Environmental Disclosures in Global Supply Chains

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Abstract

Economies committed to environmental goals, such as mitigating global warming, face the challenge that pollution and emissions originate to a large extent from activities in foreign countries. While governments may attempt to tax domestic firms' sourcing of inputs from brown international firms, such approaches often have to rely on voluntary disclosures by foreign companies. Addressing this issue, we examine international supply chain partners' disclosure choices and their interplay with a domestic government's optimal regulatory policies. Such disclosures are key to SCOPE-3 emissions calculations and meaningful ESG ratings. Contrary to regulations implemented via carbon credit markets, optimal policies in our environment account for endogenous information asymmetries and the exercise of market power. Our analysis characterizes how domestic households' exposures to global externalities shape both a government's optimal regulations and the precision of foreign firms' voluntary disclosures.

Keywords: Carbon credit markets; ESG ratings; Global warming; Asymmetric information; Optimal regulation

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1 Introduction

Many countries view environmental goals such as tackling global warming as a first-order objective underlying a wide range of policies and initiatives (UNFCCC, 2015). Yet economies across the globe face differing trade-offs related to pollution and emissions and thus frequently disagree on the optimal stringency of environmental regulations. Figure 1 illustrates the divergence in major economies' trends by plotting total carbon emissions for the United States, China, and the EU over the past few decades. Activities in foreign countries are evidently first-order drivers of global emissions, raising the concern that domestic activities and associated local laws alone have limited impact on the problem at hand.

However, given the importance of international production, countries may increase their reach by leveraging domestic firms' global supply chains. In fact, a large portion of pollutive activities arises from internationally traded production inputs (see, e.g., Peters et al., 2008), and policy makers increasingly recognize the importance of SCOPE-3 emissions, that is, *indirect* emissions that occur in a company's value chain. Governments may therefore attempt to use their regulatory authority pertaining to domestic firms to discourage the sourcing of inputs from brown international supply chain partners (see, e.g., Copeland and Taylor, 2003). Similarly, investors concerned with the environment may rely on domestic firms' ESG scores, which have to incorporate supply chain partners' greenness to be meaningful. The efficacy of such approaches, however, is contingent on disclosures by foreign producers, which are typically voluntary (Hartmann and Stafford, 2018).

Motivated by these observations, we study the interaction between foreign firms' voluntary environmental disclosures and both domestic firms' supply chain strategies and governments' taxation policies. Our analysis provides novel insights on the shortcomings of carbon credit markets and other common regulatory interventions in the presence of international information asymmetries. We present a model of a domestic firm sourcing inputs from a

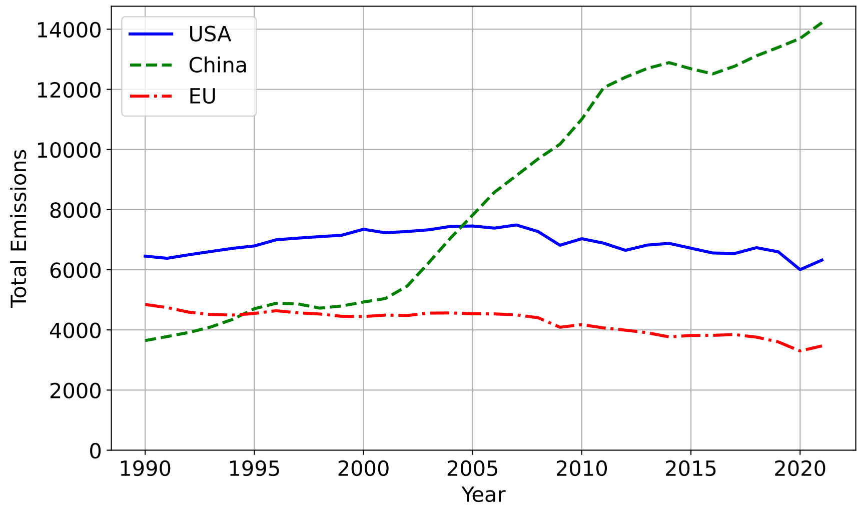


Figure 1: Total carbon emissions for major economies. The graph plots total emissions for the United States, China, and the EU as measured by megatonnes of carbon dioxide equivalent per year, as reported by the Climate Action Tracker (2023).

foreign firm that provides voluntary disclosures on its production-related environmental externalities. These externalities negatively affect domestic households and are insufficiently internalized by both the domestic and the foreign firm. Moreover, our analysis recognizes the fact that many large firms headquartered in developed countries most concerned with global warming exert substantial market power when sourcing international inputs (see, e.g., Antràs and Staiger, 2012).

We start our analysis by examining the global supply chain equilibrium absent government interventions. In this setting, voluntary environmental disclosures increase the global supply chain partners' joint private surplus, yet they may expand activities generating negative externalities. This result emerges as private disclosures limit the rationing of international transactions due to the domestic firm's exercise of market power. Moreover, the foreign producer optimally chooses to commit to a disclosure regime whereby the domestic trade partner obtains imprecise but still useful information about environmental standards and the associated production costs. The privately optimal disclosure by the foreign producer balances its incentives to retain private information about production costs when facing a trade partner with market power with the recognition of the fact that excessive information asymmetries are harmful, as they impede efficient trade.

We then proceed to analyzing a domestic government's interventions with policies accounting for domestic firms' SCOPE-3 emissions. In particular, we study the optimal mechanism from a domestic country's perspective and its implementation via taxes that condition on foreign firms' voluntary disclosures. Optimal tax schedules in this environment are non-linear functions of the disclosed environmental externalities created *within* a given supply chain relation. Rather than effectuating a system with one tax rate or price per unit of emissions, a government should use the endogenously coarse disclosures of foreign input producers and account for the distributional properties of international information asymmetries.

This prescription contrasts with prevalent existing environmental policy proposals, such as carbon credit markets. Markets such as the European Union Emissions Trading Scheme (EU ETS) feature a common market price for carbon allowances traded within the system, which covers multiple sectors, including power generation, manufacturing, and aviation. In contrast to models suggesting the optimality of such markets, our approach recognizes the real-world complexities that foreign producers optimally retain private information about the brownness of their production processes and that large domestic firms often exercise significant market power when sourcing inputs. In the presence of these frictions, optimal carbon taxes vary across sectors, as a function of the distributions characterizing information asymmetries. These distributions determine how supply elasticities relate to the brownness of foreign input production.

Further, taxation policies are naturally anticipated by the foreign supply chain partners. Our analysis reveals when and how penalizing trade with pollutive suppliers interferes with the precision of their disclosures. Interestingly, the anticipation of government interventions can make voluntary disclosures more or less informative, with the direction depending crucially on the strength of the domestic country's exposure to externalities. Moreover, while the optimal domestic mechanism can prevent the excessive use of brown technologies from a global surplus perspective, we find it does not do so when the domestic country's households are sufficiently strongly exposed to environmental externalities.

Related literature. Our paper contributes to the existing literature studying optimal government interventions in the context of environmental externalities. Weitzman (1974) is a seminal contribution to the debate on whether it's more efficient to regulate pollutants using prices (taxes) or quantities (emission caps). Nordhaus (1991) examines the economic implications of global warming and provides one of the earliest assessments of the benefits and costs of slowing climate change and associated government policies. Poterba (1991) analyzes the practical challenges of designing a carbon tax, considering the interactions of policies with existing tax systems and the potential challenges in their political implementation. Pindyck (2013) surveys existing models on climate change policies, providing an examination of existing models and their limitations. Golosov et al. (2014) derive optimal carbon tax policies in a dynamic general equilibrium model with capital accumulation that recognizes the non-renewability of fossil-fuel inputs. Döttling and Rola-Janicka (2023) show that carbon taxes may be dominated by a cap-and-trade system or abatement subsidies in a model with financial constraints and endogenous climate-related transition and physical risks.

Our paper is further related to the existing work examining how firms in supply chains possessing significant market power might strategically react to carbon taxes. In particular, Fabra and Reguant (2014) examines how carbon costs are passed through to electricity prices in the presence of market power. Their findings suggest that strategic firms with market power might not fully pass through these costs to consumers, especially when demand is inelastic.

Our paper also contributes to the literature examining issues related to taxation and regulation in the context of international supply chains, where foreign firms cannot be regulated directly. Elliott et al. (2010) discusses how introducing carbon taxes can affect international trade patterns and highlights carbon taxes in one country might merely shift production and emissions elsewhere. Fowlie et al. (2016) explores the implications of market-based emissions regulations on industry dynamics, especially concerning firms' exit and entry decisions, and how this interacts with international supply chains.

Another strand of the literature touches on the problem of emissions underreporting when rules or regulations rely on firms' disclosures. Lyon and Kim (2011) empirically investigates the strategic disclosure of greenhouse gas emissions. It finds that firms often disclose emissions in a manner that serves their own interests, particularly when disclosure is voluntary. Our theoretical analysis recognizes that the reliance on voluntary foreign disclosure is particularly relevant in the context of efforts to curb global warming and pollution, since domestic policy makers cannot mandates specific disclosure standards in foreign jurisdictions.

Finally, our paper is related to the theoretical literature examining voluntary disclosure, but that abstracts from externalities affecting third parties and the associated scope for government interventions. Grossman (1981b) and Milgrom (1981) find that when disclosures are ex post verifiable, it is optimal for an agent to fully reveal his private information to his counterparties. This result emerges since agents making the disclosure decision in these papers do not face counterparties with market power, implying that the agent who discloses information is only concerned with his counterparties' conditional beliefs about the mean asset payoff. "Unraveling" obtains then since any information that is withheld is interpreted to be unfavorable (see also Grossman and Hart (1980); Milgrom and Roberts (1986)).[1] In

[1] Verrecchia (1983) modifies a setting akin to Grossman (1981b) and Milgrom (1981) by adding disclosure costs, whereas Fishman and Hagerty (1990) assume that a subset of private information cannot be disclosed. In both cases, maximal disclosure may not be optimal for the informed party. Admati and Pfleiderer (2000),

contrast, as in Glode et al. (2018), the disclosing entity in our setting is concerned with the full conditional distributions of payoffs resulting from disclosures, since the counterparty has market power and decides to screen the agent based on the shapes of these conditional distributions. As a result, our environment leads to optimal partial rather than full disclosure. Moreover, the presence of externalities and the differences in how they are affecting different parties implies that contrary to the efficiency results in Glode et al. (2018), disclosures generally do not ensure trade that maximizes total surplus, even when the domestic government employs on optimal mechanism.[2] More broadly, our focus on market power also relates our paper to Gal-Or (1985) who models oligopolistic firms that can commit ex ante to sharing noisy signals of their private information about the uncertain demand for their products, although in that setting, the unique symmetric pure-strategy equilibrium is characterized by no information sharing among firms.

2 Model

Two firms from distinct countries interact in a global supply chain relationship. A domestic firm (D) sources an input from a foreign firm (F) and provides the final product to domestic households (H). The foreign firm's production of the input involves technologies that generate environmental externalities e. The foreign firm is privately informed about the value e, which captures the notion that in practice, a producer is best informed about the specific technologies and practices it is employing. In contrast, outside parties have imprecise prior

however, show that a firm may pick a socially optimal disclosure plan despite disclosure costs if that firm is a monopolist that captures all gains to trade. Matthews and Postlewaite (1985), Okuno-Fujiwara et al. (1990), Fishman and Hagerty (2003), Shin (2003), Acharya et al. (2011), and Guttman et al. (2014) show, in different environments, that full disclosure becomes suboptimal once there is uncertainty about the existence of private information or its content.

[2] Ali et al. (2023) echo the results of Glode et al. (2018) in the context of voluntary disclosures in interactions with a monopolist. Monopoly pricing is also studied by Bergemann et al. (2015) who analyze how exogenously providing monopolists with additional information for price discrimination affects total surplus and its allocation. Inostroza and Tsoy (2022) investigate optimal security design with information design, and the main result shows that trade always occurs in equilibrium.

information about the amount of negative externalities created by the foreign company's manufacturing activities. Outsiders' beliefs are characterized by the cumulative distribution function (CDF) $G(e)$. The function $G(e)$ is continuous and differentiable and the probability density function (PDF), denoted by $g(e)$, takes strictly positive values on the support $[\underline{e}, \overline{e}]$.

The foreign firm can be a cost-efficient producer, which motivates the domestic firm to potentially source its inputs from this firm. However, the foreign firm's production costs are not only affected by its efficiency, but also negatively related to the brownness of its production process: Pollutive production is cheaper. For instance, a brown production process may be cheaper as it economizes on abatement efforts. Formally, the foreign firm's production costs are given by $(c-e)$, where c represents production costs unrelated to externalities.

Two key features of the global supply chain we model are (1) the foreign firm's private information about its environmental standards, and (2) the domestic firm's market power. Specifically, the domestic firm chooses a price p that it will offer to the foreign firm in a take-it-or-leave-it offer. If the offer is rejected by the foreign firm, it is not used to source inputs and all parties obtain a payoff that is normalized to 0.[3] In contrast, if the foreign firm accepts the offer, it produces and delivers the input to the domestic firm, yielding it a payoff:

$$u_F = p - \underbrace{(c-e),}_{\text{production costs}} \tag{1}$$

where the first term represents the proceeds from the transaction and the terms in brackets capture the production costs accounting for the cost savings associated with brown technologies that generate high environmental externalities.

Absent government interventions, the domestic firm is not directly impacted by the negative externalities e. This assumption captures the more general notion that the domestic firm does not fully internalize the externalities associated with its sourcing of inputs. Conditional

[3] This normalized payoff could reflect in reduced form the possibility that the domestic firm instead relies on an outside option, such as a domestic supplier with known environmental standards.

on production and trade occurring, the domestic firm's payoff is given by:

$$u_D = v - p, \tag{2}$$

where v represents the value the domestic firm internalizes. In contrast, the domestic household sector is negatively affected by the environmental externalities. In particular, given that production occurs and generates externalities e, domestic households suffer a disutility of $-\lambda e$, where $\lambda > 0$ captures the household's exposures to environmental damages. Separately from this disutility associated with externalities, the domestic households benefit from the production by internalizing a consumer surplus equal to h. Their overall payoff conditional on production occurring is thus given by:

$$u_H = h - \lambda e. \tag{3}$$

Overall, the domestic surplus conditional on trade occurring is then given by:

$$u_D + u_H = v + h - \lambda e - p, \tag{4}$$

and conditional global surplus takes the form:

$$u_D + u_H + u_F = h + v - c + (1 - \lambda)e. \tag{5}$$

Environmental Disclosures. We analyze the foreign firm's decision to publicly share a subset or all of its information before trade occurs. Sharing information might hurt the foreign firm since possessing private information yields information rents, but it might also reduce the domestic firm's incentives to charge inefficient mark-ups that reduce the expected gains from trade in the supply chain.

We assume that the foreign firm must design its disclosure plan prior to obtaining private information, and that it can commit to this plan, as is common in models of information design. Assuming that the foreign firm is uninformed at the time of the information design increases the tractability of the analysis, as it eliminates the existence of signaling concerns. Yet the disclosures we characterize are robust to this timing assumption under reasonable equilibrium refinements (see Glode et al., 2018). Further, we restrict our attention to ex post verifiable disclosures, which ensures that actual disclosures are in fact consistent with the disclosure plan to which the foreign firm voluntarily commits. Note that it is generally technologically feasible that a foreign firm subjects itself to environmental certification processes administered by international agencies. Yet the question is whether a foreign firm finds it privately optimal to commit to such verification. Under ex post verifiability, a firm may always choose not to commit to providing incremental information. Ex post verifiability is also a common assumption in the disclosure literature (see Verrecchia (2001); Milgrom (2008a); Beyer et al. (2010) for related surveys). We formally define ex post verifiability as follows.

Definition 1. *A signal whose realization s belongs to a set S is called "ex post verifiable" if it can be represented by a function $D : [\underline{e}, \overline{e}] \to S$ such that $D^{-1}(s) \equiv \{v : D(v) = s\} \in \mathscr{B}([\underline{e}, \overline{e}])$ $\forall s \in S$, where $\mathscr{B}([\underline{e}, \overline{e}])$ denotes the Borel algebra on $[\underline{e}, \overline{e}]$.*

This definition implies that for any signal realization $s \in S$, $D^{-1}(s)$ is a Borel set in $[\underline{e}, \overline{e}]$. Since a Borel set in $[\underline{e}, \overline{e}]$ must be characterized by unions of intervals, designing a disclosure plan implies combining partitions to inform the trade partner about possible realizations of e. In the literature, it is common to impose monotonicity restrictions with regards to the disclosure functions agents choose, since doing so significantly increases analytical tractability (see Orlov, Zryumov, and Skrzypacz, 2023).[4] We follow this approach as stated in the following assumption.

[4]Monotonicity is also imposed in the context of the security design literature, where it has similar justifications. See, e.g., Innes (1990), Nachman and Noe (1994), and DeMarzo and Duffie (1999).

Assumption 1. *Disclosure plans $D(e)$ are restricted to be monotone in e.*

Disclosure plans satisfying these assumptions can capture for example the discrete ratings categories typically encountered in practice. In particular, a disclosure plan $D(e)$ can be represented as follows:

$$D(e) = \begin{cases} \underline{e}, & \text{for } e \in [\underline{e}, e_1), \\ e_1, & \text{for } e \in [e_1, e_2), \\ e_2, & \text{for } e \in [e_2, e_3), \\ \dots \\ e_n, & \text{for } e \in [e_n, \overline{e}], \end{cases} \tag{6}$$

where the partition cutoffs $e_1, ..., e_n$, with $\underline{e} < e_1 < e_2 < ... < e_n < \overline{e}$, separate the domain of types $[\underline{e}, \overline{e}]$ into disjoint subsets.

Government interventions. Since the domestic and foreign firms do not internalize the negative externalities affecting domestic households, there is a potential role for interventions by the government. In the presence of a tax τ that is applied to the transaction between the domestic and the foreign firm, the domestic firm's payoff conditional on trade occurring is given by:

$$u_D = v - p - \tau. \tag{7}$$

Timing and equilibrium. The timing of the game is as follows:

1. The foreign firm chooses a disclosure plan represented by a function $D : [\underline{e}, \overline{e}] \to S$.

2. The government chooses a tax schedule that is a function of the possible disclosures S.

3. The foreign firm privately observes e.

4. A disclosure S consistent with the plan $D(e)$ is made.

5. The domestic firm makes a take-it-or-leave-it offer to the foreign firm.

6. The foreign firm accepts or rejects the offer.

7. International production occurs conditional on an acceptance and payoffs are realized.

Figure 2 illustrates this timeline. An equilibrium consists of the foreign firm's disclosure plan, the government's tax scheme, the domestic firm's take-it-or-leave-it offer, and the foreign firm's acceptance decision. We analyze Perfect Bayesian Equilibria (PBE) of this game.

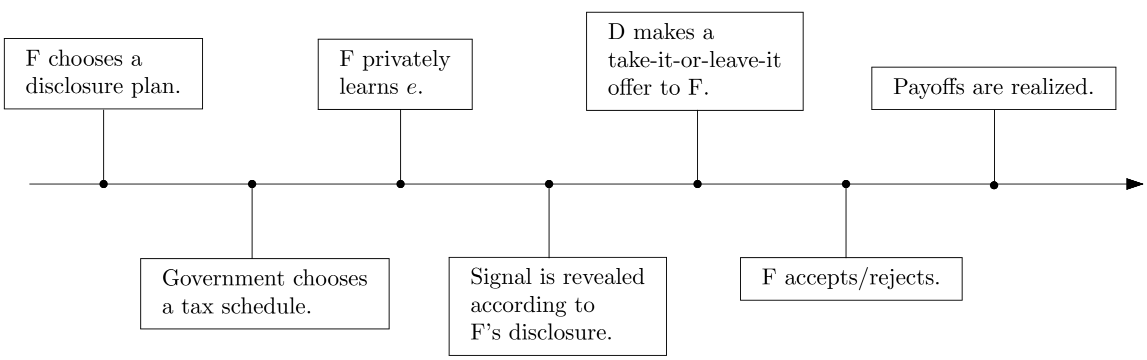


Figure 2: Timeline. The figure illustrates the timeline of the game.

Observability of ex post realizations absent disclosures. One might wonder to what extent it might be feasible for a domestic government to tax parties creating high emissions based on the ex post realizations of emissions (rather than using their voluntary disclosures). A typical feature of externalities such as carbon emissions is that they are not measurable at the level of an individual firm unless measurements are taken locally, at the time of their creation, as allowed by the producers. Otherwise, it is not possible to trace emissions back to their source. Formally, this is consistent with an environment where each supply chain relation is atomistic in size, yet households are exposed to aggregate emissions which represent the integral across all individual supply chain interactions. In this case, observing aggregate emissions does not reveal an individual firm's production externalities and thus cannot be used to determine penalties for such entities.

3 Analysis

In this section, we first analyze equilibrium outcomes absent government interventions. Thereafter, we examine government regulations.

3.1 Laissez-faire Equilibrium

Trade absent disclosure. Absent government interventions and absent informative disclosures by the foreign firm, the domestic firm's optimal pricing decision is characterized by the following program:

$$p^* = \arg\max_{p} \{(v-p) \cdot (1-G(c-p))\}, \tag{8}$$

where the first term represents the domestic firm's payoff conditional on trade occurring, and where the second term is the probability of trade; all foreign firm types satisfying $e \geq (c-p)$ accept a price offer p. This problem is equivalent to the domestic firm choosing the marginal foreign firm type $x = c - p$ that is just indifferent between accepting and rejecting the offer. The solution to the following problem yields the corresponding optimal marginal type:

$$e^* = \arg\max_{x \in [\underline{e}, \overline{e}]} \{(v-c+x) \cdot (1-G(x))\}. \tag{9}$$

If $e^* = \underline{e}$, trade occurs with probability one, that is, irrespective of the realization of e. In this case, not disclosing information is optimal for the foreign firm, since the equilibrium offer by the domestic firm is already the highest possible price. To focus our analysis on scenarios where disclosures may optimally occur in equilibrium absent government interventions, we make the following assumption going forward.

Assumption 2. $e^* > \underline{e}$.

When Assumption 2 is satisfied, trade may break down absent disclosures due to the presence of asymmetric information and the domestic firm's exercise of market power. In particular, trade breaks down for low levels of externalities $e < e^*$, since greener production is associated with relatively high production costs for the foreign firm.

In case an interior solution obtains, $e^* \in [\underline{e}, \overline{e}]$, the first-order condition:

$$\Pi'(e^*) = 1 - G(e^*) - (v - c + e^*) \cdot g(e^*) = 0 \tag{10}$$

applies. We assume that the marginal profit function, $\Pi'(\cdot)$, is decreasing, such that the first-order condition (10) holds at the optimum, unless there is a corner solution.

Trade with disclosure. Conditional on the foreign firm disclosing a signal $\tilde{s} \in S$ revealing that $e \in [a, b)$ and implying the associated conditional CDF:

$$G_{\tilde{s}}(e) \equiv \frac{G(e) - G(a)}{G(b) - G(a)}, \tag{11}$$

the domestic firm solves the program:

$$e^*_{\tilde{s}} = \arg \max_{x \in [a,b)} \{(v - c + x) \cdot (1 - G_{\tilde{s}}(x))\}. \tag{12}$$

Conditional on an interior solution, this yields the first-order condition:

$$\Pi'_{\tilde{s}}(e^*_{\tilde{s}}) = 1 - G_{\tilde{s}}(e^*_{\tilde{s}}) - (v - c + e^*_{\tilde{s}}) \cdot g_{\tilde{s}}(e^*_{\tilde{s}}) = 0. \tag{13}$$

A useful property that we will leverage in our analysis below is that the optimal marginal type is unaffected if a signal leads to the truncation of the unconditional distribution $G(e)$ from below, provided that the truncation is weakly below the unconditional optimum. That is, suppose that absent disclosures, the optimal marginal type is interior, $e^* \in [\underline{e}, \overline{e}]$, and solves equation (10). If the domestic firm now receives a signal $\tilde{s}$ that truncates the distribution $G(e)$ from below at $a \leq e^*$, revealing that $e \in [a, \overline{e}]$, we obtain the conditional CDF:

$$G_{\tilde{s}}(e) = \frac{G(e) - G(a)}{1 - G(a)}. \tag{14}$$

Substituting this expression into equation (12) yields

$$e^*_{\tilde{s}} = \arg \max_{x \in [a,b)} \{(v - c + x) \cdot \left(\frac{1 - G(x)}{1 - G(a)} \right) \}, \tag{15}$$

which has the same solution as the unconditional program (9), since scaling the objective by a constant factor $(1 - G(a))$ does not affect the optimum.

Voluntary disclosure. Next, we consider the case where the foreign firm chooses a privately optimal disclosure plan. The following lemma characterizes a key property of such disclosure plans.

Lemma 1. *Absent government interventions, the foreign firm optimally designs a partial disclosure plan that ensures that trade occurs if and only if it generates positive joint surplus* *for the domestic and foreign firms, that is, for*

$$u_D + u_F \geq 0 \quad \Leftrightarrow \quad e \geq c - v. \tag{16}$$

The proof of Lemma 1 is by contradiction.[5] Suppose that contrary to Lemma 1 the foreign firm chose a disclosure plan that potentially generates a signal conditional on which trade does not occur with types e for which the bilateral surplus is positive, that is, where $e > c - v$. Specifically, the plan includes a possible disclosure $\tilde{s} \in S$ revealing that $e \in [a, b)$ and the optimally chosen marginal type conditional on this disclosure is $e^*_{\tilde{s}} > c - v$. If there are excluded types e satisfying

$$c - v < e < e^*_{\tilde{s}}, \tag{17}$$

the foreign firm can strictly improve its ex ante utility by adjusting its disclosure plan as follows: it can split the original disclosure interval $[a, b)$ into two new disclosure intervals, $[a, e^*_{\tilde{s}})$ and $[e^*_{\tilde{s}}, b)$, associated with the new signals $\hat{s}_1$ and $\hat{s}_2$, while keeping the rest of the disclosure plan unchanged. With this adjusted disclosure plan, conditional on a disclosure $\hat{s}_2$ indicating that $e \in [e^*_{\tilde{s}}, b)$, the price optimally charged by the domestic firm is still $p = c - e^*_{\tilde{s}}$, implying that all types in the interval $[e^*_{\tilde{s}}, b)$ are still trading at the same price under this revised disclosure plan (see the truncation property highlighted in the previous subsection).

Moreover, there will be trade with a positive measure of previously excluded types belonging to the interval $[a, e^*_{\tilde{s}})$ at a price exceeding $p = c - e^*_{\tilde{s}}$. Conditional on a signal $\hat{s}_1$ revealing that $e \in [a, e^*_{\tilde{s}})$, the optimal marginal type is a strictly interior element of the interval $[c - v, e^*_{\tilde{s}})$. The marginal type will be interior for the following reasons: (1) Offering a price $p = c - e^*_{\tilde{s}}$ would yield the domestic firm a payoff of zero, since the acceptance probability would be zero. (2) Offering a price $p = v$ would yield the domestic firm zero since

[5] A related result is derived in Glode, Opp, and Zhang (2018).

this is its valuation for the good. (3) Offering a price in between these two prices (below v and above $c - e^*_{\tilde{s}}$) yields a strictly positive probability of trade (since the PDF $g(\cdot)$ takes strictly positive values everywhere on the domain), while the price is also below v, and thus will yield the foreign firm a positive surplus. At the same time, this (interior) price offer will yield the foreign firm an information rent, since all types above the marginal type (conditional on the disclosure $\hat{s}_1$) will obtain strictly positive surplus. As a result, the foreign firm obtains strictly higher ex ante utility under this revised disclosure plan, implying that the initial supposition is inconsistent with optimality and cannot be an equilibrium.

Going beyond this general characterization, we will characterize specific optimal disclosure plans in Section 4.1.

3.2 Government Interventions

In this section, we first consider the case where the government imposes an unconditional transaction tax τ that does not vary with either the foreign firm's disclosures or the domestic firm's price offers (naturally τ is a subsidy when it takes negative values). Thereafter, we characterize the optimal mechanism from the perspective of the domestic country.

3.2.1 Unconditional Tax Schemes

With an unconditional tax, we can rewrite the domestic firm's payoff conditional on trade occurring as follows:

$$u_D = (v - \tau) - p = v' - p, \text{ where } v' \equiv v - \tau. \tag{18}$$

Note that the domestic firm and the foreign firm in this case solve problems that are equivalent to the ones absent government interventions, except that one needs to replace the variable v by v'. As a result, when the foreign firm chooses an optimal disclosure plan, trade occurs if and only if the joint payoff of the two firms, after accounting for taxes, is positive, that is, when:

$$u_D + u_F \geq 0 \;\;\Leftrightarrow\;\; e \geq c - v + \tau. \tag{19}$$

As a result, unconditional taxes ($\tau > 0$) lead to the rationing of *low-externality* (that is, relatively green) transactions relative to the case absent government interventions.

3.2.2 Domestic Planner Solution

In this section, we analyze the domestic planner solution. To isolate the role of private information in influencing optimal policies, we start by analyzing a benchmark setting with symmetric information. Subsequently, we turn to the asymmetric-information case.

Symmetric information. Suppose that all agents have symmetric but incomplete information about emissions. Let $\mathscr{F}$ denote the common information set. The domestic planner maximizes

$$\max_p \{ (v + h - \lambda\, \mathbb{E}[e|\mathscr{F}] - p) \cdot \mathbf{1}_{p \geq c - \mathbb{E}[e|\mathscr{F}])} \}. \tag{20}$$

With symmetric information and market power, the domestic planner solution imposes a price offer to the foreign firm that renders that firm indifferent between accepting and rejecting, subject to the constraint that the offer yields weakly positive surplus for the domestic sector. In this case, the domestic planner imposes a break-even price that implies zero surplus for the foreign firm:

$$\tilde{p} = c - \mathbb{E}[e|\mathscr{F}]. \tag{21}$$

Otherwise, no trade is optimal for the domestic sector, which is achieved by offering less than the break-even price $\tilde{p}$. The domestic sector's surplus given an offer $\tilde{p}$ is:

$$v+h-\lambda\,\mathbb{E}[e|\mathscr{F}]-\tilde{p}=v-c+h-(\lambda-1)\,\mathbb{E}[e|\mathscr{F}]. \tag{22}$$

The price $\tilde{p}$ maximizes domestic surplus provided that (22) is positive.

Asymmetric information. Next, we consider the case where the foreign firm possesses private information. If the domestic government can directly mandate a price offer p it chooses that price to maximize total domestic surplus,

$$u_D+u_H=v+h-\lambda e-p, \tag{23}$$

conditional on trade occurring. To consider the interesting cases where the total global payoff conditional on trade occurring, $(u_H+u_D+u_F)$, can be either positive or negative, we impose the following condition on parameters.

Assumption 3. $v+h-c+(1-\lambda)\underline{e}>0$ *and* $v+h-c+(1-\lambda)\overline{e}<0$.

This assumption implies that $\lambda>1$, since $\overline{e}>\underline{e}$. Assumption 3 states that global welfare is positive at the minimum level of externalities $e=\underline{e}$ and negative at the maximum level of externalities $e=\overline{e}$. As a result, there is a unique interior threshold level $\hat{e}\in(\underline{e},\overline{e})$ at which the global surplus conditional on trade occurring is exactly zero. This threshold level is given by:

$$\hat{e}=\frac{v+h-c}{\lambda-1}. \tag{24}$$

As shown in Section 3.1, voluntary disclosure plans generally ensure that trade occurs if and only if it generates positive bilateral surplus (see also Glode, Opp, and Zhang, 2018). In contrast, this result does not hold in our environment, even when the domestic government can cause the domestic firm to behave as if it maximizes total domestic surplus (in which case we effectively have a bilateral transaction between the domestic sector and the foreign firm). The fact that the domestic sector in our environment can generically have very different views on the desirability of high-externality transactions than the foreign trade partner leads to the violation of technical conditions that were assumed in the prior disclosure literature. Proposition 1 provides sufficient conditions for the emergence of such excessive international trade in the presence of optimal government interventions.

Proposition 1. *Suppose $e \cdot g(e)$ is an increasing function, which is for example satisfied when e is uniformly distributed. Further, suppose the government uses a tax scheme that ensures that the domestic firm acts as if it maximizes total domestic surplus. Then, there exists a threshold level $\hat{\lambda}$, such that when $\lambda \geq \hat{\lambda}$, the foreign firm's optimal disclosure plan induces excessive trade, that is, trades occurs for a range of externalities e such that*

$$(u_H + u_D + u_F) < 0. \tag{25}$$

Proof. See Appendix. □

When the domestic households are sufficiently strongly exposed to environmental damages, which is the case for high enough values of the parameter λ, the foreign firm chooses a disclosure plan that pools types above the threshold level $\hat{e}$ with those below that level. As a result, when the disclosure indicates that externalities are in that region, trade occurs even though it may destroy global surplus. Economically, the divergence in how the domestic and the foreign parties are affected by high environmental externalities can cause this type of excessive pooling, which is absent in the existing literature studying related environments.

3.2.3 Tax Implementation of the Domestic Planner Solution

We now examine how this solution can be implemented by taxing the domestic firm's supply chain interaction with the foreign firm.

Symmetric information. Under symmetric information, the domestic firm also potentially chooses the break-even price $\tilde{p}$ detailed in equation (21). Yet absent government interventions, the condition under which it charges this price differs from the one optimally used by the domestic planner:

$$v - \tilde{p} = v - c + \mathbb{E}[e|\mathscr{F}] > 0. \tag{26}$$

Since the domestic firm does not internalize the externalities of the supply chain interaction, it generates excessive trade from a domestic perspective. Specifically, this is the case when (22) is negative whereas (26) is positive.

The domestic government can address this inefficiency by charging a Pigouvian tax. Facing a tax τ, the domestic firm's payoff from charging a price $\tilde{p}$ is:

$$v - \tilde{p} - \tau = v - (c - \mathbb{E}[e|\mathscr{F}]) - \tau = v - (c - \mathbb{E}[e|\mathscr{F}]) - \tau. \tag{27}$$

It can be easily verified that the following Pigouvian tax can implement the planner solution:

$$\tilde{\tau} = \lambda \cdot \mathbb{E}[e|\mathscr{F}] - h. \tag{28}$$

Asymmetric information. Turning to the case where the foreign firm has private information, we examine the domestic government's optimal tax scheme as a function of the foreign firm's disclosure. Suppose the foreign firm discloses a signal $\tilde{s}$ revealing that $e \in [a,b)$ and that the optimal marginal type $e^{**}_{\tilde{s}}$ for the domestic planner is an interior solution $e^{**}_{\tilde{s}} \in [a,b)$, which satisfies the first-order condition (13). :

$$1 - G_{\tilde{s}}(e^{**}_{\tilde{s}}) = (v + h - c + (1-\lambda) \cdot e^{**}_{\tilde{s}}) \cdot g_{\tilde{s}}(e^{**}_{\tilde{s}}). \tag{29}$$

The following proposition characterizes how the optimal tax depends on this marginal type $e^{**}_{\tilde{s}}$.

Proposition 2. *Assume that $H(e) \equiv \frac{1-G(e)}{g(e)} - e$ is a decreasing function of e. Suppose the foreign firm's discloses a signal $\tilde{s}$ revealing that $e \in [a,b)$, and the domestic planner solution induces trades for $e \geq e^{**}_{\tilde{s}}$, where $e^{**}_{\tilde{s}} \in (a,b)$. Then the government can implement this solution by imposing a tax*

$$\tau = \lambda e^{**}_{\tilde{s}} - h. \tag{30}$$

Proof. Consider the domestic firm's problem when there is a candidate tax $\tau = \lambda e^{**}_{\tilde{s}} - h$. The first-order condition for the domestic firm is

$$1 - G_{\tilde{s}}(e) = (v - c - \tau + e) g_{\tilde{s}}(e) = (v + h - c - \lambda e^{**}_{\tilde{s}} + e) g_{\tilde{s}}(e). \tag{31}$$

This equation has the same solution for as the domestic planner's first-order condition (29).

□

Comparing the optimal tax under asymmetric information (30) to the optimal tax under symmetric information (28) reveals that both taxes have a similar structure. However, whereas the tax under symmetric information leads the domestic firm to internalize the *expected* externality if trade were to occur (potentially off equilibrium), the optimal tax under asymmetric information causes the domestic firm to internalize the externality caused by the *marginal* type $e^{**}_{\tilde{s}}$ with which trade occurs under the domestic planner solution. This marginal type depends on the equilibrium disclosure choices of the foreign firm and the residual information asymmetry characterized by the conditional distribution $G_{\tilde{s}}(e)$.

4 Examples

In this section, we solve for optimal disclosure plans under concrete distributional assumptions and perform comparative statics with respect to structural parameters in the presence of government interventions.

4.1 Uniformly Distributed Environmental Externalities

In this subsection, we provide a full characterization of optimal government policies and optimal disclosure plans when externalities are uniformly distributed, $e \sim U[\underline{e}, \overline{e}]$. As a first step, the following proposition characterizes the government's optimal planner solution conditional on any disclosure by the foreign firm. Moreover, it details how the planner solution can be implemented via taxes.

Proposition 3 (Optimal Mechanism & Tax Implementation)**.**

1. *Suppose $\lambda < 2$ and the foreign firm's disclosure reveals that $e \in [a,b)$. The domestic planner solution and its implementation via taxes have the following properties:*

   - *If $a \geq \frac{b-(v+h-c)}{2-\lambda}$, all foreign firm types $e \in [a,b)$ trade with the domestic firm. The government can implement this solution by imposing a tax*

$$\tau \leq 2a - b + v - c. \tag{32}$$

   - *If $a < \frac{b-(v+h-c)}{2-\lambda} < b$, the optimal marginal foreign firm type is given by $e^* =$*

$\frac{b-(v+h-c)}{2-\lambda}$. *The government can implement this solution by imposing a tax*

$$\tau = \frac{\lambda(b-v+c)-2h}{2-\lambda}. \tag{33}$$

- *If* $\frac{b-(v+h-c)}{2-\lambda} \geq b$, *trade between the domestic and the foreign firm does not occur. The government can implement this solution by imposing a tax*

$$\tau \geq b+v-c. \tag{34}$$

2. *Suppose* $\lambda > 2$ *and the foreign firm's disclosure reveals that* $e \in [a,b)$. *The domestic planner solution and its implementation via taxes have the following properties:*

   - *If* $v+h-\lambda\frac{a+b}{2}-(c-a) \geq 0$, *all foreign firm types* $e \in [a,b)$ *trade with the domestic firm. The government can implement this solution by imposing a tax*

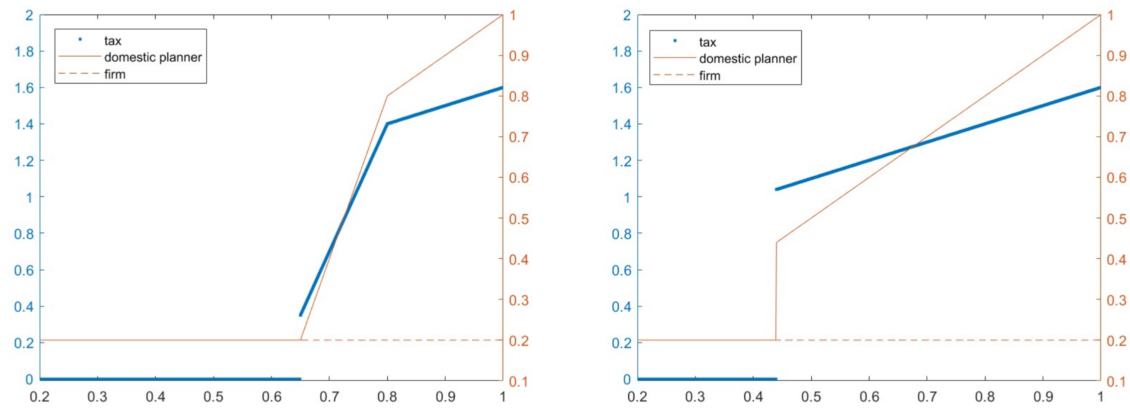
$$\tau \leq 2a-b+v-c. \tag{35}$$

   - *Otherwise, trade between the domestic and the foreign firm does not occur. The government can implement this solution by imposing a tax*

$$\tau \geq b+v-c. \tag{36}$$

Proof. See Appendix. □

Proposition 3 shows that the outcomes are dramatically different between the cases of $\lambda < 2$ and $\lambda > 2$. We provide the intuition that under the uniform distribution $\lambda = 2$ arises as the cut-off in these two cases. The domestic planner's payoff is given by the probability



(a) $\lambda = 1.75$

(b) $\lambda = 2.5$

Figure 3: The figure considers a parameterization where $e \sim U[0,1]$, $h = 0$, and $(v-c) = 0.6$. It illustrates for a generic disclosure revealing that $e \in [0.2, b)$ three objects as a function of the upper bound b of the disclosure interval: 1) the marginal foreign firm type absent government intervention, 2) the marginal foreign firm type under the domestic planner solution, and 3) the tax implementing the domestic planner solution. The left-hand side panel considers the case where $\lambda = 1.75$, and the right-hand side panel the case where $\lambda = 2.5$.

of trade time the payoff conditional on trade, which is

$$v + h - c - \lambda E[e|e \geq e^*] + e^*, \tag{37}$$

where e^* is the cut-off-type firm that trades. Since a higher induced cut-off type leads to a lower trade probability, the probability of trade is a decreasing function of e^*. When e follows a uniform distribution with upper bound b, we can integrate the expectation and find that the domestic planner's payoff condition on trade is $v + h - c - \lambda \frac{e^*+b}{2} + e^*$. It is evident that when $\lambda < 2$, the payoff condition on trade is an increasing function of e^* while when $\lambda > 2$, it is a decreasing function. In the former case ($\lambda < 2$), there is typically an interior e^* that maximizes the domestic planner's payoff. In the latter case ($\lambda > 2$), the domestic planner optimally induce an equilibrium that is either all types of firms trade or no types trade, depending on whether inducing all types trade leads to a positive payoff. The no trade case corresponds to that adverse selection is severe enough (e is too high that the planner is worried about any possibility of trade). Knowing the domestic planner's strategy, when $\lambda > 2$, the foreign firm optimally disclose at most two intervals where one of the them ensures that all types in the interval trade and the other contains the no-trade types.

Figure 3 illustrates the results of Proposition 3 with comparative statics. It plots for a generic disclosure revealing that $e \in [0.2, b)$ three objects as a function of the upper bound b of the disclosure interval: 1) the marginal foreign firm type absent government intervention, 2) the marginal foreign firm type under the domestic planner solution, and 3) the tax implementing the domestic planner solution. The left-hand side panel considers the case where $\lambda = 1.75$, and the right-hand side panel the case where $\lambda = 2.5$. Throughout, absent government intervention, the marginal foreign firm type is equal to the lower bound of the disclosure interval, 0.2, that is, trade occurs with probability 1 for all values of the upper-bound parameter b between 0.2 and 1.

In contrast, under the domestic planner solution, the optimal marginal foreign firm type starts to exceed the value 0.2 for sufficiently high values of b, both in the case of $\lambda = 1.75$ and the case where $\lambda = 2.5$. Intuitively, once a disclosure indicates the possibility of sufficiently high environmental externalities, the government takes measures to reduce trade. First, consider the case where domestic households are strongly exposed to the externalities caused by the foreign firm's production, $\lambda = 2.5$ (right-hand side panel). As we increase the upper-bound parameter b, the domestic planner solution discretely switches between choosing a marginal foreign firm type equal to the lower bound 0.2 (in which case trade occurs always) and choosing the upper bound b (in which case trade never occurs). This is implemented by first imposing no taxes and then discretely shifting to a positive tax that increases with the upper bound b.

Second, consider the case where domestic households are less exposed to the externalities, $\lambda = 1.75$ (left-hand side panel). Now, as we increase the upper-bound parameter b, there is also a threshold level for b at which the government switches from imposing no taxes to imposing a strictly positive tax. For an intermediate range of values of the parameter b, this tax ensures that there is an interior marginal foreign firm type, and trade occurs only if externalities *exceed* that marginal type. Why would this be an optimal outcome from the perspective of the domestic economy? The answer is that brown production (high values for e) also has the benefit of being associated with low costs for the foreign producer, which, in turn, is passed through via low prices to the domestic economy. However, once the negative externalities e can be high enough, the tax schedule yet again ensures that there is no trade between the domestic firm and the foreign firm. Such a tax is still increasing with the upper bound of the disclosure interval b. Overall, these results illustrate the intricate properties of optimal domestic taxation in response to foreign firms' disclosures.

Anticipating this domestic planner solution, the foreign firm chooses its optimal disclosure plan, which is characterized in the following proposition.

Proposition 4 (Optimal Disclosure)**.** *Suppose the government implements the domestic planner solution.*

1. *When $\lambda < 2$, the privately optimal disclosure plan chosen by the foreign firm ensures that trade occurs if and only if $u_H + u_D + u_F > 0$. The disclosure plan can be represented by the function*

$$D(e) = \begin{cases} \underline{e}, & \text{for } e \in [\underline{e}, e_1), \\ e_1, & \text{for } e \in [e_1, e_2), \\ e_2, & \text{for } e \in [e_2, e_3], \\ \cdots & \\ \overline{e}, & \text{for } e \in [\hat{e}, \overline{e}], \end{cases} \tag{38}$$

where the infinite sequence $\{e_1, e_2, \cdots\}$ is defined by the recursive relation $e_{i+1} =$

$(2-\lambda)e_i + (v+h-c)$, with $e_0 \equiv \underline{e}$ and $\lim_{n\to\infty} e_n = \hat{e}$.

2. *When $\lambda \geq 2$, the privately optimal disclosure plan chosen by the foreign firm separates the domain into two disjoint intervals. The optimal disclosure plan can be represented by the function*

$$D(e) = \begin{cases} \underline{e}, & \text{for } e \in [\underline{e}, e_1], \\ e_1, & \text{for } e \in (e_1, \overline{e}], \end{cases} \tag{39}$$

where

$$e_1 = \frac{2(v+h-c)+2\underline{e}}{\lambda} - \underline{e}. \tag{40}$$

Trade occurs with probability 1 when the foreign firm discloses $\underline{e}$ and with probability 0 otherwise. Global surplus, $(u_H + u_D + u_F)$, is strictly negative when externalities take values in the interval $(\hat{e}, e_1]$.

Proof. See Appendix. □

Proposition 4 shows that the parameter λ characterizing domestic households' exposures to environmental damages has first-order implications for the shape of disclosure plans and the extent to which government interventions effectuate behavior that maximizes global surplus. When externalities are less substantial ($\lambda < 2$), disclosure plans may feature more than two intervals and supply chain outcomes maximize global surplus. In contrast, when externalities are severe ($\lambda > 2$), disclosure plans collapse to 2 intervals. Moreover, international trade is excessive in the sense that it does not yield the first-best level of global surplus.

We illustrate the results of this section with additional comparative statics.

Example 1. Suppose the environmental externalities are uniformly distributed, $e \sim U[0,1]$, that is, $\underline{e} = 0$ and $\overline{e} = 1$, and suppose that $h = 0$.

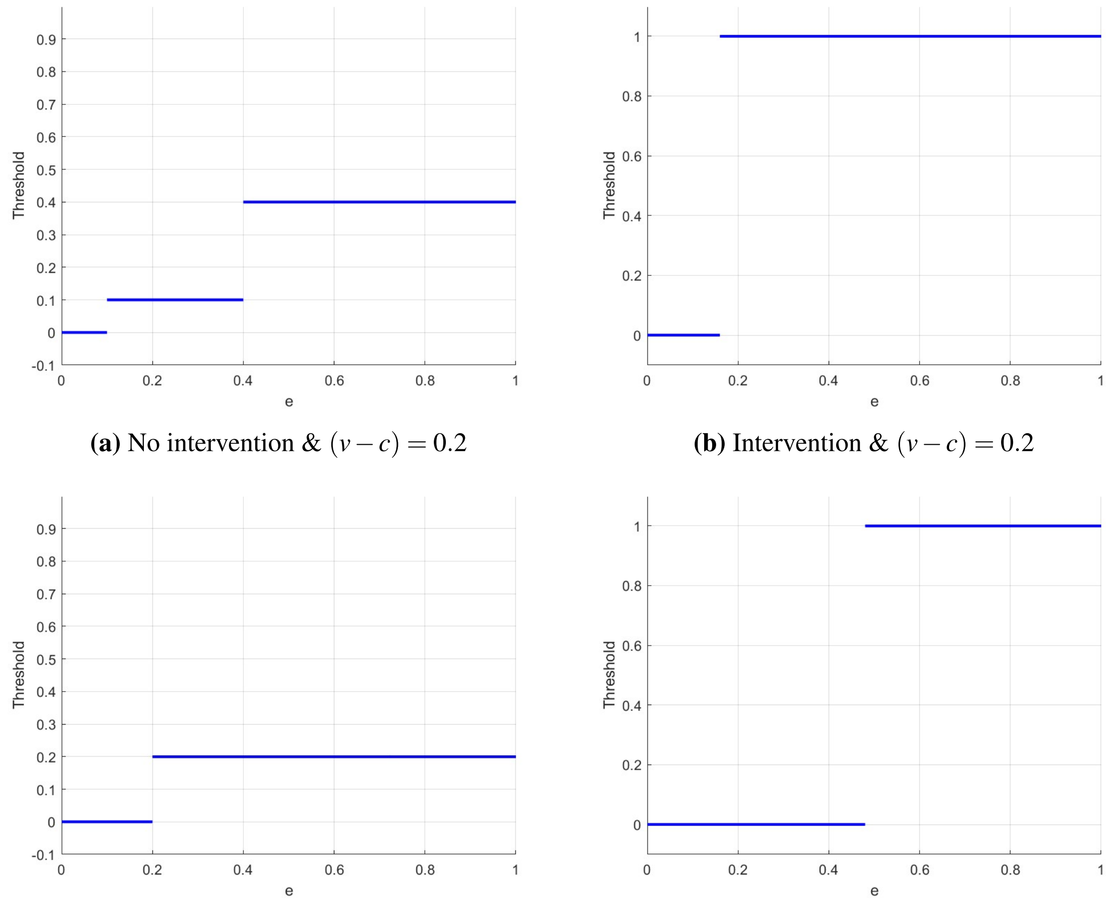
No government interventions. Absent government interventions, an optimal disclosure plan for the foreign firm is given by:

$$D(e) = \begin{cases} 0, & \text{for } e \in [0, e_1), \\ e_1, & \text{for } e \in [e_1, e_2), \\ \dots & \\ e_n, & \text{for } e \in [e_n, 1], \end{cases} \tag{41}$$

where the values $e_1 \dots e_n$ are defined by the recursive sequence the recursive sequence $e_i = \frac{e_{i+1} - (v-c)}{2}$, where $e_{n+1} \equiv 1$ and where $n = \max_{i \in N^+} \{e_1 \geq 0\}$.

Domestic planner solution. Suppose the government imposes an optimal conditional tax scheme that implements the domestic planner solution as stated in Proposition 3. Further, the foreign firm chooses the corresponding optimal disclosure schedule as stated in Proposition 4.

Figure 4 compares the optimal disclosure plan for different levels of bilateral trade surplus, $(v-c)$, and conditional on no government intervention (left-hand side panels) and in the presence of the optimal domestic tax scheme (right-hand side panels). When firms' bilateral trade surplus is low ($(v-c) = 0.2$; see Panels (a) and (b)) and the government does not intervene, the foreign firm optimally provides a relatively granular disclosure plan that splits the domain of externalities into three intervals. Doing so ensures that trade occurs for all externality levels, despite the presence of lower gains from trade. In contrast, once the government taxes transactions conditional on such disclosures (see Panel (b)), the foreign firm chooses a less granular plan with only two intervals, and where the lowest interval pools



(a) No intervention & $(v-c)=0.2$ **(b)** Intervention & $(v-c)=0.2$

(c) No intervention & $(v-c)=0.6$ **(d)** Intervention & $(v-c)=0.6$

Figure 4: The figure illustrates the privately optimal disclosure plans chosen by the foreign firm absent government intervention (left-hand side panels) and in the presence of the optimal domestic tax scheme (right-hand side panels). The parameterization follows Example 1 and sets $\lambda = 2.5$.

more types.

In contrast, when firms' bilateral trade surplus is higher ($(v-c)=0.6$; see Panels (c) and (d)), the privately optimal disclosure plan absent government intervention is already coarser and features only two intervals (see Panel (c)). However, when the government further imposes taxes conditional on disclosures (see Panel (d)), the foreign firm again increases the low-externality disclosure interval, leading to excessive pooling.

Overall, these results reveal that when international trade involves countries that have substantially different exposures to the environmental damages, tax schedules should generally be a non-linear function of disclosed externalities. This prescription contrasts with the presence of one common price for emissions in carbon credit markets in practice. Moreover, our analysis reveals how the goal of penalizing high-externality production interferes with the precision of disclosures, highlighting the limits of optimal government interventions that target domestic firms' import practices.

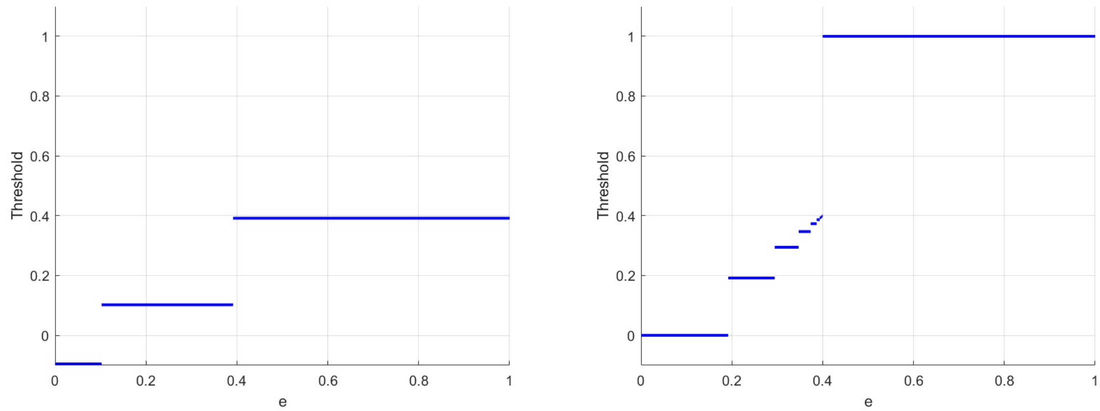
4.2 Normally Distributed Environmental Externalities

In this subsection, we analyze the case where externalities follow a truncated normal distribution and households are not severely exposed to externalities.

First, we consider optimal disclosure plans chosen by the foreign firm both absent interventions and in the presence of the optimal domestic tax scheme. Figure 5 shows that absent interventions, the foreign firm chooses a fairly coarse disclosure plan with three potential signals (see Panel (a)). In contrast, in the presence of government interventions (Panel (b)), the optimal disclosure plan becomes increasingly granular as externalities approach $\hat{e} \approx 0.4$, the level where global surplus turns negative. Interestingly, in this case the anticipation of government taxes and the associated reduction in gains from trade between the domestic and foreign firm necessitates more informative disclosures to avoid inefficient trade break downs. That is, contrary to the case where households are strongly exposed to externalities (see Figure 4), government interventions can increase the precision of disclosures when households are less exposed.

5 Conclusion

In this paper, we analyze voluntary environmental disclosures in the context of global supply chains and study a government's optimal reliance on such disclosures in regulations. We show that tax schedules should generally be a non-linear function of the environmental ex-



(a) No intervention

(b) Intervention

Figure 5: The figure illustrates the foreign firm's privately optimal disclosure plan with and without government intervention. Externalities follow $e \sim N(0.5, 1)$, truncated from below at 0, and from above at 1. We set $\lambda = 1.5$.

ternalities disclosed by a foreign trade partner, contrasting with the notion of a common price for CO2 emissions in carbon credit markets. Our analysis reveals how penalizing trade with foreign firms that reveal the brownness of their production technologies can interfere with the precision of their disclosures, but whether it does so crucially depends on the domestic sector's exposure to externalities.

A Proofs

Proof of Proposition 1. Given a generic disclosure that implies $e \in [a,b)$, we characterize the cutoff type D induces to trade. D's problem is

$$\max_p \frac{G(b)-G(c-p)}{G(b)-G(a)} \left[v+h-p-\lambda\, \mathbb{E}[e|e \geq c-p]\right].$$

Let $x = c-p$, the problem can be rewritten as

$$\max_x \frac{G(b)-G(x)}{G(b)-G(a)} \left[v+h-c+x-\lambda\, \mathbb{E}[e|e \geq x]\right].$$

Equivalently,

$$\max_x (G(b)-G(x)) \left[v+h-c+x\right] - \lambda \int_x^b edG(e).$$

Let $d(x) = (G(b)-G(x))\left[v+h-c+x\right] - \lambda \int_x^b edG(e)$, which is linear in λ. We have

$$\frac{\partial^3 d}{\partial x^2 \partial \lambda} = \frac{\partial (xg(x))}{\partial x} > 0.$$

This is to say that for sufficiently large λ, $d(x)$ is convex in x.

Returning to the proof of the proposition, we argue by contradiction. Suppose under F's optimal disclosure schedule, trade is efficient. That is, the disclosure schedule separates types above $\hat{e}$ and types below $\hat{e}$. Assume that one of the disclosure implies $e \in [e', \hat{e})$, where $e' \geq \underline{e}$. We shall consider a small perturbation in the disclosure schedule such that F earns a higher ex ante expected payoff, which leads to a contradiction. For ease of exposition, we let $e' = \underline{e}$ so that there are two disclosures: $\{[\underline{e}, \hat{e}), [\hat{e}, \overline{e}]\}$. Consider the following disclosure schedule: $\{[\underline{e}, \hat{e}+\varepsilon), [\hat{e}+\varepsilon, \overline{e}]\}$. When $e \in [\hat{e}+\varepsilon, \overline{e}]$, there is no trade due to negative social surplus, so nothing changes comparing to the original disclosure schedule.

Next, we claim that we can choose ε so that D still induces trading for all $e \in [\underline{e}, \hat{e}+\varepsilon)$.

Setting $a = \underline{e}, b = \hat{e} + \varepsilon$. D;s expected payoff function $d(x)$ is convex for large enough λ. So D induces either $x = \hat{e} + \varepsilon$ or $x = \underline{e}$. Since inducing $x = \hat{e} + \varepsilon$ implies no trade, it implies that $d(\hat{e} + \varepsilon) = 0$. If we choose ε small enough $d(\underline{e}) > 0$. This is because in the original disclosure schedule $[\underline{e}, \hat{e})$, D's payoff by inducing $\underline{e}$ is strictly positive. By continuity argument, when ε is small enough, $d(\underline{e}) > 0$ under the new disclosure schedule.

Now, F's payoff is strictly higher under the new disclosure schedule than under the original schedule, since types in $[\hat{e}, \hat{e} + \varepsilon)$ are earning strictly positive payoffs. Overall, the original disclosure schedule can not be the equilibrium outcome. So the equilibrium can not feature efficient trade. Using the arguments in the case with no interventions, the case with simple tax scheme and the arguments in Glode, Opp, and Zhang (2018), the equilibrium can not feature inefficiently low trade. As a result, the only possibility is that equilibrium features inefficiently excessive trade. □

Proof of Proposition 2. We note that e^* is interior since $e^* \in (a, b)$. Thus, the first order condition holds:

$$1 - G(e^*) = (v + h - c + (1 - \lambda)e^*)g(e^*).$$

Consider the domestic firm's problem when there is a tax $\tau = \lambda e^* - h$. The FOC is

$$1 - G(e) = (v - c - \tau + e)g(e) = (v + h - c - \lambda e^* + e)g(e).$$

Thus, $e = e^*$ satisfies the above condition. Moreover, since $\frac{1-G(e)}{g(e)} - e$ is a decreasing function of e, the FOC has at most one solution. Overall, with a tax $\tau = \lambda e^* - h$, the domestic firm optimally charges a price that induces the threshold e^* over which type foreign firms accept the price.

Proof of Proposition 3. We first consider the domestic planner solution when $\lambda < 2$:

$$p = \arg\max_{p}(v+h-\lambda E[e|e \geq c-p, e \in [a,b)] - p)(b-(c-p)).$$

Since $\lambda < 2$, from the first order condition we find that $e^* = \frac{b-(v+h-c)}{2-\lambda}$. We first assume $e^* \in (a,b)$, that is, $a < \frac{b-(v+h-c)}{2-\lambda} < b$. Suppose a tax is imposed so that D's payoff is $v-p-\tau$ when there is a trade. Following the same argument, the optimal threshold $e^* = \frac{b-(v-\tau-c)}{2}$. Setting $\frac{b-(v-\tau-c)}{2} = \frac{b-(v+h-c)}{2-\lambda}$, we obtain $\tau = \frac{\lambda(b-v+c)-2h}{2-\lambda}$.

We discuss the case $e^* \leq a$ or $e^* \geq b$.

- Suppose $e^* \leq a$, or $a \geq \frac{b-(v+h-c)}{2-\lambda}$. D's optimal price under the domestic planner solution is given by $c-a$, in which case the cut-off type is a. Since when a tax is imposed the optimal threshold $\frac{b-(v-\tau-c)}{2}$, government can implement the same outcome by imposing a tax such that $\frac{b-(v-\tau-c)}{2} = a$, equivalently, $\tau = 2a-b+v-c$.

- Suppose $e^* \geq b$, or $\frac{b-(v+h-c)}{2-\lambda} \geq b$. D's optimal price under the domestic planner solution is given by $c-b$, in which case the threshold is b. Since when a tax is imposed the optimal threshold $\frac{b-(v-\tau-c)}{2}$, government can implement the same outcome by imposing a tax such that $\frac{b-(v-\tau-c)}{2} = b$, equivalently, $\tau = v-c+b$.

Next consider $\lambda > 2$. The domestic planner solution is given by the following program.

$$p = \arg\max_{e^*=c-p}(v+h-\lambda E[e|e \geq e^*, e \in [a,b)] - p)(b-e^*).$$

As we discussed in the proof of Proposition 4, the above program is convex in e. So the optimal e^* is either a or b. There are two possibilities.

- If $v+h-\lambda\frac{a+b}{2}-(c-a) \geq 0$, D's optimal price under the domestic planner solution is given by $c-a$, in which case the cut-off type is a. Since when a tax is imposed the optimal threshold $\frac{b-(v-\tau-c)}{2}$, government can implement the same outcome by imposing a tax such that $\frac{b-(v-\tau-c)}{2} = a$, equivalently, $\tau = 2a - b + v - c$.

- Otherwise, D's optimal price under the domestic planner solution is given by $c - b$, in which case the cut-off type is b. Since when a tax is imposed the optimal threshold $\frac{b-(v-\tau-c)}{2}$, government can implement the same outcome by imposing a tax such that $\frac{b-(v-\tau-c)}{2} = b$, equivalently, $\tau = b + v - c$.

□

Proof of Proposition 4. Following the proof of Proposition 1, when G is a uniform distribution and $e \in [a, b)$, D's problem is

$$\max_x (b - x)\left[v + h - c + x - \lambda \frac{x + b}{2}\right].$$

When $\lambda < 2$, D's objective function is concave. From the first order condition, the optimal $x = \frac{b-(v+h-c)}{2-\lambda}$. We note that if $b > \hat{e}$, then $\frac{b-(v+h-c)}{2-\lambda} > b$, since $v + h - c = (\lambda - 1)\hat{e}$ and $\lambda > 1$. In this case, D's optimal $x = b$, yielding a zero profit. This observation implies that if the right end side of an interval is greater than $\hat{e}$, then there is no trade. Thus, F optimally discloses $[\hat{e}, \overline{e}]$, which induces no trade. It is left to solve the optimal disclosure schedule for $e \in [\underline{e}, \hat{e})$. We assume that the disclosure schedule is given by

$$[\underline{e}, e_1), [e_1, e_2), \cdots$$

We write $e_0 = \underline{e}$ for convenience. We first observe that the arguments in Glode, Opp, and Zhang (2018) apply, and trade occurs with probability 1 when $e \in [e_i, e_{i+1})$. This implies that $e_i \geq \frac{e_{i+1}-(v+h-c)}{2-\lambda}$. F's expected payoff is given by

$$\sum_{i=0}^{\infty} \int_{e_i}^{e_{i+1}} (e-e_i)\, de$$
$$= \sum_{i=0}^{\infty} \frac{(e_{i+1}-e_i)^2}{2}.$$

Define the following two functions. $rb(\cdot)$ is the right bound of an interval such that trade occurs with probability 1, $lb(\cdot)$ is the left bound of an interval such that trade occurs with probability 1,

$$rb(e) = (2-\lambda)e_i + (v+h-c)$$
$$lb(e) = \frac{e_i-(v+h-c)}{2-\lambda}.$$

Suppose $e_{i-1} > \frac{e_{i+1}-(v+h-c)}{2-\lambda}$, we ask which value of e_i maximizes F's expected payoff. We note that F's expected payoff is a quadratic function of e_i with a positive coefficient on e_i^2. This suggests that to maximize F's expected payoff, e_i should achieve the boundary values, i.e., $rb(e_{i-1})$ or $lb(e_{i+1})$. Moreover, the quadratic function is minimized at $\frac{e_{i-1}+e_{i+1}}{2}$. We next show that whether $rb(e_{i-1})$ is always further from $\frac{e_{i-1}+e_{i+1}}{2}$ than $lb(e_{i+1})$

$$rb(e_{i-1}) + lb(e_{i+1}) > e_{i-1} + e_{i+1}$$
$$\Leftrightarrow (2-\lambda)e_{i-1} + v + h - c + \frac{e_{i+1}-(v+h-c)}{2-\lambda} > e_{i-1} + e_{i+1}$$
$$\Leftrightarrow -e_{i-1} - \frac{v+h-c}{2-\lambda} + \frac{e_{i+1}}{2-\lambda} > 0,$$

which holds given the assumption $e_{i-1} > \frac{e_{i+1}-(v+h-c)}{2-\lambda}$. As a result, to maximize F's expected payoff, $e_i = rb(e_{i-1})$. Repeatedly applying this result, we obtain the optimal disclosure in the proposition.

When $\lambda > 2$, D's objective function $(b-x)\left[v+h-c+x-\lambda\frac{x+b}{2}\right]$ is convex in x. Thus, the maximum is achieved at the two extremes when $x = a$ or $x = b$. Since $x = b$ yields a zero profit, D is willing to quote $x = a$ if and only if

$$v + h - c + a - \lambda \frac{a+b}{2} > 0. \tag{A1}$$

Equivalently,

$$b < \frac{2(v+h-c)+(2-\lambda)a}{\lambda}. \tag{A2}$$

We next show that under the optimal disclosure plan, there are at most one signal realization that leads to trade between D and F. We argue by contradiction. Suppose D is willing to quote the lower bound when $e \in [\underline{e}, a)$ and when $e \in [a, b)$, then D is also willing to quote the lower bound when $e \in [\underline{e}, b)$.

We observe that

$$b < \frac{2(v+h-c)+(2-\lambda)a}{\lambda} \tag{A3}$$

$$< \frac{2(v+h-c)+(2-\lambda)\underline{e}}{\lambda} \tag{A4}$$

where the first inequality comes from (A2) and the second inequality comes from $a > \underline{e}$. Applying (A2) again, it is evident that D is also willing to quote the lower bound when $e \in [\underline{e}, b)$.

Overall, there is at most one signal realization that leads to trade. Applying (A2):

$$e^o = \frac{2(v+h-c)+(2-\lambda)\underline{e}}{\lambda}$$

□

Combining the results of Propositions 3 and 4 we obtain the following equilibrium results. We first consider the case when $\lambda < 2$. When the disclosure is $[e_i, e_{i+1})$, the government prefers to induces a price of $c-e_i$ so that trade always occurs. If a tax τ_i is levied, D's optimal price is given by $c-\frac{e_{i+1}-(v-\tau-c)}{2}$. Setting it equal to $c-e_i$,

$$\tau_i = (v-c)-(e_{i+1}-2e_i).$$

Since $e_{i+1} = (2-\lambda)e_i + (v+h-c)$, we solve

$$e_i = \hat{e} - (2-\lambda)^i(\hat{e} - \underline{e}).$$

With algebraic manipulation, we obtain

$$\begin{aligned}\tau_i &= (v-c)-(e_{i+1}-2e_i)\\ &= v-c+\hat{e}-\lambda(2-\lambda)^i(\hat{e}-\underline{e})\\ &= \lambda e_i + (v-c)-(\lambda-1)\hat{e}.\end{aligned}$$

Upon the signal $[\hat{e}, \overline{e}]$, the government prefers to induces a price of $c-\overline{e}$ so that trade never occurs. The minimal tax is given by $(v-c)-(\overline{e}-2\overline{e}) = v-c+\overline{e}$.

We next consider $\lambda \geq 2$. When the disclosure is $[e^o, \overline{e}]$, then government prefers to induces no trade between D and F. In this case, government can impose a large enough tax so that D's optimal pricing induces no trade with F. Let τ^H denote the tax. Then D's problem is

$$\max_x (v-c-\tau^H+x)(1-\frac{x-e^o}{\overline{e}-e^o})$$

FOC implies

$$(\overline{e}-x)-(v-c-\tau^H+x) = 0$$

Thus, $x^* = \frac{\overline{e}-(v-c-\tau^H)}{2}$. No trade requires that

$$\frac{\overline{e}-(v-c-\tau^H)}{2} \geq \overline{e}$$

Equivalently,

$$\tau^H \geq \overline{e}+v-c$$

Now consider $e \in [\underline{e}, e^o)$. Let τ^L denote the tax. Then D's problem is

$$\max_x (v-c-\tau^L+x)(e^o-x)$$

Then $x^* = \frac{e^o-(v-c-\tau^L)}{2}$. Full trade requires that

$$\frac{e^o-(v-c-\tau^L)}{2} \leq \underline{e}.$$

Equivalently,

$$\tau^L \leq 2\underline{e}-e^o+v-c$$

Plugging in e^o,

$$\tau^L \leq 3\underline{e} - \frac{2(v+h-c)+2\underline{e}}{\lambda} + v - c$$

Overall, if the tax scheme (τ^L, τ^H) satisfies the above two conditions, then D would optimally quote a price that induces trade when $e \in [\underline{e}, e^o)$ and that induces no trade when $e \in [e^o, \overline{e}]$. $\square$

B Additional Results

B.1 Interim Disclosure

In the main text, we have assumed that F chooses the disclosure plan prior to learning his private information to eliminate the signaling concerns. We now study the robustness of our results to the "interim" disclosure game, that is, the scenario where F chooses the disclosure plan after obtaining private information but before the realization of e becomes publicly observable, in line with Grossman (1981a), Milgrom (2008b), and the large literature that followed. While there are multiple equilibria, we will show that the outcome studied in the main text can be supported in an equilibrium in the interim disclosure while satisfying sensible and well-known refinements.

The timeline of the interim game we now study is as follows.

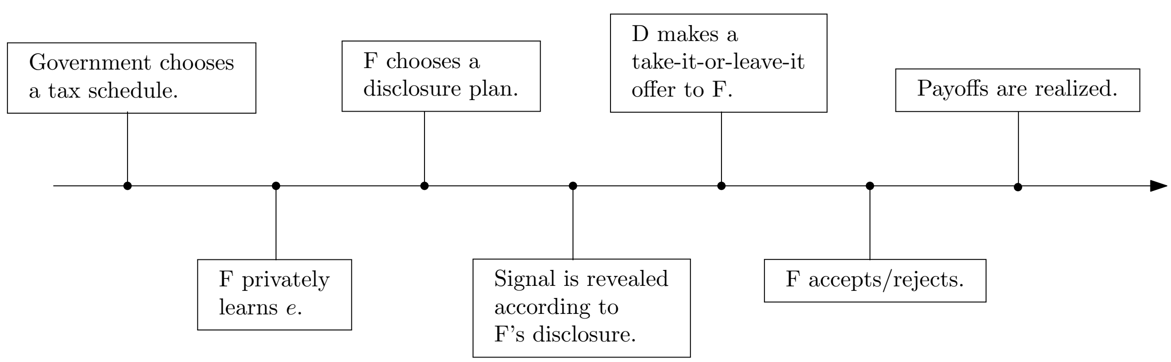


Figure 6: Timeline. The figure illustrates the timeline of the interim game.

We make two remarks. First, since $D(e)$ is now chosen by F after he observes e, we can interpret $D(e)$ as the pure-strategy message that F sends in this signaling game. Finally, upon receiving a signal s, D forms beliefs about the F's type e, which we denote by the distribution function $\mu(s) \in \Delta([\underline{e}, \overline{e}])$.[6] Then D quotes a price, which we now denote as $p(\tau, s)$, to

[6]We use $\Delta([\underline{e}, \overline{e}])$ to denote the set of all possible probability distributions on $[\underline{e}, \overline{e}]$.

maximize his expected profit, and F decides whether to accept. F's optimal strategy in that last stage is simply to accept the offer if and only if the quoted price is weakly higher than production cost, $c-e$. For ease of exposition, we do not introduce extra notation for this final stage and directly impose that F follows this dominant strategy.

Second, government chooses the tax schedule at the beginning to maximize the domestic sector's welfare. Due to normalization, the welfare is zero when there is no trade. Thus, government would choose the tax to induce the trade whenever $v+h-\lambda e-p>0$. We formalized the definition of equilibrium as follows.

Definition 2. *A $(\tau(\cdot),D(\cdot),\mu(\cdot),p(\cdot,\cdot))$ profile forms a perfect Bayesian equilibrium of the interim game if:*

1. *For every possible signal s, the tax schedule $\tau(s)$ maximizes the domestic welfare.*
2. *For every possible signal s and tax τ, $p(\tau,s)$ maximizes D's expected profit* $\max_p(v-p-\tau)Pr_{\mu(s)}[c-e\leq p]$.
3. *For every $e\in[\underline{e},\overline{e}]$, $D(e)$ solves arg* $\max_s\{\max[p(\tau(s),s)-(c-e),0]\}$*, where $e\in D(e)$.*
4. *For every s in the range of D (i.e., every Borel set s that can be disclosed in equilibrium), D's belief $\mu(s)$ is obtained by applying Bayes' rule given the particular signal s.*

Since beliefs are unrestricted following off-equilibrium deviations, there exist beliefs such that D (who has market power) drives the F's information rents to zero following any off-equilibrium deviation in disclosure. This leads to the existence of multiple perfect Bayesian equilibria with various degrees of information revelation, as opposed to a unique equilibrium with full revelation as in Grossman (1981a) and Milgrom (2008b).[7]

[7] For instance, either full disclosure, partial disclosure, or no disclosure can be supported in equilibrium if

Given this multiplicity, we restrict our attention to the sets of equilibria that survive the following two standard refinements. First, we consider as F-preferred equilibria the set of equilibria that are not dominated among F types — in the Pareto sense — by another equilibrium based on their interim payoffs. Second, we consider an alternative equilibrium refinement known as Grossman-Perry-Farrell, based on the perfect sequential equilibrium of Grossman and Perry (1986) and the neologism-proof equilibrium of Farrell (1993).[8] This refinement is commonly used in models of verifiable disclosure (see, e.g., Bertomeu and Cianciaruso (2018) and the references therein). Instead of comparing equilibria in a Pareto sense as above, this refinement eliminates equilibria with off-equilibrium beliefs deemed unreasonable given agents' incentives to deviate from their equilibrium strategies. We now state our result for the interim disclosure game.

Proposition 5. *An equilibrium disclosure plan of the ex ante disclosure game can be sustained in both a buyer-preferred equilibrium and a Grossman-Perry-Farrell equilibrium of the interim disclosure game.*

Proof. We first show how to construct a strategy profile that supports the optimal disclosure plan of the ex ante game in the interim game. Suppose the optimal disclosure plan of the ex ante game is denoted by $D : [\underline{e}, \overline{e}] \to S$. In the interim game, consider a candidate equilibrium in which:

1. Disclosure follows the ex ante disclosure $D(e)$.

2. For every possible signal s, the tax schedule $\tau(s)$ maximizes the domestic welfare.

the seller has the following beliefs: if for any s not in the range of D (that is, whenever s is an off-equilibrium signal), the belief $\mu(s)$ assigns probability 1 to type $\bar{v}(s)$, where $\bar{v}(s) \equiv \sup s$ (recall that s is a Borel set). Here, an equilibrium is said to feature full disclosure if $\mu(D(v))$ assigns probability 1 to type v, whereas it is said to feature no disclosure if $D(v) = [v_L, v_H]$ for all $v \in [v_L, v_H]$, and thus $\mu([v_L, v_H])$ is equal to $F(v)$, the prior distribution of v.

[8] We adopt the terminology "Grossman-Perry-Farrell" from Gertner et al. (1988), Lutz (1989), and Bertomeu and Cianciaruso (2018).

3. For $s \in S$, the belief $\mu(s)$ is given by G conditional on s. For any $s \notin S$ (that is, whenever s is an off-equilibrium signal), the belief $\mu(s)$ assigns probability 1 to type $\bar{e}(s)$.

4. For every possible signal s, $p(s)$ maximizes $\max_p (v-p-\tau)Pr_{\mu(s)}[c-e \leq p]$.

We can show that the constructed strategy profile forms a F-preferred equilibrium. By contradiction, suppose $(D_1(\cdot), \mu_1(\cdot), p_1(\cdot))$ is an equilibrium that dominates $(D(\cdot), \mu(\cdot), p(\cdot))$ among F types in the Pareto sense based on their interim payoffs. Let $S_1 = \{D_1(e) : e \in [\underline{e}, \overline{e}]\}$ and consider an ex ante disclosure $D_1 : [\underline{e}, \overline{e}] \to S_1$. Since $\mu_1(\cdot)$ is obtained by applying Bayes' rule on the equilibrium path, F's expected payoff under the disclosure D_1 of the ex ante game is equal to his expected payoff under the $(D_1(\cdot), \mu_1(\cdot), p_1(\cdot))$ equilibrium of the interim game. It then follows that F's expected payoff under the disclosure plan $D_1(\cdot)$ is strictly higher than the one under the disclosure plan $D(\cdot)$ in the ex ante game, contradicting the fact that $D(\cdot)$ is an optimal disclosure plan of the ex ante game.

We now show that the constructed strategy profile above also forms a Grossman-Perry-Farrell equilibrium of the interim game. We argue by contradiction, that is, suppose there exists a self-signaling set s_0 in that case. Let $S = \{D(e) : e \in [\underline{e}, \overline{e}]\}$ be the set of signals that are on the equilibrium path. We first show that $s_0 \notin S$. Otherwise, the signal s_0 is on the equilibrium path: $s_0 \in S$, implying that for some $e_0 \in s_0$, $D(e_0) = s_0$. Then, $U(v_0, s_0, \mu_{s_0}) = U(v_0, D(v_0), \mu(D(v_0)))$,where $U(e, s, \mu(s))$ is the F's utility if his type is e, he sends a message s, and D quotes an optimal price given the belief $\mu(s)$. Recall also that μ_s is the distribution of e conditional on $e \in s$. contradicting the fact that s_0 is a self-signaling set.

Now we turn to the ex ante game. Let $S_2 = S \cup \{s_0\}$. Consider the following ex ante disclosure plan $D_2 : [\underline{e}, \overline{e}] \to S_2$:

$$D_2(e) \equiv \begin{cases} D(e) & \text{if } e \notin s_0, \\ s_0 & \text{otherwise.} \end{cases} \quad \text{(A5)}$$

For F whose types are not in s_0, their payoffs are equal to their payoffs under the $(D(\cdot), \mu(\cdot), p(\cdot))$ equilibrium of the interim game. For F whose type is $e \in s_0$, his payoff is now given by $U(e, s_0, \mu_{s_0})$, which is strictly greater than $U(e, D(e), \mu(D(e)))$. Thus, the ex ante disclosure plan $D_2(\cdot)$ yields a strictly higher expected buyer payoff than the disclosure plan $D(\cdot)$, contradicting the fact that $D(\cdot)$ is an optimal disclosure plan of the ex ante game. □ □

B.2 Domestic Firm's Choice of Disclosure

In the main text, we have assumed that the disclosure plan is chosen by the foreign firm F. In this appendix, we study the case when the disclosure plan is chosen by the domestic firm. We can interpret this kind of disclosure as ESG ratings purchased by the domestic firm. While the domestic government strictly prefer a finer disclosure, the domestic firm may not. This is because it is possible that D can find trade with F profitable but G may not due to the high externality suffered by H. The timing of the game is as follows:

1. The domestic firm chooses a disclosure plan represented by a function $D : [\underline{e}, \overline{e}] \to S$.
2. The government chooses a tax schedule that is a function of the possible disclosures S.
3. The foreign firm privately observes e.
4. A signal according to the disclosure plan $D(e)$ is released and becomes publicly known.
5. The domestic firm makes a take-it-or-leave-it offer to the foreign firm.
6. The foreign firm accepts or rejects the offer.

7. International production occurs conditional on an acceptance and payoffs are realized.

To obtain analytic results, we make three additional assumptions. First, we assume that government charges the least-absolute-value tax whenever government is indifferent among several different taxes. This ensures that no tax is charged if zero tax belongs to the set of optimal taxes. Second, we assume that e follows a uniform distribution $U[\underline{e},\overline{e}]$. Third, we assume $h = 0$ and $\underline{e} = 0$.

Proposition 6. *When the domestic firm chooses the disclosure plan, he chooses the finest disclosure plan when* $\lambda < \frac{7+\sqrt{17}}{4}$*, otherwise he chooses the disclosure plan* (39) *(i.e., the disclosure with two ratings) when* λ *is sufficiently large.*

Proof. To solve for D's optimal disclosure plan, we first need to solve for government's optimal tax conditional on a disclosure that informs $e \in [a,b)$. This problem is identical to what we learned in Proposition 3. Applying the proposition, the optimal tax is given by the following.

1. Suppose $\lambda < 2$

   (a) If $a \geq \frac{b-(v-c)}{2-\lambda}$, the optimal tax is $\tau = 0$.

   (b) If $a < \frac{b-(v-c)}{2-\lambda} < b$, the optimal tax is $\tau = \frac{\lambda(b-v+c)}{2-\lambda}$.

   (c) If $\frac{b-(v-c)}{2-\lambda} \geq b$, the optimal tax is $\tau = b+v-c$.

2. Suppose $\lambda > 2$

   (a) If $v - \lambda\frac{a+b}{2} - (c-a) \geq 0$, the optimal tax is $\tau = 0$.

   (b) Otherwise, the optimal tax is $\tau = b+v-c$.

First, we consider the case when $\lambda < 2$. We first claim that under D's optimal disclosure plan, we should not expect case (b). We argue by contradiction. Suppose $a < \frac{b-(v-c)}{2-\lambda} < b$.

Then D can choose a new disclosure plan, which inherits the existing one but divides the interval $[a,b)$ into two subintervals $[a, \frac{b-(v-c)}{2-\lambda})$ and $[\frac{b-(v-c)}{2-\lambda}, b)$. By doing so, D does not lose when $e \in [\frac{b-(v-c)}{2-\lambda}, b)$ but strictly gains when $e \in [a, \frac{b-(v-c)}{2-\lambda})$, a contradiction. Next, we observe that trade occurs with zero probability under case (c), so D earns a zero profit whenever $\frac{b-(v-c)}{2-\lambda} \geq b$. Thus far, we have shown that D earns a nonzero profit only in case (a). In case (a), $a \geq \frac{b-(v-c)}{2-\lambda}$. Recall that the threshold at which global surplus is zero is given by $\hat{e} = \frac{v-c}{\lambda-1}$. We note that whenever $b > \hat{e}$, we also have $\frac{b-(v-c)}{2-\lambda} \geq b$, which is in case (c). So D does not gain to pool types above $\hat{e}$. For types below $\hat{e}$, by choosing case (a), government always charges a zero tax. Thus, for $e \leq \hat{e}$, the finest disclosure will give D the maximal possible surplus by charging a price such that F breaks even. Note that in case (c), the finest disclosure also gives D a zero profit. Overall, the finest disclosure constitutes an optimal disclosure for D.

Second, we consider the case when $\lambda > 2$. Similarly, D can only earn a positive profit when $v - \lambda \frac{a+b}{2} - (c-a) \geq 0$ holds. There are two possibilities. First, it is possible that for any disclosure $b \leq \hat{e}$, in which case, D prefer the finest disclosure and his expected payoff is given by

$$\int_{\underline{e}}^{\hat{e}} (v-(c-e))dG(e) = \frac{(v-c)(\hat{e}-\underline{e}) + \frac{1}{2}(\hat{e})^2 - \frac{1}{2}\underline{e}^2}{\overline{e}-\underline{e}}.$$

Second, unlike the case with $\lambda < 2$, it is now possible that $b > \hat{e}$. In this case, D prefers finest disclosure for $e \leq a$ and pool all types between $[a,b)$, where $v - \lambda \frac{a+b}{2} - (c-a) \geq 0$. His expected payoff is given by

$$\int_{\underline{e}}^{a} (v-(c-e))dG(e) + \int_{a}^{b} (v-c+a)dG(e)$$
$$= \frac{(v-c)(a-\underline{e}) + \frac{1}{2}a^2 - \frac{1}{2}\underline{e}^2 + (b-a)(v-c+a)}{\overline{e}-\underline{e}}.$$

To maximize D's expected payoff, he would choose the largest possible b. That is, $v-$

$\lambda\frac{a+b}{2}-(c-a)=0$, equivalently $b=\frac{2}{\lambda}(v-c+a)-a$. We can verify that the above equation is a convex function of a. So D would choose $a=\underline{e}$ or $a=\hat{e}$. Choosing $a=\hat{e}$ is optimal whenever

$$(v-c)(\frac{v-c}{\lambda-1}-\underline{e})+\frac{1}{2}\left(\frac{v-c}{\lambda-1}\right)^2-\frac{1}{2}\underline{e}^2\geq\left(\frac{2}{\lambda}(v-c+\underline{e})-2\underline{e}\right)(v-c+\underline{e}).$$

When $\underline{e}=0$, the above condition can be further simplified to

$$\frac{1}{\lambda-1}+\frac{1}{2(\lambda-1)^2}>\frac{2}{\lambda},$$

which holds whenever $\lambda<\frac{7+\sqrt{17}}{4}\approx 2.78$. Overall, when $\lambda<2.78$, D chooses the finest disclosure; when $\lambda>2.78$, D chooses the disclosure plan (39), which coincides with F's disclosure, i.e., disclosure with two ratings. □

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