Adverse Selection as a Policy Instrument: Unraveling Climate Change

Cicala (Tufts), Hémous (U Zurich) and Olsen (U Copenhagen)

University of Namur, November 2023

Research question

- Economists' typical advice to tackle environmental externality: tax the externality at the source of harm (Pigouvian taxation).
  - E.g. carbon tax = social cost of carbon (or cap-and-trade system with a price = social cost of carbon).
- But in practice there are often obstacles to Pigouvian taxation:
  - jurisdiction (carbon tariffs), costly monitoring of emissions, political economy reasons, ...
  - How can we design policies to overcome these?
- Idea: exploit adverse selection to design better regulations.

Unraveling mechanism

- Akerlof (1970): markets can unravel in the presence of adverse selection.
- Can we use this insight to design better regulation?
    - Consider a setting where we do not initially tax emissions but we can tax output;
    - Allow firms to voluntarily reveal their true emission rate;
    - The cleanest firms will want to participate and be taxed at the emission level instead of the output tax;
    - Revealing that the remaining firms are dirtier;
    - Allowing to tax those more;
    - Leading to more revelation....

Preview of the results

- Compute sufficient statistics for the welfare gains of a certification program over an output tax.
- In a domestic setting:
  - Welfare gains result from reallocation of production and abatement gains;
  - Algorithm to unravel distribution;
  - Application to methane emissions from Permian Basin in Texas: voluntary emissions tax reduces methane by 80% per vintage, worth $1.2B/year.
- In an international setting with unilateral environmental policy:
  - Extend carbon policy and abatement incentives beyond jurisdiction
  - Program can but need not increase welfare.
  - Application to Brazilian steel: a well-calibrated certification program from OECD countries generates 3/4 of the welfare gains of the first best.
  - Certification program in line with European CBAM.

Literature review

- Our Approach: Apply Lessons from Private Markets.
  - Akerlof (1970)'s "unraveling".
- Voluntary Disclosures
  - Warranties, Audits (Grossman, 1981, Milgrom, 1986, 2008)
  - Product quality: used cars, HMO benefits (Lewis, 2011, Jin, 2005)
  - Downpayment for credit selection (Einav, Jenkins, and Levin, 2012)
- Use optional participation to unravel distribution
  - Electricity consumption: Borenstein (2005, 2013)

Outline of Talk

Modeling Framework: Domestic Setting

- Quasilinear utility, disutility from aggregate emissions:

$$U = C_0 + u(C) - vG$$

- Normalize price of the numeraire to 1 and denote price of the polluting good C, p: $u'(C) = p$.
- Unit mass of competitive, atomistic firms with convex cost $c(q)$.
    - Leading to supply function $s(p_i)$ where p_i is the post-tax price faced by firm i
- Market Clearing: $C = Q = \int_0^1 q(i)\,di$
- Heterogeneous emissions: $e \sim \Psi(e)$ on $[0, \overline{e}]$, pdf $\psi(e)$
- Outside good is clean, so that total emissions are:

$$G = \int_0^1 e(i)q(i)\,di = \int_{\underline{e}}^{\bar{e}} eq(e)\psi(e)\,de.$$

Policies

- Output tax t: all firms face a post tax price $p - t$.
    - Optimal output tax is $t = vE(e)$.
    - Optimal policy if emission rates are unobserved.
- Emission tax τ: firms face a post tax price $p - \tau e$
    - Optimal emission tax is $\tau = v$.
    - Optimal policy if emission rates can be directly observed.
    - But not if there are monitoring costs and emission tax may not be implementable directly (ex: methane leaks in Texas).

Voluntary certification: program (1)

- By default firms face an output tax t;
- But they can choose to reveal / certify their emission rate e, in which case they face an emission tax τ.
  - Certification involves some social costs $F \geq 0$; and the government may want to impose a certification tax f.
  - Output tax is set at $t = \tau E(e|NC)$ where NC denotes the set of uncertified firms.
- In equilibrium, firms choose to certify when

$$\pi(p - \tau e) - (F + f) \geq \pi(p - t).$$

Voluntary certification: program (2)

- Firms below a threshold $\hat{e}$ certify, firms above the threshold do not.
- Therefore, $t = \tau E\left[e|e > \hat{e}\right]$ and $\hat{e}$ obeys

$$\pi(p - \tau\hat{e}) - (F + f) = \pi(p - \tau E\left[e|e > \hat{e}\right]).$$

- Firms face the post tax price $p - \tau\varepsilon$ where ε is the effectively taxed emissions rate:

$$\varepsilon = e \begin{cases} e & \text{if} \quad e < \hat{e} \\ E(e|e > \hat{e}) & \text{if} \quad e \geq \hat{e} \end{cases}.$$

- If $F + f = 0$ we obtain full revelation.

Comparing certification program and output tax

- Compare the results of the certification program (denoted ^{V}) with those of the output tax (^{U}).
- To derive sharp characterization, assume that taxes or social cost of emissions are a small share of total costs. general case
  - For small τ, supply function is close to linear: $Q^{V}(p) = Q^{U}(p) + o(\tau)$ and prices are close to constant: $p^{V} = p^{U} + o(\tau)$.

Theorem

The differences in welfare and emissions between a voluntary certification program tax and an output tax are given by:

$$W^{V} - W^{U} = \left(v - \frac{\tau}{2}\right) \tau s'(p_0)\, Var(\varepsilon) - F\Psi(\hat{e}) + o\left(\tau^2\right)$$

$$G^{V} - G^{U} = -\tau s'(p_0)\, Var(\varepsilon) + o(\tau)$$

Optimal policy

- Social planner maximizes welfare under the constraints that:
  - Emissions can only be taxed if the certification cost is paid (any communication requires paying F);
  - Firms can mimick any emission rate weakly higher than their true emission rate.
- The optimal policy can be decentralized with:
  - An emissions tax $\tau = \nu$ for certified firms;
  - An output tax $t = \nu E[e|e > \hat{e}]$ for uncertified firms;
  - A certification tax $f = \nu \left[E[e|e > \hat{e}] - \hat{e}\right] s \left(p - \nu E[e|e > \hat{e}]\right)$;
  - Taxes are redistributed lump-sum.
- Therefore, there is "too much certification" in equilibrium (for $F > 0$):
  - When a firm certifies, it increases the tax paid by uncertified firms;
  - The social planner takes that pecuniary externality into account.

Unraveling Algorithm (1)

- What we have assumed so far:
  - The government does not know the emission rate of each firm,
  - But knows the distribution of emission rate and can "predict" $\widehat{e}$ and market outcomes.
- Assume instead that the government only knows the average emission rate.

Unraveling Algorithm (2)

- Government can introduce sequential certification:
  - Government chooses $t_n = \tau E\left(e|e > \widehat{e}_{n-1}\right)$ (with $e_0 = 0$).
  - Firms forecast the price p_n^e and certify if $\pi\left(p_n^e - \tau e\right) - F > \pi\left(p_n^e - t_n\right)$, leading to a certification threshold $\widehat{e}_n$.
  - Everyone observes certification and the market equilibrium with associated prices arise.
  - (in the simplest case p_n^e is constant but more generally we need some rule setting price expectation).
- The procedure converges monotonically toward the equilibrium level of certification $\widehat{e}$ when
  - i) $E[e|e > x] - x$ is decreasing in x
  - and ii) τ is small enough.

Abatement

- A second advantage of an emission tax (and therefore a certification program) is that it incentivizes abatement.
- A firm can reduce its emission rate by a by spending $b(a)$ per unit/
  - $b'(a) > 0$ and $b''(a) > 0$ for $a > 0$ with $b'(0) = b(0) = 0$.
  - Certified firms abate $a^* = b'^{-1}(\tau) = \tau / b''(0) + o(\tau)$.
- Emissions are further reduced:

$$G^V - G^U = -\tau \left(s'(p_0)\, Var(\varepsilon) + \frac{s(p_0)}{b''(0)} \Psi(\widehat{e}) \right) + o(\tau);$$

- And welfare increases further with:

$$W^V - W^U = \tau \left(v - \frac{\tau}{2} \right) \left(s'(p_0)\, Var(\varepsilon) + \frac{s(p_0)}{b''(0)} \Psi(\widehat{e}) \right) - F\Psi(\widehat{e}) + o\left(\tau^2\right)$$

heterogeneity in productivity

The user case for unraveling in the domestic context

- Compared to an output tax: welfare gains from reallocation + abatement.
- Compared to an emission tax:
  - saving on monitoring costs;
  - very low information requirements (algorithm);
  - possibly easier to implement (regulation vs. legislation);
  - potentially lower political opposition: some of the costs are backloaded and opposition to greater certification is divided at each stage.

Methane Emissions from Oil and Gas

- Methane leaks in the US: 13Tg at $1500/t: a $20B/year problem (Alvarez et al. 2018)
- Enormous heterogeneity in emissions (Robertson et al. 2020)
  - 70% of emissions from 15% of sites
  - Not monitored, lightly regulated
- Proposals to internalize carbon emissions:
  - Royalty adder (Gillingham et al., 2016, Gerarden et al., 2020, Prest and Stock, 2021): Output tax for carbon content on federal land (executed administratively).
  - "Methane emissions reduction program": limited in scope (only include between 1/3 and 1/15 of emissions) and use emission-factors instead of monitoring emissions (earlier draft included our design).
  - A Pigouvian tax instead would require a new law, which faces a filibuster risk in the senate.
- Focus on the Permian basin in Texas (1/3 of US oil, 10% of gas).

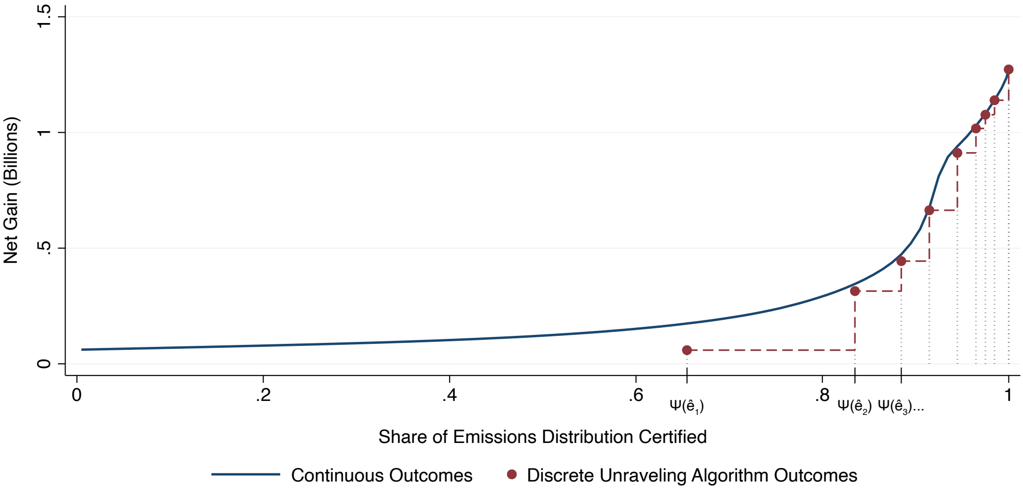
Data and Methods

- Adapt the model to a model of "drilling". data
  - Leads to a very similar formula (with a q-weighted variance of emission rates).
- Lease-level production from TX and NM for 2019.
- Emissions distribution from Robertson et al. (2020) survey (=> bootstrap).
- Supply elasticity of 1.26 (average of Newell, Prest, and Vissing, 2019, and Newell and Prest, 2019).
- Match abatement level at the social cost of methane from Marks (2022).
- Monitoring costs: methane imaging cameras cost around 1000$ per well and 3,000 wells drilled in 2019

Permian Wells Drilled in 2019: Output versus Emissions Taxes

		Predicted Change		
	Observed	Output Tax (Approximation)	Emissions Tax (Approximation)	Emissions Tax (Exact)
Quantities				
Production (Billions BOE)	2.92	-0.10	-0.10	-0.06
		[-0.19,-0.05]	[-0.19,-0.05]	[-0.12, -0.04]
Methane Emissions (Tg)	2.11	-0.08	-1.70	-1.14
	[1.12, 4.21]	[-0.28, -0.02]	[-3.74, -0.76]	[-2.40, -0.59]
Welfare				
Producer Surplus (Billion USD)		-3.10	-1.89	-1.96
		[-6.10, -1.67]	[-3.56, -1.07]	[-3.86, -1.09]
Tax Revenue (Billion USD)		3.04	0.61	1.45
		[1.66, 5.89]	[0.24, 0.99]	[0.81, 2.73]
External Cost (Billion USD)	3.16	-0.12	-2.55	-1.71
	[1.69, 6.31]	[-0.42, -0.03]	[-5.61, -1.14]	[-3.60, -0.88]
Total (Billion USD)		0.06	1.27	1.20
		[0.01, 0.21]	[0.57, 2.80]	[0.61, 2.46]

Permian Wells Drilled in 2019: Output versus Emissions Taxes



Motivation: Improved Border Carbon Adjustment

- Underwhelming success of international climate negations has pushed some countries toward unilateral actions (e.g. EU ETS).
- Border Carbon Adjustment (BCA) to address leakage, but:
  - BCAs are generally considered an output tax (as it is very hard to measure emissions of a specific input);
  - Leading to an inefficient allocation of resources and no incentive to abate.
- Goal is to extend carbon policy and abatement incentives beyond jurisdiction.
  - One third of global CO_2 embodied in international trade

Modeling Framework: International Setting

- Two countries, Home (H) and Foreign (F) with the same preference structures as before.
  - Emissions G are a global externality
- Distribution of emissions: $\Psi_H(e)$ and $\Psi_F(e)$.
  - Potentially different production technologies.
- Assume Home imports the polluting good (with balanced trade).
  - Transport costs of κ.
- Focus on global welfare.
  - H taxes domestic emissions at rate $\tau_H = \nu$.
  - F does not tax emissions.

Voluntary certification

- H imposes a tariff with voluntary certification on imports:
  - Uncertified firms face an output tariff t_F;
  - Certified firms pay an emission tax $\tau_F = \nu$, and certification costs $f + F$;
  - This leads to a threshold $\hat{e}$, where firms with $e \leq \hat{e}$ are certified;
  - $t_F = \nu E_F (e|e > \hat{e})$ and a lower f is associated with more certification.
- As H is a net importer, H firms only supply the H market.
- F firms only certify to exports so certified firms exports to H.
  - In effect certified F firms now behave “like” H firms.
- Uncertified foreign firms may either produce for H or for $F \implies$ Two types of equilibria.

Pooled equilibrium (1)

- In pooled equilibrium, uncertified firms produce for both markets, which fixes the price gap between H and F:

$$\rho \equiv p_F - (p_H - \nu E_F(e|e > \hat{e}) - \kappa) = 0$$

  - This occurs when not too many F firms certify.
  - An increase in $\hat{e}$ increases $p_H - p_F$. p_F goes down and p_H generally goes up (for small τ).
- The change in welfare (relative to an output base CBA) is given by:

$$W^V - W^U = \underbrace{s_F' \frac{\nu^2}{2} Var_F(\varepsilon)}_{\text{Reallocation Effect}} + \underbrace{\frac{\nu^2}{2} \frac{s_F \Psi_F(\hat{e})}{b''(0)}}_{\text{Abatement Effect}}$$

$$-\underbrace{F\Psi_F(\hat{e})}_{\text{Cert. costs}} - \underbrace{D_F' \frac{\nu^2 \Delta p_F}{2} \left(E_F(e) + E_F(e|e > \hat{e})\right)}_{\text{Consumption Leakage Effect}} + o(\tau^2),$$

Pooled equilibrium (2)

- As before:
  - Positive Reallocation and Abatement effects;
  - Negative Certification costs effect.
- The Consumption Leakage effect is negative here:
  - The implementation of an output based border adjustment reduces the price in F.
  - This leads to an increase in F consumption of the polluting good (instead of exporting the good).
  - But F consumption is completely untaxed and inefficiently overconsumed.
  - The certification program increases the price gap and therefore aggravates the distortion.

Separating equilibrium (1)

- If more F firms certify all the demand from H is satisfied by domestic or certified F firms.
- Separating equilibrium where uncertified firms only serve F: $\rho > 0$.
  - If $\hat{e}$ increases, fewer firms produce in F market. p_F increases and p_H decreases.
- The change in welfare (relative to an output base CBA) is given by:

$$W^V - W^U = \text{Reall. effect} + \text{Abatement effect} + \text{Cert. costs}$$

$$-\underbrace{D_F' \frac{\nu \Delta p_F}{2} \left(\nu \left(E_F(e) + E_F(e|e > \hat{e})\right) - \rho\right)}_{\text{Consumption Leakage Effect}} - \underbrace{s_F' \left(1 - \Psi^F\left(\widehat{e}\right)\right) \frac{\left(\Delta p_H + \rho\right)\rho}{2}}_{\text{Backfilling Effect}} + o(\tau^2),$$

Separating equilibrium (2)

- Reallocation, Abatement and Certification costs: same as before.
- The Consumption Leakage effect is ambiguous:
    - Since the price gap decreases with $\hat{e}$, $p_H - p_F$ may increase or decrease relative to the output based tariff.
- The backfilling effect is negative:
    - In the separating equilibrium, the dirtiest F producers avoid any taxation by opting out of the H market.
    - Their price is too high by a factor ρ, leading to too much production by the dirtiest firms.
    - The price change they face had they been forced to export instead would have been $\Delta p_H + \rho$.

Unraveling in an international setting

- In both types of equilibria, certification may no longer give welfare benefits gross of certification costs. second best
  - Attention to distortions makes it possible to design programs with positive benefits: Application to Brazilian Steel Exports

Steel Trade between OECD and Brazil

- Iron and steel sector is one of the most energy and carbon-intensive sectors responsible for 10.5% of total CO_2 emissions.
    - Heavily traded;
    - Very heterogeneous emission rates: Two technologies blast furnace (BF) and electric arc furnace (EAF) and heterogeneity within each;
    - Simple to monitor.
- Focus on trade between Brazil and the OECD.
    - Brazil is one of the major steel producers in the world and exporters.
    - Net exports to OECD > 25% of Brazilian production.
    - Emission rate in Brazil is 1.71 tCO_2/t steel (vs 0.98 in the US) but EAF is cleaner in Brazil.
    - Assume OECD implements a carbon policy but Brazil does not.
- BCA is neutral between BF and EAF. Certification program would expand market for EAF.

Calibration

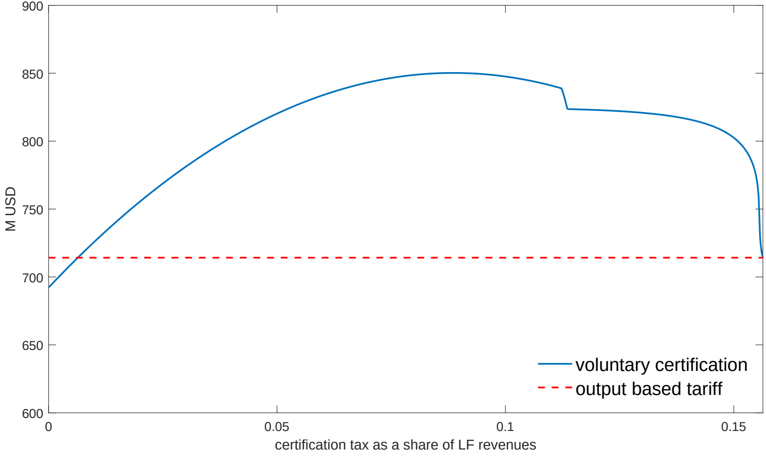
- 2 country world economy with Brazil and OECD in 2019.
  - Data on production, trade and prices (including transport costs).
  - Data on emission rates per technology.
    - To capture within technology heterogeneity, rely on the st. dev. of log productivity in the basic metal products sector in Brazil (Schor, 2004).
- SCC at \$51.
- Estimates for slope of the marginal abatement function $b''(0)$ from Pinto (2018).
- Demand elasticities of -0.306 for OECD (US) and -0.414 for Brazil (Fernandez, 2018).
- Supply elasticity of 3.5 (EPA, 2002).
- Certification cost based on the monitoring cost of hazardous air pollutants (manganese, lead, benzene, etc. but not CO_2) in the US: $\$0.49/t$.

Results (1)

Welfare gains relative to no taxation on F producers.

	First Best	BCA	Voluntary Certification $f = 0$	$f = f^*$
Welfare				
Gains in M USD	1212	714	692	866
% of First Best Gains	100	58.9	58.4	71.5
Emissions				
Reduction in Mt	24.4	5.6	6.3	11.1

Results (2)



sensitivity analysis

The EU CBAM (1)

- Within EU quota system (EU ETS) Price ≈ 100 euros per tonne.
- CBAM seeks to expand this to imports.
  - Importers must buy quotas corresponding to the emissions embedded in production
  - Cement, iron and steel, aluminium, fertilisers, electricity and hydrogen (50 per cent of industries covered by EU ETS)
  - Passed May 2023
  - "Practice" period Oct 2023-Jan 2024
  - Gradual transition until Jan 2026
  - Permanent system from 2026 with posssible expansion to other industries thereafter
- Concerns: predictable, feasible and complying with WTO.

The EU CBAM (2)

- EU CBAM consistent with the mechanism proposed here.
- Producers who are not certified are set in accordance wih average emissions + markup.
  - Separate certification for direct and indirect emissions.
  - Environmental taxes abroad will be rabated.
- Certification takes place through "independent external body".

When actual emissions cannot be adequately determined by the authorised CBAM declarant, default values shall be used. Those values shall be set at the average emission intensity of each exporting country and for each of the goods listed in Annex I other than electricity, increased by a proportionately designed mark-up. This mark-up shall be determined in the implementing acts adopted pursuant to Article 7(6) of this Regulation and shall be set at an appropriate level to ensure the environmental integrity of the mechanism, building on the most up-to-date and reliable information, including on the basis of information gathered during the transition period.

Conclusion

- Large welfare differences between output and emissions taxes when:
  - Emissions rates are heterogeneous
  - Supply is elastic
  - Marginal abatement curve is relatively flat
- An opt-in emissions tax coupled with a sliding default can:
  - Unravel non-participation, replicating emissions tax.
  - Economize on regulatory costs
  - Extend carbon pricing internationally
  - Otherwise overcome obstacles to mandatory Pigouvian taxation.

Comparing certification program and output tax: emissions

- We now compare the results of the certification program (denoted ^{V}) with those of the output tax (^{U}).
- The effect on emissions is given by

$$G^V - G^U = Cov\left[\varepsilon, s\left(p^V - \tau\varepsilon\right)\right] + E\left(e\right)\left\{E\left[s\left(p^V - \tau\varepsilon\right)\right] - s\left(p^U - \tau E\left(e\right)\right)\right\}$$

- First term is negative and represents the reduction in emissions from the reallocation of production to cleaner firms.
- Second term has an ambiguous sign and reflects the change in production from output tax to voluntary certification.
  - Cleaner firms produce more, which could lead to a rebound effect.
- Overall, emissions decrease if s is weakly convex in p and $es(p - \tau e)$ is concave in e.

Comparing certification program and output tax: welfare

$$W^V - W^U = \underbrace{E\left(\pi\left(p^V - \tau\varepsilon\right)\right) - \pi\left(p^V - \tau E\left(e\right)\right)}_{\text{reallocation effect}} - \underbrace{F\Psi\left(\hat{e}\right)}_{\text{certification costs}}$$
$$+ \underbrace{\int_{p^U}^{p^V} \left(s\left(p - \tau E\left(e\right)\right) - D\left(p\right)\right) dp}_{\text{price effect}} - \underbrace{\left(v - \tau\right)\left(G^V - G^U\right)}_{\text{untaxed emissions effect}}$$

- Reallocation effect: increase in profits from taxing some firms at their true emission level.
- Price effect: further potential welfare gains from price adjustment.
- Untaxed emissions effect: ambiguous sign and depends on whether τ is Pigouvian rate or not.
- Certification costs reduce welfare benefits. back

Heterogeneous productivity (1)

- Firms now differ in their production costs as well with $c_i(q) = q^{1+1/\alpha}/\varphi$, where φ denotes productivity.
  - The supply function is isoelastic: $s_i(p) = (\varphi p)^{\alpha}$.
  - No abatement for simplicity.
- Set output tax t equal to τ times total emissions divided by total output for uncertified firms.
  - For $\tau = \nu$, this is the optimal output tax / the optimal output tax for uncertified firms when certification is possible.
  - This is only true for isoelastic supply function.

Heterogeneous productivity (2)

- The previous welfare formula still applies with weighted output variance: $Var(\varepsilon)$ is replaced by

$$\tilde{Var(\varepsilon)} = \int_{\varphi} \int_{\varepsilon} (\varepsilon - \tilde{E}(\varepsilon))^2 \tilde{\psi}(\varphi, \varepsilon) d\varepsilon d\varphi,$$

  - where $\tilde{\psi}(\varphi, \varepsilon) = \varphi^{\alpha} \psi(\varphi, \varepsilon) / \left(\int_{\varphi} \int_{\varepsilon} \varphi^{\alpha} \psi(\varphi, \varepsilon) d\varepsilon d\varphi \right)$ is a density distribution rescaled by output (proportional to φ^{α})
  - and $\tilde{E}(\varepsilon) = \int_{\varphi} \int_{\varepsilon} \varepsilon \tilde{\psi}(\varphi, \varepsilon) d\varepsilon d\varphi = G^U / S^U$. back

Adapting the model

- Adapt the model to a model of "drilling":
  - Wells don't expand but are either drilled or not drilled.
  - Wells are heterogeneous in quantity, price, emission rate and drilling costs.
  - Drilling costs are assumed to be proportional to revenues + noise.
  - Abatement is proportional.
- This delivers the same sufficient statistics formula (for $\tau = v$)

$$W^V - W^U = \frac{v^2}{2}\left(s'(p_0)\, Var_q(\varepsilon) + \frac{s(p_0) E_q\left(e^2 | e \leq \hat{e}\right)}{b''(0)} \Psi_q\left(\widehat{e}\right)\right) - F\Psi\left(\widehat{e}\right) + o\left(\tau^2\right)$$

  - where $Var_q(\varepsilon)$ is a quantity weighted variance of the "revealed" emission rate ε and $s'(p_0)$ the aggregate supply slope. back

Second best policy (1)

- The optimal output based tariff is given by (Markusen, 1975):

$$t_F^* = \nu \frac{s_F'(p_F)}{s_F'(p_F) - D_F'(p_F)} E_F(e)$$

  - The tariff is lower than the Pigovian rate to account for the consumption leakage effect.
- The optimal program when H can tax at the true rate foreign firms which pay a cost F involves:
- An emission tariff $\tau_F^* = \nu$ on certified exporters;
  - Certification moves exporters away from their domestic market, so they can be taxed at the Pigovian rate.

Second best policy (2)

- An output tariff $t_F^* = \nu \frac{s_F'(p_F)(1-\Psi_F(\hat{e}))}{s_F'(p_F)(1-\Psi_F(\hat{e}))-D_F'(p_F)} E_F(e|e > \hat{e})$ on uncertified foreign firms;
  - This is the Markusen (1975) formula but for the set of foreign firms with $e > \hat{e}$.
- A certification tax $f^* = [t_F^* - \nu \hat{e}] \, s_F(p_F)$ which plays the same role as in the domestic case. back

Decomposing the effect

	Certification Fee	
	$f = 0$	$f = f^*$
Welfare Component		
Reallocation	150	150
Abatement	37	37
Consumption Leakage	40	-19
Backfilling	-228	-10
Certification Costs	-4	-4
Total Change in Welfare Relative to BCA	-6	152

Sensitivity analysis

Welfare gains relative to no taxation on F producers. back

	Border carbon adjustment	Optimal output tax	Voluntary $f = 0$	Certification $f = f^*$	First best
1. Baseline	714	719	708	866	1212
2. More heterogeneity in Brazil BOF	714	719	561	884	1411
3. x2 supply elasticity in Brazil	1410	1413	1342	1706	2203
4. /2 demand elasticity in Brazil	750	751	723	914	1212
5. -25% abatement costs in Brazil	714	719	717	875	1245
6. 50% more trade	728	731	818	928	1212
7. Same τ_F but x2 SCC	998	2878	1483	1430	4849
8. Calibration to the US	516	520	497	635	979