Environmental Taxation, Information Precision, and Information Sharing

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Introduction

Pricing Externalities

- Environmental economists have considered several broad classes of instruments to correct negative externalities.
- Pricing pollution is typically the most economically efficient way to drive down emissions. Further, it has some economic advantages over purely legal-based or mandated regulatory actions.
- To this end, public authorities may put in place a price-based and/or quantity-based regulatory policy, the main purpose being to give the appropriate incentives to polluters in managing their externalities.
- By explicitly pricing pollution externalities, such instruments also provide crystal clear and strong incentives to polluters to seek out and exploit the lowest cost ways of reducing emissions.
- Environmental taxation is a market-based approach designed to regulate emissions and protect environmental quality: it is supposed to accomplish deep and structural changes in the economic and ecological behavior of economic agents by adjusting price signals in an environmentally positive manner.

Environmental Taxation

- In general, polluters have no sufficient incentives to manage their emissions effectively if they don't face the social costs of their actions.
- Following decades of large-scale implementation and experimentation, it is widely accepted today that environmental taxes represent a cost-effective regulatory mechanism to steer agents' behavior toward a greener economy.
- Environmental taxes directly set a price on pollution and internalize the social costs of emissions. Well designed, environmental taxes alter relative prices, lead to an adjustment in polluter's behavior, and tackle pollution issues.
- Under idealized conditions, the tax-setting task can be optimally achieved: If regulators observe perfectly all sources of information, then they could impose well-structured direct taxes that maximize welfare, which brings private costs into line with social costs.
- Unfortunately, processes of setting taxes are shrouded with uncertainties and informational asymmetries.

Uncertainties and Asymmetries

- Informational asymmetry is one of the great difficulties of policy making because firms have the opportunity and the incentive to exploit their informational advantages to undermine the intended goals of a well-meaning regulator.
  - Regulators DO NOT know as much about regulated firms' abatement and production costs as do the firms themselves.
  - Firms typically know their marginal costs with greater precision than the regulator and have NO incentives to reveal their true marginal costs to the regulator or to their rivals.
- At the firm level, the production process involves considerable uncertainties, which indirectly affects the efficiency of emissions taxes:
  - Firms are buffeted by various kinds of shocks to costs: ex-ante estimates of costs differ from the ex-post observations (Harrington et al., 2000; Elofsson, 2007).
  - Ex-ante costs are inaccurate if technological innovation is not accounted for or cost information is out-of-date.

Motivations and Research Questions

- To account for real-world complications, this paper seeks to overcome some identified weaknesses in the design of existing emissions taxes, and to identify ways that help environmental regulators to set more effective taxes.
- To this end, we confine our attention to informational uncertainties about costs and look at answering the following questions:
    - Facing industry-wide and private shocks, what are the properties of the optimal tax policy in uncertain polluting industries?
    - What role does precision of privately-held information play in pollution problems?
    - How does the precision of information affect social welfare?
    - What is the social value of information in regulating emissions through taxes?
    - Do firms have incentives to pool the information about their marginal costs? If yes, what are the welfare consequences of concerted practices between players within an industry?

Motivations and Research Questions

- To this end, we consider a Stackelberg-Cournot setting with uncertainties about the state of the world in informationally complex markets:
    - In the first period, the regulator has NO information at the time polluters make their decisions, and commit to tax schedules that are contingent on signals about costs. This public policy, once made, remains in force for an extended period of time while rivals respond in the marketplace.
    - In the second period, facing industry-related shocks (common signal) and firm-specific shocks (private signals), firms compete in the marketplace as Cournot rivals and choose outputs.
- This setting allows us to focus on the regulator's information deficit and on the strategic behavior of rival firms when unraveling information from signals and to analyze the influence of common and privately-held signals on the efficiency of the regulatory instrument.

Roadmap

- The model set-up
- Timing and players' objectives
- The optimal environmental policy
- Information sharing and welfare consequences
- Conclusion

Environmental Taxation

The model set-up

Emissions taxes

- Pricing pollution have been explored in depth conceptually. A large literature spanning the field of environmental economics has investigated emissions taxes under different informational structures (See for instance, Christiansen and Smith, 2015; Elofsson, 2007; Espínola-Arredondo and Muñoz-García, 2015; Fikru and Gautier, 2016; Goulder and Parry, 2008; Ikefuji et al., 2016; Pindyck, 2007; Pizer, 2002; Stavins, 1996, 2020; Weitzman, 1974).
- Here, we set-up a model based on signaling games and put a high premium on statistical inferences in setting the tax policy to handle uncertainties by considering linear-quadratic framework and linear conditional expectations.
- Firms receive private signals about the private-value shocks and industry-wide signals about shocks that have a common value nature.
- In addition, we step away from symmetric or Gaussian setting by allowing signals to have some interesting arbitrary probability distributions.

Applications

- Our model may characterize a variety of markets where firms face persistent and perpetual cost uncertainties yielding potentially significant forecast errors, which implies failure to deliver cost-effective decisions.
- This setting is relevant in industries where players generate negative externalities (e.g., SO_2/CO_2 emissions in the energy market) and where uncertainties cloud the regulators' task in setting efficient environmental policy.
- Examples are the U.S. energy sector or the European wholesale energy market, where an homogeneous product, i.e., electricity, can be produced with different energy inputs.
- The model may also represent the chemicals industry (fracturing) where competitors accumulate some information about costs of complying with the environmental regulation (due to recurrent interaction).

Basic Elements

- We consider a single polluting industry, with $I = \{1, 2\}$ non-identical risk-neutral firms producing a homogeneous final good. We assume that players are facing the following inverse demand:

$$p\left(q_i + q_j\right) = a - b\left(q_i + q_j\right), \text{ for } i, j, \text{ with } i \neq j$$

where p denotes the market-clearing price. We assume that a is sufficiently high to avoid shutdown.

- On the supply side, the technology used by each firm is stochastic but it exhibits constant returns to scale. Emissions depend on the technology of production used by each firm:

$$e_i = \varphi q_i, \text{ with } 0 < \varphi < 1 \text{ for any } i \in I.$$

which yields the environmental damage, $D = \frac{1}{2} d E^2$, where $E = \sum_{i=1}^{2} e_i\left(q_i\right)$ represents the aggregate level of emissions. $d > 0$ is an exogenous variable that captures the degree of convexity of the damage function.

Information Structure

- Before choosing their production strategies, firms face the same prospects and have access to some common and private information values about marginal costs, $\widetilde{c}_i$.
- Each firm receives unbiased noisy estimates of $\widetilde{c}_i$ such that:

$$\widetilde{c}_i = \widetilde{s} + \widetilde{\varepsilon}_i, \text{ for } i, j, \text{ with } i \neq j.$$

where,

  - the positive random variable $\widetilde{s}$ is a structural parameter representing the industry-related shocks and is distributed according to some prior density:

$$\widetilde{s} \sim \left(\mu_s, \sigma_s^2\right), \sigma_s^2 \in \mathbb{R}_+$$

  - the second component $\widetilde{\varepsilon}_i$ is generated by an iid random process and represents firm-specific shocks:

$$\widetilde{\varepsilon}_i \sim \left(\mu_{\varepsilon_i}, \sigma_{\varepsilon_i}^2\right), \sigma_s^2 \in \mathbb{R}_+$$

- Let $\frac{1}{\sigma_s^2}$ denotes the precision of $\widetilde{s}$ and $\frac{1}{\sigma_{\varepsilon_i}^2}$ as the precision of $\widetilde{\varepsilon}_i$.

Firms' expectations

Lemma (1)

A firm can make inferences about the marginal cost of its rival based upon its private information. For every player i and each player j, with $i \neq j$, the conditional expectation $\mathbb{E}[\tilde{c}_i|\tilde{c}_j]$ is a linear function of $\tilde{c}_j$ and is given by:

$$\mathbb{E}[\tilde{c}_i|\tilde{c}_j] = \gamma_j \tilde{c}_j + \lambda_j,$$

where $\gamma_j = \frac{\sigma_s^2}{\sigma_s^2+\sigma_{\varepsilon_j}^2}$, $\lambda_j = \mu_i - \gamma_j \mu_j$, $\mu_i = \mu_s + \mu_{\varepsilon_i}$, *and* $\mu_j = \mu_s + \mu_{\varepsilon_j}$.

Proof.

In line with Elnaboulsi et al. (2018) and based on the Law of Iterated Expectations, it is easy to compute the posterior expectations $\mathbb{E}[\tilde{c}_i|\tilde{c}_j]$, i.e., firm i's expectations about firm j's signal. $\square$

Expectation and information precision

- Lemma (1) implies that signals are affiliated such that if the signal of one player increases, then it increases the probability that the competitor has a high signal relative to the probability that the competitor has a low signal.
- Hence, if one player has precise information, then the rival is more informed as well based on the inference effect. To see this, recall that

$$\mathbb{E}[\tilde{c}_i|\tilde{c}_j] = \gamma_j \left(\tilde{c}_j - \mu_j\right) + \mu_i, \text{ for } i, j, \text{ with } i \neq j.$$

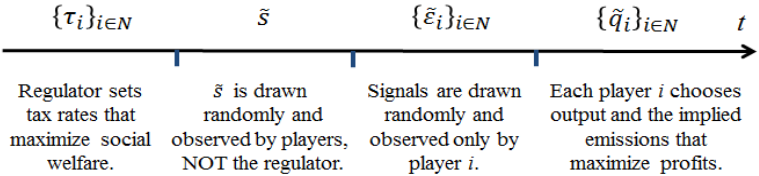
  where $\gamma_j = \frac{\sigma_s^2}{\sigma_s^2 + \sigma_{\varepsilon_j}^2}$ refers to the relative precision of the private information held by firm j, keeping σ_s^2 implicitly fixed. $\forall i, j = 1, 2$,
    - if $\sigma_{\varepsilon_i}^2 \to \infty$ then $\gamma_i \to 0$: the signal is uninformative;
    - if $\sigma_{\varepsilon_i}^2 \to 0$ then $\gamma_i \to \infty$: the signal is informative.
- Therefore, lower values (respectively higher) of $\sigma_{\varepsilon_i}^2$ means that all players are more (less) informed about the magnitude of the value of marginal production costs.

Environmental Taxation

Timing and players' objectives

Timing of the game

- The sequence of events and actions is as follows:
  1. In the first stage of the game, the risk-neutral regulator sets $\{\tau_i\}_{i \in I}$ to maximize $\mathbb{E}\left[\widetilde{W}\right]$, before the realization of the random variables.
  2. In the second stage of the game, the common component of the marginal costs $\widetilde{s}$ is drawn randomly. This signal is observed by both players, but NOT the regulator.
  3. In the third stage of the game, the private signal of the marginal cost $\{\widetilde{\varepsilon}_i\}_{i \in I}$ is drawn randomly. Each player i privately observes its signal $\widetilde{c}_i$, but NOT the regulator neither the rival.
  4. In the final stage, risk-neutral firms act simultaneously in the product market and choose their output and emission abatement levels.



Regulator sets tax rates that maximize social welfare.

$\tilde{s}$ is drawn randomly and observed by players, NOT the regulator.

Signals are drawn randomly and observed only by player i.

Each player i chooses output and the implied emissions that maximize profits.

Firms' Problem

- At the second period, conditional on the received signals, firm *i*'s problem is to $\max_{<\widetilde{q}_i>} \ \mathbb{E}_{\widetilde{c}_j}\left[\pi\left(\cdot\right)\right]$.

Proposition

Making use of Lemma 1 and given the payoff functions in the second period of the game, there exist coefficients $(\theta_{i1}, \theta_{i2})$*, for* $i \in N$*, such that the Bayesian Nash equilibrium for this regulatory game is unique and characterized by a linear decision rule. More explicitly, the equilibrium production strategy is given by:*

$$\widetilde{q}_i = \theta_{i1} + \theta_{i2}\widetilde{c}_i, \ \textit{for } i \in N$$

where, $\theta_{i1} = \frac{a+\varphi(\tau_j-2\tau_i)}{3b} + \frac{2\lambda_i\left(2-\gamma_j\right)-\lambda_j(2-\gamma_i)}{3b\left(4-\gamma_i\gamma_j\right)}$ *and* $\theta_{i2} = -\frac{(2-\gamma_i)}{b\left(4-\gamma_i\gamma_j\right)}$.

Proof.

Focusing on linear arbitrary strategies yields the following proposition. ☐

Regulator's Problem

- At the first period of the game, and given the best response functions for both firms, the regulator maximizes the expected welfare, $\widetilde{W}\left(\cdot\right)$, to set the optimal taxes:

$$\max_{<\tau_i,\tau_j>} \mathbb{E}_{\widetilde{c}_i,\widetilde{c}_j}\left[\left(\widetilde{CS}-\widetilde{D}\right)+\sum_{i\in N}\mathbb{E}(\widetilde{\pi}_i)+\ell\ \mathbb{E}(\widetilde{R})\right]$$

where,

  - $\ell' = \ell - 1$, $1 < \ell < 2$, represents the indirect social benefit of environmental taxation,
  - $\mathbb{E}(\widetilde{CS})$ stands for the expected consumer surplus,
  - $\sum_{i\in N}\mathbb{E}(\widetilde{\pi}_i)$ is firms' expected profits,
  - $\mathbb{E}(\widetilde{R})$ stands for the government's total expected revenues generated by the compensation rule on the remaining emissions,
  - $\mathbb{E}(\widetilde{D})$ represents the expected value of environmental damage due to firms' production process.

Environmental Taxation

Optimal Environmental Policy

Equilibrium under common and private signals

Proposition

In uncertain polluting industries characterized by common and private information structure about costs, a risk neutral planner sets, as an environmental pricing policy, differentiated emissions taxes given by:

$$\tau_i = \frac{(2\omega + \ell' - 1)\left[2a - (\mu_i + \mu_j)\right]}{4\varphi(\omega + \ell')} + \frac{(1 - \ell')(\mu_i - \mu_j)}{4\varphi\ell'}; \forall i, j, i \neq j$$

where $\mu_i = \mu_s + \mu_{\varepsilon_i}$, *for* $i \in N$, *and* $\omega \equiv \left(\frac{1}{3} + \frac{d\varphi^2}{3b}\right) \geq \max\left\{\frac{1-\ell'}{2}, \frac{1}{3}\right\}$.

Proof.

Using the same steps as Elnaboulsi et al. (2018), we can deliver the intensity of emissions taxes. ☐

Policy implications

- While in real world strong administrative and political economy arguments in favor of uniform taxation remain, cost-based policy differentiation is unambiguously welfare maximizing and is robust to unanticipated cost realizations.
- If $\mu_i = \mu_j$, i.e., $\mu_{\varepsilon_i} = \mu_{\varepsilon_j} = \mu_\varepsilon$, then the implied tax rule becomes:

$$\tau_i = \frac{(2\omega + \ell' - 1)\left[2\left(a - \mu_s - \mu_\varepsilon\right)\right]}{4\varphi\left(\omega + \ell'\right)}$$

  A uniform emission-based policy is set and can not correct efficiently a pollution externality.
- For instance, some pollutants, e.g., nitrogen oxides (NO_x) and sulfur dioxide (SO_2), have historically been subject to undifferentiated market-based regulation in the United States. Fowlie and Muller (2019) showed that, when ex-post realized abatement costs manifest differently than expected, it is possible to achieve the socially efficient outcome under differentiated taxes.

Welfare analysis and information precision

Proposition

An increase in the relative precision of information induces a decrease in the expected welfare as long as $\omega \leq \frac{4}{5}$*, where* $\left(\gamma_i, \gamma_j\right)$ *being defined on* $\mathcal{A} = \left]0,1\right] \times \left]0,1\right]$*. However, if* $\omega > \frac{4}{5}$*, then an increase in the relative precision of information may enhance the expected welfare, which is true under severe environmental damages. Thus,*

- *If* $\omega \in \left[\frac{1}{3}, \frac{4}{5}\right]$ *, then* $\frac{\partial \overline{W}}{\partial \gamma_i}\left(\gamma_i, \gamma_j\right) < 0, \frac{\partial \overline{W}}{\partial \gamma_j}\left(\gamma_i, \gamma_j\right) < 0;$
- *If* $\omega > \frac{4}{5}$*, then,*

$$\left\{ \begin{array}{l} \frac{\partial \overline{W}}{\partial \gamma_i}\left(\gamma_i, \gamma_j\right) = \frac{\partial \overline{W}}{\partial \gamma_j}\left(\gamma_i, \gamma_j\right) > 0 \Leftrightarrow \left(\gamma_i, \gamma_j\right) \in A_{-}^{\rho} \\ \frac{\partial \overline{W}}{\partial \gamma_i}\left(\gamma_i, \gamma_j\right) = \frac{\partial \overline{W}}{\partial \gamma_j}\left(\gamma_i, \gamma_j\right) = 0 \Leftrightarrow \left(\gamma_i, \gamma_j\right) \in A_{0}^{\rho} \\ \frac{\partial \overline{W}}{\partial \gamma_i}\left(\gamma_i, \gamma_j\right) = \frac{\partial \overline{W}}{\partial \gamma_j}\left(\gamma_i, \gamma_j\right) < 0 \Leftrightarrow \left(\gamma_i, \gamma_j\right) \in A_{+}^{\rho} \end{array} \right.$$

The family of the non-empty sets $A_{-}^{\rho}, A_{0}^{\rho}, A_{+}^{\rho}$*, defines a partition of* $\mathcal{A}$*.*

Welfare analysis and information precision

- The parameter ω may represent the severity of environmental damages due to emissions:

$$\omega = \frac{(1+\eta)}{3}$$

where $\eta \equiv \frac{d\varphi^2}{b}$ is the ratio of the slopes of the marginal damage $\left(d\varphi^2\right)$ and the marginal consumer surplus (b).

  - More precise signals yield welfare loss as long as $\omega \leq \frac{4}{5}$, or equivalently $\eta \leq \frac{7}{5}$. Viewed another way, if this condition is binding, then less precise prior information leads to greater welfare since any uninformed firm has incentives to increase its production which entails higher consumers' surplus.
  - More precise signals are welfare enhancing when $\omega > \frac{4}{5}$ or equivalently $\eta > \frac{7}{5}$. When there are threats of serious environmental damage, well informed firms have no incentives to produce further in order to avoid the burden of the tax, which yields a reduction in emissions, and hence improves social welfare.

Welfare and information precision

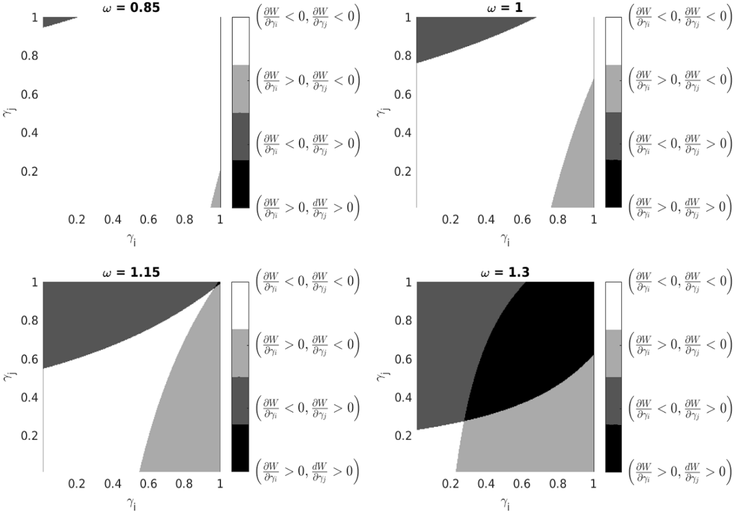


Figure 1: Social welfare and the precision of signals for admissible value of ω.

Information Sharing and Welfare Consequences

Sharing information

- Suppose that some mechanism (mandated disclosure platforms) exists for firms to truthfully share information on their private costs, while the regulator still remains uninformed about costs.
- Questions:
    - Under what conditions do firms have incentives to share information about costs?
    - What happens if firms engage in tacit collusion to cooperatively choose a strategy to face an environmental policy?
- For instance, increased risks in exploration and high volatility of crude oil prices are considered as important reasons for information sharing activities. Another real-world example experiencing serious and unfortunate distortions of competition is the energy market. Under different E.U. and U.S. transparency-enhancing, resilience and security regulations, increased effort and focus have been put on information sharing in the energy sector.

The tax rule under information sharing

Proposition

Suppose that a sharing agreement (S) is reached between firms and ensured using an information sharing platform or any other channel. Suppose also that firms truthfully signal their private information and receive perfectly the full vector of rivals' costs. In this case, since the regulator can neither foresee nor control the uncertainties at the time it sets the environmental policy which remains in force for an extended period of time, then the optimal tax rules is the same as in the non-sharing information game (NS).

Proof.

Since the regulator's information set remains the same, information sharing does not affect the expected welfare maximization problem, which gives the same tax rules. ☐

Incentives to collude

Proposition

When a regulator uses taxes as a pricing policy to correct harmful externalities in uncertain industries, firm i has incentives to collude with firm j and vice versa if and only if

$$\left(c_j - \mu_j\right) \geq \left(c_i - \mu_i\right) z\left(\gamma_i, \gamma_j\right)$$

where the function $z\left(\gamma_i, \gamma_j\right) = \left(\frac{2-2\gamma_i\gamma_j+3\gamma_i}{4-\gamma_i\gamma_j}\right) > 0$, *is defined on the support* $\mathcal{D} = [0,1]^2$, $\forall \gamma_i, \gamma_j \in [0,1]$, *reaching its maximum value,* $z_{\max}\left(\gamma_i, \gamma_j\right) = 1.25$, *for* $\left(\gamma_i = 1, \gamma_j = 0\right)$, *and its minimum value,* $z_{\min}\left(\gamma_i, \gamma_j\right) = 0.5$, *when* $\gamma_i = 0$, $\forall \gamma_j \in [0,1]$. *Further, collusion by sharing information is a dominant strategy in highly uncertain industries than under deterministic ones if the uncertainty is characterized by privately hold information.*

Numerical simulations

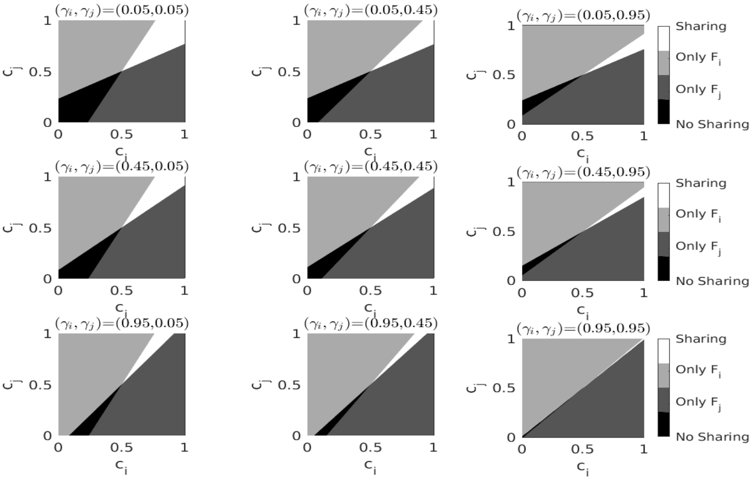


Figure 2: Simulations results, incentives to share information for admissible values of (c_i, c_j), $\left(\gamma_i, \gamma_j\right) \in [0, 1]^2$.

Collusion and welfare

Proposition

Under the informational framework adopted in this paper, i.e., common and private information, when taxes are used to regulate an uncertain and asymmetric polluting Cournot industry, collusion that would arise through cost sharing agreements is unambiguously better for welfare as long as the ratio of the slopes of the marginal environmental damage $\left(d\varphi^2\right)$ *and the marginal consumers' surplus* (b), η, *is less than one. However, if the ratio is higher than one, i.e.,* $\eta > 1$, *then collusion may have large negative impact on social welfare. This is the case under extremely and severe environmental irreversibilities.*

Proof.

Examining the expression of the welfare total differential, $\Delta W\left(q_i, q_j\right)$, yields this proposition. ☐

Collusion and Welfare

- To deliver the insight behind this proposition, consider the following two subsequent cases:
    1. If $\omega \leq \frac{2}{3}$, i.e., the ratio $\eta \leq 1$, then $\Delta W \geq 0$. In words, when the slope of the marginal environmental damages $\left(d\varphi^2\right)$ is less than the slope of the marginal benefits for consumers (b), then, for an exogenously given level of information precision, collusion between players is welfare improving. Hence, collusion generates information gains due to the information aggregation and eventually the subsequent production rationalization.
    2. If $\omega > \frac{2}{3}$, then ΔW may be negative. This is true when the slope of the marginal damages $\left(d\varphi^2\right)$ relative to the slope of the marginal benefits for consumers (b) is higher than one, i.e., $\eta > 1$. This is particularly the case under severe and extreme environmental circumstances. Hence, these is no reason for for postponing any carbon pricing policy.

Environmental Taxation

Conclusion

Conclusion

- Despite tremendous progress in the field, environmental taxes have come under increasing criticism from both outside and inside the environmental economics profession due to the large number of empirical anomalies and failures to deal with some externalities, e.g., GHG emissions or high-risk toxic pollutants.
- It is crystal clear that, to reduce emissions, sharply and effectively, a great surge has to be done in decision makers' attitude toward policy settings. To succeed in such a difficult task, a fine-tuning of the intensity of the tax rule towards environmental circumstances is needed.
- This study has several limitations and further research should address issues such as product differentiation or investment decisions in clean technology to extend the analysis in terms of policy implications.