizing that alternative.

Model Basics, Caveats, and Welfare Analysis

- No dynamics
- Only tax policy
- No costly monitoring
- Ignore other market failures
- Closed economy, CRTS
- n identical households

First, two simple special cases help explain our GE model: constant producer prices, no endogenous income, and no economy-wide resource constraint

$$p_i = c_i + \tau_i \text{ for } i = G, B, U$$

Household:

$$\mathcal{L} = \Psi[G, B, U;\ nG, nB, nU] + \lambda[I - p_G G - p_B B - p_U U]$$

Social Planner:

$$\frac{d\Psi}{\lambda I} = (\tau_G - \mu_G)\frac{G}{I}\hat{G} + (\tau_B - \mu_B)\frac{B}{I}\hat{B} + (\tau_U - \mu_U)\frac{U}{I}\hat{U}$$

first-best optimal tax rates are $\tau_G = \mu_G$, $\tau_B = \mu_B$, and $\tau_U = \mu_U$

Corlett & Hague (1953) result, as in Auerbach & Hines (2002)

$$G = G(p_G, p_B, p_U, I) \quad \Rightarrow \quad \hat{G} = a_{GG}\widehat{p_G} + a_{GB}\widehat{p_B} + a_{GU}\widehat{p_U} + \hat{I}$$

$$B = B(p_G, p_B, p_U, I) \quad \Rightarrow \quad \hat{B} = a_{BG}\widehat{p_G} + a_{BB}\widehat{p_B} + a_{BU}\widehat{p_U} + \hat{I}$$

$$U = U(p_G, p_B, p_U, I) \quad \Rightarrow \quad \hat{U} = a_{UG}\widehat{p_G} + a_{UB}\widehat{p_B} + a_{UU}\widehat{p_U} + \hat{I}$$

$$p_G = c_G + \tau_G \quad \Rightarrow \quad \widehat{p_G} = t_G\widehat{\tau_G}$$

$$p_B = c_B + \tau_B \quad \Rightarrow \quad \widehat{p_B} = t_B\widehat{\tau_B}$$

$$T = \tau_G G + \tau_B B \quad \Rightarrow \quad \hat{T} = \theta_{TG}\left(\widehat{\tau_G} + \hat{G}\right) + \theta_{TB}\left(\widehat{\tau_B} + \hat{B}\right) = 0$$

no externalities ($\mu_G = \mu_B = \mu_U = 0$)

$$\frac{t_B}{t_G} = \frac{a_{GB} + a_{GU} + a_{BG}}{a_{BG} + a_{BU} + a_{GB}}$$

using *ad valorem* tax rates $t_G \equiv \tau_G/p_G$ and $t_B \equiv \tau_B/p_B$.

Sallee (2025), with externalities & *with* a lump-sum tax

- Two green goods and two dirty-but-legal goods that policymakers choose not to tax.
- One exogenous tax change ($\widehat{\tau_B} > 0$) with no change in the other tax rate ($\widehat{\tau_G} = 0$).
- Use six linear eq. above to find six unknown changes ($\widehat{p_G}$, $\widehat{p_B}$, $\widehat{p_U}$, $\hat{G}$, $\hat{B}$, and $\hat{U}$).
- One untaxed (U). Insert those quantity changes into the welfare equation and solve:

$$\tau_G^* = \mu_G + \mu_U \frac{U(a_{UB}a_{BG} - a_{UG}a_{BB})}{G(a_{GB}a_{BG} - a_{GG}a_{BB})}$$

$$\tau_B^* = \mu_B + \mu_U \frac{U(a_{UB}a_{GG} - a_{UG}a_{GB})}{B(a_{BB}a_{GG} - a_{BG}a_{GB})}$$

- Sallee equations use partial derivatives and ours use elasticities (we show match).
- His point: each FBO tax rate requires only MED, but SBO rates need much more info.
- But also, with one untaxed, we use Allen (1938) conditions on elasticities to show:

$$\tau_G^* = \mu_G - \mu_U \quad \text{and} \quad \tau_B^* = \mu_B - \mu_U \qquad \text{FBO deposit-refund system}$$

Our Analytical General Equilibrium Model

- For tractability, keep it simple: one polluting good X and non-polluting good Y
  - Only one primary factor K in fixed supply but mobile (labor, capital, land)
  - So, linear production: $X = K_X/c_X$ and $Y = K_Y/c_Y$
- Fixed total waste W per unit of X in production or post-consumer disposal
- But flexible allocation: $X = W(G, B, U)$, like an isoquant combination of 3 inputs
- Each h.h. chooses own X and Y, but not total of each negative externality

$$\mathcal{L} = \Psi[W(G, B, U), Y;\ nG, nB, nU] + \lambda[I - p_X^F X - p_Y Y]$$

where $p_W X = p_G G + p_B B + p_U U$ and $p_X^F X = p_X X + p_W \mathrm{X}$

- Write 19 basic eqs & differentiate. Solve 19 linear eqs for the effect of one tax shock on all 19 changes (prices, quantities, welfare).

Lots of equations, but simple differentiation

- Prod^{n} functions; zero-profits $p_X X = p_K K_X$ and $p_Y Y = p_K K_Y$, *etc*.
- Resource constraint: $\bar{K} = K_X + K_Y + K_G + K_B + K_U$ (θ_{Ki} shares)
- Gov't budget constraint: $T = \tau_G G_X + \tau_B B_X$ (θ_{TG} , θ_{TB} shares)
- Fixed total government revenue.
- Income is $I = p_K \bar{K} + T$

$$X = K_X / c_X \quad \Rightarrow \quad \hat{X} = \widehat{K_X} \tag{3.1}$$

$$p_X X = p_K K_X \quad \Rightarrow \quad \widehat{p_X} + \hat{X} = \widehat{p_K} + \widehat{K_X} \tag{3.2}$$

$$Y = K_Y / c_Y \quad \Rightarrow \quad \hat{Y} = \widehat{K_Y} \tag{3.3}$$

$$p_Y Y = p_K K_Y \quad \Rightarrow \quad \widehat{p_Y} + \hat{Y} = \widehat{p_K} + \widehat{K_Y} \tag{3.4}$$

$$K_G = c_G G \quad \Rightarrow \quad \widehat{K_G} = \hat{G} \tag{3.5}$$

$$K_B = c_B B \quad \Rightarrow \quad \widehat{K_B} = \hat{B} \tag{3.6}$$

$$K_U = c_U U \quad \Rightarrow \quad \widehat{K_U} = \hat{U} \tag{3.7}$$

SKIP

$$\bar{K} = K_X + K_Y + K_G + K_B + K_U \quad \Rightarrow \tag{3.8}$$

$$0 = \widehat{K_X}\theta_{KX} + \widehat{K_Y}\theta_{KY} + \widehat{K_G}\theta_{KG} + \widehat{K_B}\theta_{KB} + \widehat{K_U}\theta_{KU}$$

$$p_G G = p_K c_G G + \tau_G G \quad \Rightarrow \quad \widehat{p_G} + \hat{G} = \theta_{Gp}(\widehat{p_K} + \hat{G}) + \theta_{G\tau}(\widehat{\tau_G} + \hat{G}) \tag{3.9}$$

$$p_B B = p_K c_B B + \tau_B B \quad \Rightarrow \quad \widehat{p_B} + \hat{B} = \theta_{Bp}(\widehat{p_K} + \hat{B}) + \theta_{B\tau}(\widehat{\tau_B} + \hat{B}) \tag{3.10}$$

$$p_U U = p_K c_U U + \tau_U U \quad \Rightarrow \quad \widehat{p_U} + \hat{U} = \theta_{Up}(\widehat{p_K} + \hat{U}) + \theta_{U\tau}(\widehat{\tau_U} + \hat{U}) \tag{3.11a}$$

$$\text{or} \quad p_U U = p_K c_U U \quad \Rightarrow \quad \widehat{p_U} + \hat{U} = \widehat{p_K} + \hat{U} \quad \text{with fixed } \tau_U = 0 \tag{3.11b}$$

$$p_W X = p_G G + p_B B + p_U U \quad \Rightarrow \quad \hat{X} + \widehat{p_W} = \theta_{XG}\left(\widehat{p_G} + \hat{G}\right) + \theta_{XB}\left(\widehat{p_B} + \hat{B}\right) + \theta_{XU}\left(\widehat{p_U} + \hat{U}\right) \tag{3.12}$$

$$p_X^F X = p_X X + p_W X \quad \Rightarrow \quad \widehat{p_X^F} + \hat{X} = \theta_{pX}(\widehat{p_X} + \hat{X}) + \theta_{pW}(\widehat{p_W} + \hat{X}) \tag{3.13}$$

SKIP

$$X = W(G, B, U) \quad \Rightarrow \quad \hat{X} = \theta_{XG}\hat{G} + \theta_{XB}\hat{B} + \theta_{XU}\hat{U} \tag{3.14}$$

$$\hat{G} - \hat{U} = \theta_{XG}(e_{GG} - e_{UG})\widehat{p_G} + \theta_{XB}(e_{GB} - e_{UB})\widehat{p_B} + \theta_{XU}(e_{GU} - e_{UU})\widehat{p_U} \tag{3.15}$$

$$\hat{B} - \hat{U} = \theta_{XG}(e_{BG} - e_{UG})\widehat{p_G} + \theta_{XB}(e_{BB} - e_{UB})\widehat{p_B} + \theta_{XU}(e_{BU} - e_{UU})\widehat{p_U}\,. \tag{3.16}$$

$$T = \tau_G G + \tau_B B \quad \Rightarrow \quad \hat{T} = \theta_{TG}\left(\widehat{\tau_G} + \hat{G}\right) + \theta_{TB}\left(\widehat{\tau_B} + \hat{B}\right) \tag{3.17}$$

$$I = p_K \bar{K} + T \quad \Rightarrow \quad \hat{I} = \frac{p_K \bar{K}}{I}\widehat{p_K} + \frac{T}{I}\hat{T} \tag{3.18}$$

$$\Psi = \Psi(X, Y;\, nG, nB, nU) \quad \Rightarrow \quad \hat{X} - \hat{Y} = \sigma_\Psi\left(\widehat{p_Y} - \widehat{p_X^F}\right) \tag{3.19}$$

Exogenous increase $\widehat{\tau_B} \equiv d\tau_B/\tau_B$, but including endogenous $\widehat{\tau_G}$:

$$\hat{U} = \varepsilon_{UB}\widehat{\tau_B} + \varepsilon_{UG}\widehat{\tau_G} \tag{4.1}$$

where $\varepsilon_{UB} \equiv \left[e_{UB}(1-\theta_{KU}) - e_{BB}(\theta_{KB}) - e_{GB}(\theta_{KG}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XB}\theta_{B\tau}$ and $\varepsilon_{UG} \equiv$ $\left[e_{UG}(1-\theta_{KU}) - e_{GG}(\theta_{KG}) - e_{BG}(\theta_{KB}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XG}\theta_{G\tau}$.

$$\hat{B} = \varepsilon_{BB}\widehat{\tau_B} + \varepsilon_{BG}\widehat{\tau_G} \tag{4.2}$$

where $\varepsilon_{BB} \equiv \left[e_{UB}(-\theta_{KU}) + e_{BB}(1-\theta_{KB}) - e_{GB}(\theta_{KG}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XB}\theta_{B\tau}$ and

$\varepsilon_{BG} \equiv \left[e_{UG}(-\theta_{KU}) - e_{GG}(\theta_{KG}) + e_{BG}(1-\theta_{KB}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XG}\theta_{G\tau}$.

$$\hat{G} = \varepsilon_{GB}\widehat{\tau_B} + \varepsilon_{GG}\widehat{\tau_G} \tag{4.3}$$

where $\varepsilon_{GB} \equiv \left[e_{UB}(-\theta_{KU}) - e_{BB}(\theta_{KB}) + e_{GB}(1-\theta_{KG}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XB}\theta_{B\tau}$ and

$\varepsilon_{GG} \equiv \left[e_{UG}(-\theta_{KU}) + e_{GG}(1-\theta_{KG}) - e_{BG}(\theta_{KB}) - \sigma_\Psi\theta_{pW}\theta_{KY}\right]\theta_{XG}\theta_{G\tau}$.

For an increase $\widehat{\tau_B}$, use linearized budget to solve for $\widehat{\tau_G}$ to insert above

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$$E_{TG}\widehat{\tau_G} = -E_{TB}\widehat{\tau_B} \tag{4.4}$$

where $E_{TG} \equiv \theta_{TG} + \theta_{TG}\varepsilon_{GG} + \theta_{TB}\varepsilon_{BG}$ and $E_{TB} \equiv \theta_{TB} + \theta_{TB}\varepsilon_{BB} + \theta_{TG}\varepsilon_{GB}$.

$$\hat{G} = E_{GB}\widehat{\tau_B} \quad \text{where} \quad E_{GB} \equiv \varepsilon_{GB} - \varepsilon_{GG}\frac{E_{TB}}{E_{TG}} \tag{4.5}$$

$$\hat{B} = E_{BB}\widehat{\tau_B} \quad \text{where} \quad E_{BB} \equiv \varepsilon_{BB} - \varepsilon_{BG}\frac{E_{TB}}{E_{TG}} \tag{4.6}$$

$$\hat{U} = E_{UB}\widehat{\tau_B} \quad \text{where} \quad E_{UB} \equiv \varepsilon_{UB} - \varepsilon_{UG}\frac{E_{TB}}{E_{TG}} \tag{4.7}$$

Substitute $X = W(G, B, U)$ into utility, so households maximize:

$$\mathcal{L} = \Psi[W(G, B, U), Y;\ nG, nB, nU] + \lambda[I - p_X^F X - p_Y Y]$$

Because n is large, they view nG, nB, nU as fixed.

Social planner maximizes utility subject to resource constraints:

$$\frac{d\Psi}{\lambda I} = (\tau_G - \mu_G)\frac{G}{I}\hat{G} + (\tau_B - \mu_B)\frac{B}{I}\hat{B} + (\tau_U - \mu_U)\frac{U}{I}\hat{U}$$

$d\Psi = 0$ at a welfare max. FBO at $\tau_G = \mu_G$, $\tau_B = \mu_B$, and $\tau_U = \mu_U$.

If $\tau_U = 0$, insert $\hat{G}$, $\hat{B}$, *and* $\hat{U}$; find the τ_G and τ_B that make $d\Psi = 0$.

The results are SBO tax rates τ_G^* and τ_B^*.

Closed-form SBO tax rates depend on all parameters

$$\tau_B^* = \frac{\mu_B + \underbrace{\mu_U \frac{U}{B}\left(\frac{E_{UB}}{E_{BB}}\right)}_{Corlett-Hague\ Term} + \underbrace{(\mu_G - \frac{T}{G_X})\frac{G}{B}\left(\frac{E_{GB}}{E_{BB}}\right)}_{Cross-Price\ Term}}{1 - E_{GB}/E_{BB}}$$

$$\tau_G^* = \frac{\mu_G + \underbrace{\mu_U \frac{U}{G}\left(\frac{E_{UG}}{E_{GG}}\right)}_{Corlett-Hague\ Term} + \underbrace{(\mu_B - \frac{T}{B_X})\frac{B}{G}\left(\frac{E_{BG}}{E_{GG}}\right)}_{Cross-Price\ Term}}{1 - E_{BG}/E_{GG}}$$

Start with MED term. CH term with E_{UB} for how τ_B^* affects U (with its MED, μ_U).

Add Cross-Price Term with E_{GB} for how τ_B^* affects G (with its MED, μ_G).

Each τ^* could be the shadow price on a mandate, or indirect subsidy (public spending to encourage good disposal, *e.g*, recycling).

Calibration

Table 2: Initial Equilibrium Parameter Values

Assumed Parameter Values		Calculated in Appendix K Parameter Values		Assumed Parameter Values	
θ_{KX} , θ_{KY}	0.35	$\theta_{XG}, \theta_{XB}, \theta_{XU}$	0.333	μ_G	0.05
$\theta_{KG}, \theta_{KB}, \theta_{KU}$	0.1	θ_{pX}	0.538	μ_B	0.15
$\theta_{G\tau}$, $\theta_{B\tau}$	0.1	θ_{pW}	0.462	μ_U	0.5
θ_{Gp}, θ_{Bp}	0.9	τ_G, τ_B	0.111	e_{UG}, e_{UB}	0.5
σ_Ψ	1	θ_{TG}, θ_{TB}	0.5	e_{GB}, e_{BG}	0.5
		T	0.0222	e_{GG}, e_{BB}, e_{UU}	-1

Table 3: Mapping Primary Allen PE Elasticities to Full GE Elasticities

Allen PE Elasticity	Assumed Value	$a_{ij} = e_{ij}\theta_{Xj}$	Intermediate Elasticity	Calculated Value	Full GE Elasticity	Calculated Value
e_{UG}	0.5	0.167	ε_{UG}	0.011	E_{UG}	0
e_{UB}	0.5	0.167	ε_{UB}	0.011	E_{UB}	0
e_{GB}	0.5	0.167	ε_{GB}	0.011	E_{GB}	0.050
e_{BG}	0.5	0.167	ε_{BG}	0.011	E_{BG}	0.050
e_{GG}	–1	–0.333	ε_{GG}	–0.039	E_{GG}	–0.050
e_{BB}	–1	–0.333	ε_{BB}	–0.039	E_{BB}	–0.050
e_{UU}	–1	–0.333	ε_{UU}	–0.039	E_{TG}	0.486
					E_{TB}	0.486

We assume values for the e_{ij} and then calculate the corresponding a_{ij} for the second special case below.

Table 4: PE Substitutes to GE Complements

Allen PE Elasticity	Assumed Value	Intermediate Elasticity	Calculated Value	Full GE Elasticity	Calculated Value
e_{UG}	0.5	ε_{UG}	0.011	E_{UG}	–0.053
e_{UB}	2.0	ε_{UB}	0.061	E_{UB}	0.051
e_{GB}	0.5	ε_{GB}	0.011	E_{GB}	0.048
e_{BG}	0.5	ε_{BG}	0.011	E_{BG}	0.105
e_{GG}	–1	ε_{GG}	–0.039	E_{GG}	–0.051
e_{BB}	–2.5	ε_{BB}	–0.089	E_{BB}	–0.099
e_{UU}	–2.5	ε_{UU}	–0.089	E_{TG}	0.486
				E_{TB}	0.461

Figure 1: Effects of Varying Key Parameters on the Two SBO Tax Rates

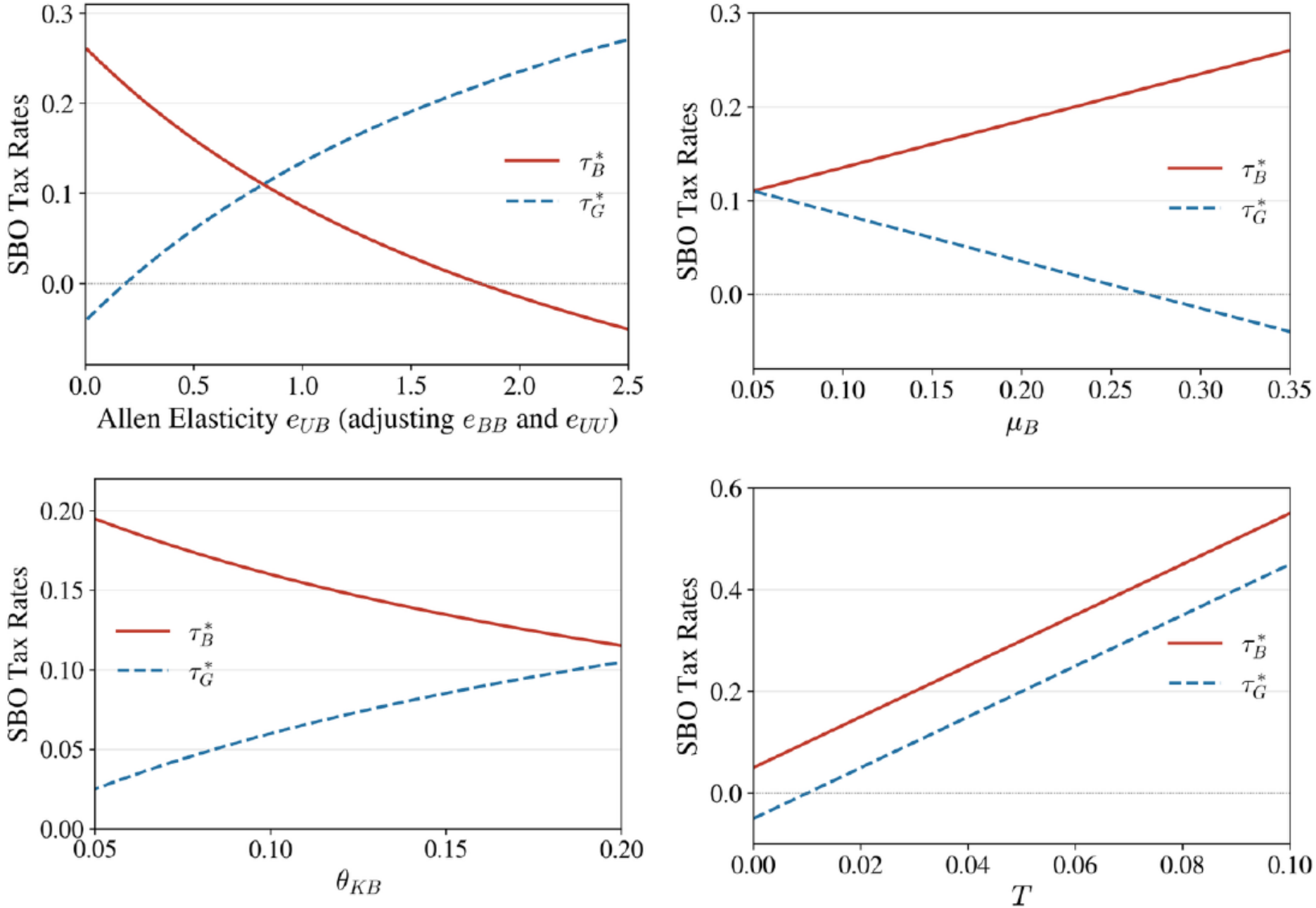


Figure 2: Relative SBO Tax Rates for Varying MED and Allen Elasticities

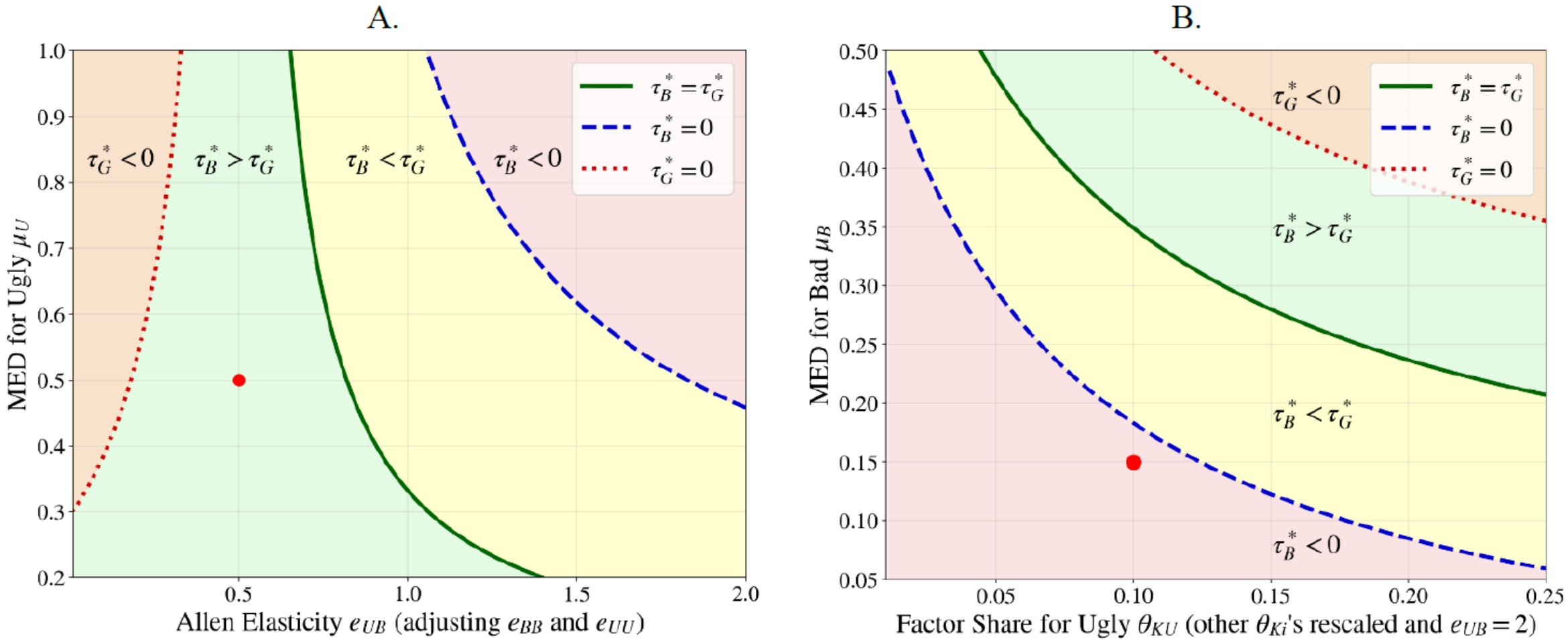
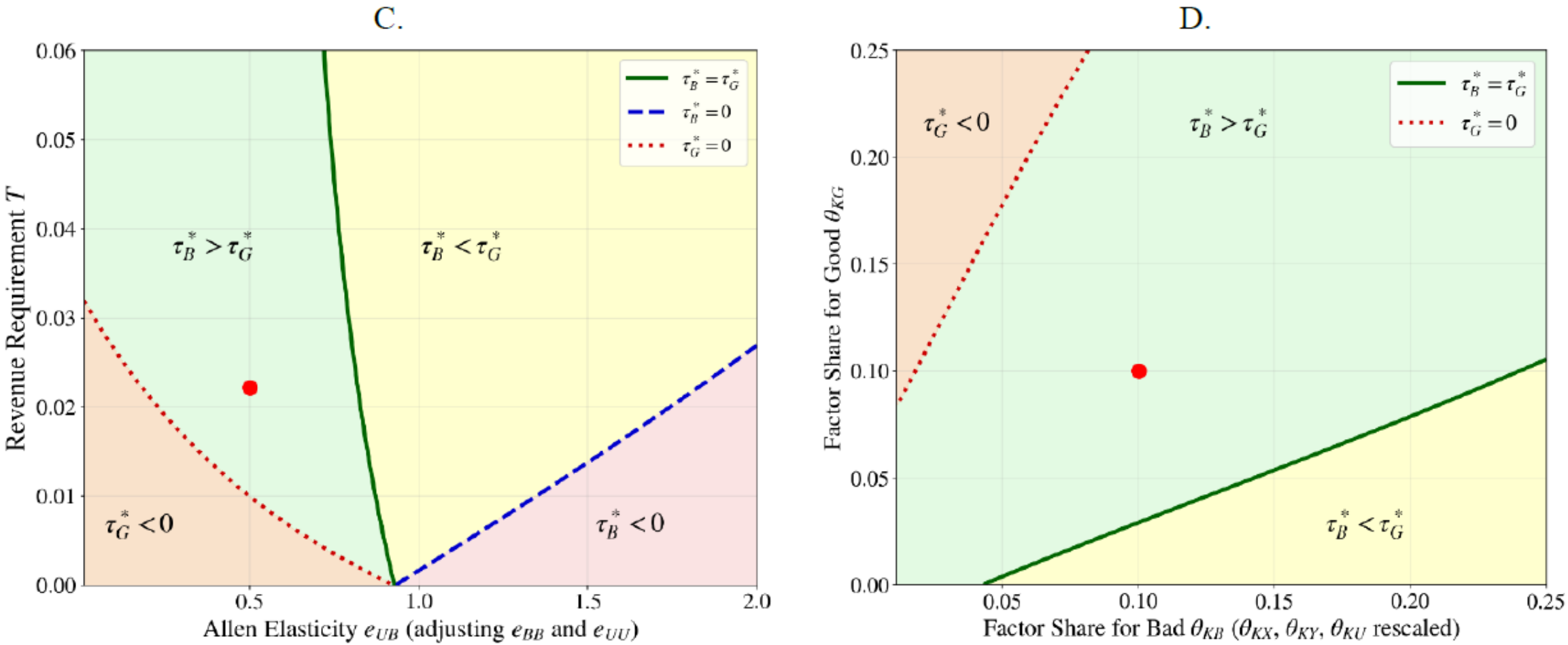


Figure 2: Relative SBO Tax Rates for Varying MED and Allen Elasticities (cont'd)



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- **Second**, we build and linearize a new AGE model to find changes in all outcomes from a small change in each tax (& two special cases)
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Thanks very much!