Strategic subsidies for green goods[1]

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Abstract

WTO agreements discipline the use of subsidies, particularly for upstream manufacturing or exports. Unlike tariff rules, the Subsidies Code lacks exceptions for transboundary externalities like human health or resource conservation, including those related to combatting global climate change. Yet support policies for green goods (like renewable energy) are much more popular internationally than imposing a cost on bads (like carbon taxes). These support policies may encourage downstream consumption (renewable energy deployment) or upstream development and manufacturing of those technologies. The strategic trade literature has devoted little attention to the range of market failures related to green goods. We consider the market for a new environmental good (e.g., an alternative renewable energy technology) that when consumed downstream may provide external benefits (like reduced emissions). The technology is traded internationally, but provided by a limited set of upstream suppliers that may operate in imperfect markets, such as with market power or external scale economies. We examine the national incentives and global rationales for offering production and consumption subsidies in producer countries, allowing that some of the downstream market may lie in non-regulating third-party countries. While producer countries can benefit from restraints on upstream subsidies, global welfare is higher without them, and market failures imply that optimal subsidies are even higher. We supplement the analysis with numerical simulations of the case of renewable energy, exploring optimal subsidies for the major renewable energy producing and consuming regions.

Keywords: international trade, subsidies, imperfect competition, externalities, emissions leakage

JEL numbers: F13, F18, H21, Q5

One sentence: Trade-distorting subsidies may be under- (not over-) provided by strategic countries when market failures are present.

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Introduction

World Trade Organization (WTO) rules create restrictions on industrial policies that distort trade, particularly subsidies. In contrast to the General Agreement on Tariffs and Trade (GATT), the Agreement on Subsidies and Countervailing Measures (Subsidies Code) lacks exceptions for transboundary externalities like human health or resource conservation, including those related to combatting global climate change. Yet support policies for green goods (like renewable energy) are much more popular internationally than imposing a cost on bads (like carbon taxes). As the global community moves toward addressing important cross-border environmental and health challenges, does the multilateral trade regime need to reconsider its approach to subsidies for green goods?

Climate policies offer a striking example of these tensions over subsidies. Economists have formed a consensus that the best way to reduce greenhouse gas (GHG) emissions would be to put a global price on those emissions (much like scientists have formed a broad consensus over the existence and potential perils of global climate change). However, while carbon pricing is obtaining a foothold—nearly 40 countries and more than 20 subnational jurisdictions are using or planning to implement carbon pricing (World Bank 2014)—the numbers pale in comparison to financial incentives for renewable energy, which are offered by nearly 100 countries and countless subnational jurisdictions (IRENA 2015). Indeed, all of the jurisdictions with carbon pricing also rely on renewable energy support. The measures range from downstream measures to support deployment to upstream incentives for R&D and manufacturing. In 2012, the value of EU interventions for renewable energy exceeded the value of all the emissions trading allowances allocated for the year.[3]

In some cases, the subsidies are becoming substantial and distorting enough to raise trade concerns. When Ontario instituted a feed-in-tariff with domestic content requirements (in essence, leveraging the downstream deployment subsidy to support upstream local

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[3] Alberici et al. (2014) find that "in 2012, the total value of public interventions in energy (excluding transport) in the EU-28 is €2012 122 billion," with €2012 41 billion for renewable energy. Meanwhile, in 2012, the annual allocation of allowances was 2170 million; at an average annual price of roughly €7, the value of the annual cap was just over €2012 15 billion. Sources: http://www.eex.com/en/market-data/emission-allowances/auction-market/european-emission-allowances-auction/european-emission-allowances-auction-download and http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer.

manufacturing), the EU, Japan and others complained, and the WTO panel and appellate body struck down the policy (Charnovitz and Fischer 2014). In another set of cases, the EU and US have brought anti-dumping and anti-subsidy complaints against China, charging that large Chinese subsidies in the form of cheap loans, land, and capital to photovoltaic producers constitute illegal aid. The WTO has stated that its rules do not hinder supporting the deployment and diffusion of green technologies (WTO 2011). Downstream subsidies can be designed in a nondiscriminatory fashion, but upstream policies almost necessarily offer preferential treatment to domestic producers. Thus, it is important to understand if an economic rationale exists to carve out exceptions in the WTO subsidies code to make room for certain kinds of green industrial policy.

Export and production subsidies have been studied in the strategic trade literature. An influential early example was the pair of studies Spencer and Brander (1983) and Brander and Spencer (1985), who study a Cournot duopoly of producer countries exporting to a third market. Dixit (1984) extends their analysis to multiple firms, Krugman (1984) to the case of increasing returns to scale, and Leahy and Neary (1999) to R&D spillovers. Eaton and Grossman (1986) compare Cournot to Bertrand competition. These studies tend to focus on the strategic interest of the producer countries, typically exporting to third countries, and whether their joint interests are better served by restricting trade interventions. However, questions of global welfare or correcting market failures—key aspects of international environmental policy—are de-emphasized or ignored. Indeed, we will show that changing this emphasis can change the policy implications for subsidies.

Market failures have been an important focus of studies of overlapping climate policies, their interactions and costs (see, e.g., Fischer and Preonas 2010, henceforth FNP; Fischer and Newell 2008 in the electricity sector; and De Gorter and Just 2010 for biofuels). Indeed, in the absence of other market failures, renewable energy subsidies increase the costs of meeting an emissions target (Boehringer and Rosendahl 2010). FNP explore the extent to which knowledge market failures or spillovers justify subsidies to correct the underprovision of R&D and learning by doing by private markets. In an application to the U.S. electricity sector, they find optimal learning (i.e., deployment) subsidies are plausibly in the range of 1 cent/kWh or less for conventional renewable energy technologies like wind, and a higher but still modest range of 4–6 cents/kWh for solar. Hübler et al. (2014) look at second-best renewable energy policies for

Europe and find that policy constraints can justify additional deployment support, but the optimal levels are again quite modest, since learning in renewables is still less cost-effective than other mitigation options in the electricity sector. Importantly, all of these studies focus on a single region and ignore the possibility of international linkages through trade in renewable energy technologies.

Carbon leakage—when reduction efforts taken in one region may, through global trade, be undone to some extent by changes in emissions abroad—may be another reason why national policy makers like to supplement or even substitute carbon pricing with low-carbon technology policies. Keeping carbon prices low for industry can avoid damaging the competitiveness of energy-intensive, trade-exposed sectors. Furthermore, spillovers from the development of green technologies can lower mitigation costs for other countries (Gerlagh and Kuik 2014; Barker et al., 2007).

The characteristics of upstream markets for the provision of clean technologies may offer additional rationales for support. Low-carbon energy technologies are newer, the number of suppliers is relatively small, and patent restrictions still play an important role, as do the emergence of scale economies. As such, the typical upstream market can hardly be considered perfectly competitive (Requate 2005), and interventions may be justified to address market failures in the provision of renewable energy technologies.

A small literature has emerged on the issue of strategic environmental policy. Buchholz and Konrad (1994) and Stranlund (1996) find that underinvestment in R&D to lower the costs of abatement technologies credibly commits countries to low emissions reductions in the future, and thereby makes other countries increase their mitigation effort. Golombek and Hoel (2004) show opposite effects when spillovers from industrialized countries' R&D investments could spur abatement in developing countries. These studies, however, abstract from the fact that abatement technology is produced in its own market, separate from the market in which technology adopters operate. Greaker and Rosendahl (2008) consider strategic abatement policies when upstream markets are imperfect, finding that an individual country may want to impose an excessively stringent environmental policy in order to reduce the mark-up of technology suppliers, and hence increase the diffusion of these technologies.

Two closely related papers focus on the question of subsidies for clean technologies. Fischer, Greaker and Rosendahl (2014a) consider the relative effects and desirability of subsidies for end-of-pipe abatement technology, in a two-country model with Cournot competitors upstream and competitive trade-exposed industries downstream. They find stronger incentives for upstream subsidies than for downstream subsidies. Downstream subsidies tend to increase global abatement technology prices, reduce pollution abatement abroad and increase emission leakage. On the contrary, upstream subsidies reduce abatement technology prices, and hence also emissions leakage. Moreover, as opposed to downstream subsidies, they provide domestic abatement technology firms with a strategic advantage.

Fischer, Greaker and Rosendahl (2014b) consider the setting of renewable energy technology, when downstream markets are regulated with renewable portfolio standards (market share mandates). Subsidies can offset underprovision upstream, but allow dirty generation to expand when the portfolio standard becomes less binding. Downstream subsidies raise all upstream profits and crowd out foreign emissions. Upstream subsidies have strategic advantages, increasing domestic upstream market share, but expand dirty output in both regions. The theoretical analysis is limited to a Cournot duopoly case, but they find the interesting result that strategic subsidies chosen noncooperatively by individual countries can be optimal from a global perspective, if each country values emissions at the global cost of carbon.

In this paper, we generalize the problem of upstream and downstream market failures and trade. We take a more comprehensive approach than previous theoretical studies, allowing multiple regions and firms, multiple upstream market failures, and different downstream externalities, as may also be driven by different downstream policy mechanisms. Using linear forms for supply and demand curves, we derive closed-form solutions for optimal and strategic Nash subsidies as a function of the market failure parameters of interest. We also present a calibrated numerical exercise that estimates optimal and strategic equilibrium subsidies for the case of renewable energy and explores their sensitivity to different market failure assumptions.

Renewable energy is an interesting application because the technologies are traded internationally and arguably are characterized by multiple market failures. For example, the top four producers of wind turbines (firms located in the U.S. and Europe) supply roughly half the global market; 70% of global production occurs in the U.S., Europe, and China. Production of solar modules distributed across more manufacturers, but over 30% occurs in China; scale economies and learning are important factors in that sector (Nemet 2006, 2009; Swanson 2006; Schaeffer 2004; Bruton 2002; Smale 2006).

The external benefits of renewable energy deployment are also highly sensitive to where and how they are applied. The extent to which they reduce emissions depends both on a country's supply mix of polluting energy sources as well as the downstream policy environment: whether countries value the social costs of carbon, and to what extent they price their emissions.

We find several potential rationales for subsidies, particularly for upstream production, not only for individual countries but also from a global perspective. In particular, we find that strategically determined subsidies may actually *under*correct market failures, rather than be overly generous to domestic producers.

In the next section we describe our general model framework. Next we derive results isolating the different market failures. Then we use a numerical model to explore optimal subsidies for renewable energy technologies used in the electricity sector. The final section concludes.

Model Framework

We present a partial equilibrium model of a single sector in which production and consumption of an identical environmental good (e.g., a wind turbine or solar panel) occurs across multiple countries with trade. As we have in mind a relatively small sector in the economy, we forego modeling general equilibrium effects, noting that under standard assumptions the results carry through in a general equilibrium model with terms of trade.[4]

Consider a world divided into three regions: a domestic producing and consuming region (1), a foreign producing and consuming region (2), and a third-party consuming region (3). Markets are decentralized, and the products are assumed to be identical; this assumption allows for consistency of representation across the different market failures, as well as for the parameterization of downstream demand for renewable energy technology in our numerical application.

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[4] Brander and Spencer (1985) show this with an additive utility function including a perfectly competitive numeraire good.

Each producing region $i = \{1, 2\}$ may offer to subsidize downstream deployment by η_i and/or to lower the unit delivery costs of the upstream technology firms by γ_i. We assume the third country has no subsidy policies (for example, a developing country without climate policy obligations); thus, $\eta_3 = 0$.

Let us assume the following linear demand functions for the technology in each country, where m_i is a measure of downstream market share of region *i* (and $\sum_i m_i = 1$).[5]

$$x_i = m_i \left(\frac{a - (P - \eta_i)}{b} \right)$$

Total demand is $X = x_1 + x_2 + x_3$. This gives us an inverse demand function facing the upstream producers of $P = A - BX$, where the slope equals the identical individual slopes $B = b$, and the intercept equals the weighted average intercept $A = a + \overline{\eta}$, where $\overline{\eta} = \sum_i m_i \eta_i$.

Consumer surplus is the area under each linear demand curve above the consumer price:

$$CS_i = \frac{m_i \left(a - (P - \eta_i) \right)^2}{2b}$$

Governments place a value on domestic profits, Π_i, domestic consumer surplus, CS_i, net revenues TR_i, and global downstream externalities, E_G. They ignore effects on foreign producer profits and consumer welfare, and possibly undervalue external benefits $(v_i < v_G)$. (Since the environmental spillover case is the most interesting, let us assume that the external benefits are reductions in a global pollutant like greenhouse gases, as opposed to a local pollutant).

Welfare for each of the three regions is

$$\begin{aligned} W_1 &= \Pi_1 + CS_1 + TR_1 + v_1 E_G \\ W_2 &= \Pi_2 + CS_2 + TR_2 + v_2 E_G \\ W_3 &= CS_3 + v_3 E_G \\ W_G &= W_1 + W_2 + W_3 + (v_G - v_1 - v_2 - v_3) E_G \end{aligned}$$

Total revenues are the cost of the upstream and downstream subsidy payments for a producer country: $TR_i = -\gamma_i Y_i - \eta_i x_i$. The external benefits are proportional to consumption of the

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[5] One could vary other demand parameters by country, as we do in the numerical simulations, but the strategic issues related to heterogeneous downstream demand are captured sufficiently by the parameter *m*.

product, and we allow different countries to have different global benefits from the environmental good: $E_G = \mu_1 x_1 + \mu_2 x_2 + \mu_3 x_3$; for example, renewable energy use can displace emissions from fossil energy by factor μ_i in country *i.*

The strategic subsidy choice can be modeled as a two-stage game. In the first stage of the game, a region chooses whether and how much to subsidize downstream and upstream. We may think of this cost subsidy as the net effect of a range of policies, including direct subsidies, R&D support etc.[6] In the second stage of the game, downstream demand is met, and the technology firms compete to supply renewable energy technology equipment to the downstream consumers in all regions.

We first solve for the optimal subsidy strategy from the point of view of a global planner. We then consider a Nash equilibrium, in which each region chooses optimal subsidies, given the choices of the others. We may also consider unilateral policies, assuming no subsidies in the other regions, or second-best subsidies, when trade rules, say, prohibit the use of either upstream or downstream subsidies.

We begin with the simplifying assumption that our two producing regions are symmetric. We will later relax this assumption to explore asymmetry numerically. All the solutions can be derived algebraically, and for convenience we do this in Mathematica and report only the results; more details are given in the Appendix, and files are available upon request. Knowing the market equilibrium response to subsidies, each actor maximizes welfare with respect to the policy levers it controls, upstream and/or downstream subsidies in the producing states, taking as given the policy choices in the other region.

Specifically, the global planner would maximize global welfare with respect to choosing upstream and downstream subsidies in each producing region; i.e., $\{\partial W_G / \partial \gamma_1 = 0, \partial W_G / \partial \eta_1 = 0, \partial W_G / \partial \gamma_2 = 0, \partial W_G / \partial \eta_2 = 0\}$. When effects are symmetric, we restrict the optimal subsidies to be symmetric, to allow better comparison to the noncooperative equilibrium. We also consider the cases in which either downstream or upstream subsidies are

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[6] The welfare effects of R&D support may be different from the effects of direct subsidies. This is disregarded in our welfare analysis below as we do not focus on innovation externalities.

restricted to zero, implying the conditions $\{\partial W_G / \partial \gamma_1 = 0, \eta_1 = 0, \partial W_G / \partial \gamma_2 = 0, \eta_2 = \eta_1\}$ or $\{\gamma_1 = 0, \partial W_G / \partial \eta_1 = 0, \gamma_2 = 0, \partial W_G / \partial \eta_2\}$.

In the Nash game, each producing country maximizes its own welfare, taking as given the subsidy choices of the other actor, and knowing the subsequent effects on the international market equilibrium. In equilibrium, $\{\partial W_1 / \partial \gamma_1 = 0, \partial W_1 / \partial \eta_1 = 0, \partial W_2 / \partial \gamma_2 = 0, \partial W_2 / \partial \eta_2 = 0\}$ all must hold. In the cases where subsidy choice is restricted either upstream or downstream, we consider $\{\partial W_1 / \partial \gamma_1 = 0, \eta_1 = 0, \partial W_2 / \partial \gamma_2 = 0, \eta_2 = 0\}$ and $\{\gamma_1 = 0, \partial W_1 / \partial \eta_1 = 0, \gamma_2 = 0, \partial W_2 / \partial \eta_2 = 0\}$.

Market Failures

We elaborate the three types of market failures: imperfect competition, downstream externalities, and external scale economies. All of our market failures lead to underprovision of the good, which can in theory be corrected by either upstream or downstream subsidies. It is important to make the distinction between these policy levers, since the strategic incentives differ, as do WTO disciplines. We also emphasize production and consumption subsidies, while the trade literature has more traditionally evaluated export subsidies; for the case of renewable energy, the former are much more important in practice than the latter.

Imperfect Competition

We begin with the market failure of imperfect competition in the upstream market. As we consider identical products, we model the well-known case of Cournot competition. The analysis is similar to Brander and Spencer (1985) and Eaton and Grossman (1986), but we include consumption as well as production subsidies, allow for multiple firms within each country, and place a greater focus on the global welfare effects of internalizing the upstream market failure.

The Cournot framework is well suited not only for placing the results in context with the previous trade literature but also for representing the renewable energy technology industry. Wind turbine manufacturing is highly concentrated among a few major players, as previously noted. Pillai and McLaughlin (2013) observe that in the solar industry, although products are vertically differentiated by module efficiency, firm markups are positively associated with firm size, as would be implied by a Cournot model.

With Cournot competition, firms essentially compete by choosing production capacity, and this commitment ensures any subsequent price competition allows for positive markups. Assume there are $N = n_1 + n_2$ firms that are identical, save for the upstream subsidy policy of their country.[7] Total production is $Y = Y_1 + Y_2 = n_1 y_1 + n_2 y_2$, and in the supply and demand equilibrium $P = A - BY$. A firm country in *i* maximizes profits, taking as given the output quantity choices of the other firms (at home and abroad) and any subsidy γ_i being offered it:

$$\pi_i = \left(A - B(y_i + Y_{-i}) - c + \gamma_i \right) y_i$$

The first-order condition has marginal revenue equal to marginal cost:

$$A - c + \gamma_i - B(Y + y_i) = 0$$

Let $\bar{\gamma} = (n_1\gamma_1 + n_2\gamma_2)/N$. From the first-order conditions and the above demand function, we have equilibrium output of a firm in each country and overall:

$$y_d = \frac{A - c + \gamma_d + N(\gamma_d - \bar{\gamma})}{B(N+1)}; \quad Y^C = \frac{N(A-c) + \bar{\gamma}}{B(N+1)}$$

And the equilibrium price, which includes a cost markup

$$P^C = c - \bar{\gamma} + \frac{A - c + \bar{\gamma}}{N+1}$$

At the social optimum, absent any other market failures, we would have $P = c$ in all jurisdictions and $Y^{C*} = (A-c)/B.$ In theory, this result could be achieved with either downstream and/or upstream subsidies; however, if the planner is restricted from setting downstream subsidies in the third region, then the optimal subsidies would be upstream and satisfy $\bar{\gamma}^* = (\bar{a} - c)/N$. The more concentrated is the industry (smaller *N*), the greater the underprovision and the higher the correcting subsidy. Note that since costs are identical, the planner does not care where production (or subsidizing) occurs; for ease of comparison, we will assume subsidies are applied symmetrically.

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[7] Firm asymmetry has been explored in de Meza (1986) and Neary (1994). We will allow for country-level asymmetries. As discussed in Eaton and Grossman (1986), Horstmann and Markusen (1984) and Venables (1985) analyze the effects of trade policy with free entry for the case of Cournot competition.

To explore the different incentives for individual regions as compared to the planner, we derive the analytical results for symmetric producer countries (as in Brander and Spencer 1985, but with multiple firms), and report them in the Appendix. (In subsequent simulations we will allow for asymmetries across regions.) Solving for the optimal subsidies, we prove the following results when the upstream market competes in Cournot fashion:

Proposition 1(a): In the Nash equilibrium, strategic countries subsidize both upstream and downstream, while the social planner subsidizes only upstream.

As discussed above, the market failure of imperfect competition is an upstream one, so the planner finds upstream subsidies sufficient to internalize it. Strategic countries, however, recognize that the upstream subsidy depresses the market price for foreign sales, and thus use some downstream subsidies to help support the global price and boost their terms of trade.

Proposition 1(b): To the extent that the third country has downstream market share, the sum of the Nash subsidies are less than the planner's subsidy.

The larger is the third country share, the more that strategic countries shift their subsidies downstream and underprovide them overall, since the downstream subsidy is less efficient at counteracting the upstream market failure. We also show that the more competition there is upstream (more firms), the smaller the subsidies, and the smaller the share of upstream subsidies.

Proposition 1(c): In the absence of a third-country market, the Nash equilibrium replicates the social optimum.

With no net exports in a symmetric equilibrium, the strategic trade incentives are eliminated, and the countries just offset the upstream market failure.

The next propositions consider the results when the parties are restricted (such as by international trade law) from implementing certain types of subsidies.

Proposition 2(a): If the downstream subsidy is not available, producer countries underprovide upstream subsidies to a greater extent.

Without the downstream subsidy to prop up the global technology price, strategic countries use smaller upstream subsidies than in the dual-policy Nash equilibrium. Furthermore, the subsidies are even lower to the extent that the third country has downstream market share, revealing both the deleterious effects on terms of trade and the insufficient concern for those consumers, compared to the global planner.

Proposition 2(b): If the upstream subsidy is not available, producer countries underprovide downstream subsidies to the extent they have downstream market share.

Without the upstream policy tool, the globally optimal downstream subsidies in the producer countries are positive, but less than the optimal upstream subsidy, given that they are a second-best instrument for counteracting the upstream market failure. Furthermore, strategic countries provide even smaller downstream subsidies, as part of the effect is to bid up the global price for their own consumers. However, if the entire technology market is for export to the third country, strategic countries provide the globally second-best downstream subsidies.

Thus, if the upstream market is characterized by Cournot competition, there is no clear need in this partial equilibrium model for restrictions on production subsidies. The emphasis on global welfare is important. For example, Brander and Spencer (1985) look at the case of Cournot countries with production subsidies and find that producing countries would be jointly better off with *lower* subsidies (which we also demonstrate in the Appendix); however, they do not note that global welfare would be higher with *higher* subsidies. In essence, based on our models, an argument for trade law restrictions on upstream subsidies is one of facilitating collusion in the upstream market, not for improving global welfare.

Competitive Upstream Markets and Downstream Externalities

To focus now on the downstream external effects, let us assume that our two producer countries have price-taking firms. Since we want to think about an international trade context that allows for asymmetric policies and thereby asymmetric costs, without imperfect competition, we must either assume imperfect substitutability (as in Melitz 2005) or upward-sloping marginal costs of own production, such as can arise from production lines of heterogeneous producers with limited capacities (as in Laffont and Tirole 1996). We take the latter route, in order keep the same demand functions with identical products. We will observe that, even without imperfect competition or downstream externalities, having positive producer surplus makes strategic countries want to engage in industrial policy, in order to influence the terms of trade.

Consider a representative, price-taking firm in each country; marginal costs are linear and upward sloping. Domestic industry profits (for $d=\{1,2\}, f=\{2,1\}$) are

$$\pi_d = \left(P+\gamma_d-(c+hy_d)\right)y_d$$

From the first-order conditions for each firm $\partial\pi_d/\partial y_d = P+\gamma_d-(c+2hy_d)=0$; with $P=A-B(y_d+y_f)$, we have in equilibrium

$$y_d = \frac{h(A-c+\gamma_d)+B(\gamma_d-\gamma_f)/2}{2h(B+h)}; \quad Y=\frac{A-c+\overline{\gamma}_D}{B+h}$$

where $\overline{\gamma}_D=(\gamma_1+\gamma_2)/2$ is the simple average subsidy. The equilibrium price is

$$P^D = c-\overline{\gamma}_D+(A-c+\overline{\gamma}_D)\frac{h}{B+h}$$

(Note that an equilibrium with both countries producing requires that one does not fill all global demand by driving the price below the marginal cost at zero production in the other country: $\gamma_f-\gamma_d \le h(A-c+\gamma_d)/B$. Since we will look at symmetric equilibria, this always holds, but in general it requires a positive *h*.)

Strategic subsidies without environmental benefits

First, it is useful to understand strategic incentives with this kind of competitive market, characterized by increasing marginal costs, regardless of environmental spillovers. All results are derived in the Appendix.

<u>Proposition 3</u>: *With a competitive upstream market, if $v_g=0$, then the optimal policy is to have no subsidies ($\gamma_i^*=0$); however, the Nash equilibrium has producer countries taxing upstream*

and subsidizing downstream by an equivalent amount, to the extent that they are net exporters: $\left(\gamma_{i,v_i=0}^{Nash} = -\eta_{i,v_i=0}^{Nash}, i = \{1,2\}\right)$.

Both of these strategies serve to drive up global technology prices and capture rents from the third region. Furthermore, since marginal production costs are increasing within a country, there may be some incentive to shift the cost of production to the other producing region. For these reasons, the tax/subsidy shift is increasing with the third party market share and, up to a point, with the slope of the supply curves.

The planner, on the other hand, has no incentive to interfere in the absence of an externality.

<u>Corrollary</u>: *In a symmetric-country duopoly, strategic subsidies are zero.*

With neither country being a net exporter, there is no incentive to influence the terms of trade. However, if the downstream demand functions differ, the duopoly equilibrium will deviate from the social optimum. For example, if one country has a larger downstream consumption market share $(m_d > m_f)$, all else equal, they will tax downstream and set an equal subsidy upstream, while the exporting country will do the opposite, but at different levels. The net effect of the taxes/subsidies is to reduce total output.

These benchmark subsidies will serve to compare with subsidies in the presence of global environmental externalities.

Strategic subsidies with environmental benefits

Now suppose that the consumption of the product downstream has an external benefit of v_G per unit, as in the case of an environmental good. Again, with this market failure, we have underprovision in the absence of subsidies. At the social optimum, we want the price to equal the marginal social cost in each downstream country: $P_{D,i}^* = c + hY - v_G\mu_i$. Since the externality is downstream, this would suggest implementing the subsidies downstream $(\eta_i^* = \mu_i v_G, \forall i)$. However, if there is a third-party country and it does not have these policy levers at its disposal, the optimum cannot be achieved with downstream subsidies alone. If the marginal benefits of the good are equal across all countries $(\mu_i = \mu, \forall i)$, then upstream subsidies of $\gamma_1^* = \gamma_2^* = v_G \bar{\mu}$ alone suffice to achieve the optimum. But when marginal benefits differ, a combination of up- and downstream subsidies are needed to maximize welfare.

We find the following results with strategic subsidies:

Proposition 4: The globally optimal policy is to subsidize upstream at the rate of the third-country marginal benefit, and to subsidize consumption in the producer countries according to the difference in the marginal benefit from that of the third country:
$\left\{\gamma_1^* = \gamma_2^* = \gamma^* = v_G \mu_3;\ \eta_i^* = v_G(\mu_i - \mu_3)\right\}, i = \{1,2\}$.

With an external environmental benefit from downstream consumption, the planner wants the total subsidy in each country to equal the social marginal benefit; i.e., that $\gamma^* + \eta_i^* = v_G \mu_i, \forall i$. If subsidies cannot be implemented in the third-party country, the optimal strategy is to use the uniform upstream subsidy to reflect the third-country's external benefit, while downstream subsidies (or taxes) are used in the producer countries to adjust net subsidy.

Proposition 5(a): In the Nash equilibrium with perfect competition, the sum *of the subsidies equals the marginal benefit as valued by that country:* $\gamma_i^{Nash} + \eta_i^{Nash} = v_i \mu_i, i = \{1,2\}$.

The individual subsidies combine the cost-shifting components defined in the subsection above with an external benefit component that is positive and increasing with v_i. Since the upstream and downstream cost-shifting components offset each other, it is the sum of the external benefit components that equals the valued marginal benefit. In other words, for $i = \{1,2\}$, $\gamma_i^{Nash}(v_i) = \gamma_i^{Nash}(0) + \chi_i^{up}(v_i)$; $\eta_i^{Nash}(v_i) = \eta_i^{Nash}(0) + \chi_i^{down}(v_i)$, and $\chi_i^{up} + \chi_i^{down} = \mu_i v_i$.

Proposition 5(b): Without a third country, in a symmetric Nash equilibrium, the noncooperative subsidies replicate the social optimum if each country values environmental changes at the global marginal benefit.

This follows from Proposition 5(a); under these conditions, neither county is a net exporter and does not want to distort the terms of trade. Thus, if $v_i = v_G$, then $\gamma_i^{\text{Nash}} + \eta_i^{\text{Nash}} = v_G \mu_i = \gamma_i^* + \eta_i^*$. To internalize the externality, they combine upstream and downstream subsidies in such a way that the total subsidies equal those desired by the planner for each region, assuming the countries adopt the global valuation of the externality. In this case, the planner is indifferent as to where to target the subsidies, as only the sum matters.

Proposition 5(c): With a third country, a symmetric Nash equilibrium provides insufficient upstream subsidies and lower environmental gains to the extent that $\mu_3 > 0$*, even if* $v_i = v_G$.

Although strategic countries may care about leakage, the incentive to maintain higher export prices remains, resulting in global underprovision of the green good. This underprovision is further exacerbated to the extent that global gains are undervalued locally.

Thus, downstream external benefits provide another situation in which strategic upstream subsidies may be too low from a global welfare perspective.

External Scale Economies

With scale effects—such as through learning-by-doing, supply chain effects, network economies, etc.— unit costs of production may depend on cumulative industry output. To the extent that these effects spill over to other firms and the benefits are not fully appropriated by the individual actors, scale will be underprovided by the market. To explore the role of spillovers from scale effects, we take the preceding model of firms as price-takers, but assume that marginal costs are influenced by own and foreign scale of production. Although some of these processes may be dynamic, let us represent them in condensed form by shifting marginal production costs according to cumulative market scale in our static model.

Consider a representative, price-taking firm in each country; costs are upward-sloping but shifted downward by total domestic production. Furthermore, domestic scale may lower foreign costs by factor β , and vice-versa. I.e., domestic industry profits are

$$\pi_d = \left(P + \gamma_d - (c + h y_d - g(Y_d + \beta Y_f))\right) y_d$$

Let ρ be the private appropriation rate for domestic scale – i.e., the extent to which the representative firm perceives its own influence on scale effects ($\rho = 0$ implies a price taker, while $\rho = 1$ implies complete appropriation at home).[8] Thus, in the competitive equilibrium we have $y_d = Y_d$ and price equals marginal cost

$$\frac{\partial \pi_d}{\partial y_d} = P + \gamma_d - c + (\rho g - 2h) y_d + g(Y_d + \beta Y_f) = 0$$

To allow for more transparent manipulation, let $\bar{\gamma} = (\gamma_d + \gamma_f)/2$ and $\bar{g} = g(1+\rho+\beta)/2$. Let us further take the case of $\rho = 0$, so that firms are complete price takers with respect to learning or scale economies. (The more general case is derived in the Appendix). In equilibrium, then,

$$Y = \frac{A - c + \bar{\gamma}}{B + h - \bar{g}}; \quad y_d = \frac{(A - c + \gamma_d)\left(B + 2h - g\right) - (A - c + \gamma_f)(B - \beta g)}{2\left(B + h - \bar{g}\right)2\left(h - \bar{g} + g\beta\right)}$$

$$P = \frac{A\left(h - \bar{g}\right) + B\left(c + \bar{\gamma}\right)}{B + h - \bar{g}}$$

To have a sensible result with positive output and proper responses to subsidies and demand changes, we restrict the parameter values to be $\{h > g(1+\beta)/2, B > \beta g\}$.

We derive the following results:

<u>Proposition 6</u>: *With external scale effects, the globally optimal policy is to offer upstream subsidies.*

The social planner would choose $\gamma^* = \left((a-c)g(1+\beta)/2\right)/\left(b + h/2 - g(1+\beta)\right); \quad \eta^* = 0$.

<u>Proposition 7</u>: *In the Nash equilibrium, strategic countries subsidize downstream and may subsidize or tax upstream, depending on whether spillover scale effects dominate individual decreasing returns.*

<u>Proposition 8</u>: *Without cross-country spillovers ($\beta = 0$), in the Nash equilibrium, countries under-subsidize in total (the sum of the subsidies is less than the planner's) to the extent there is a third-country downstream market.*

As in the other market failure examples, strategic countries want to maintain higher prices for their net exports.

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[8] See Fischer and Newell (2008) for a complete derivation of a private equilibrium with spillover effects.

Furthermore, if downstream subsidies are unavailable, countries tend to underprovide upstream subsidies in the Nash equilibrium.

Thus, if the upstream market is characterized by external scale economies, there is no clear need in this partial equilibrium model for restrictions on upstream production subsidies. Countries tend to prefer downstream subsidies, to avoid running up the marginal cost curve while enjoying the spillover benefits of overall market scale.

Combining market failures: an application to renewable energy

The theoretical analysis draws intuition for situations in which strategic trade partners may underprovide production subsidies in the presence of market failures. In this section, we explore these results quantitatively in a parameterized application to the renewable energy technology sector.

Numerical model

We represent the producer-consumer regions of Europe, the United States, and China, as well as and consumption in the rest of the world (ROW). Each region has a downstream market for electricity generation that is closed to international trade (this framework could be applied equally to renewable fuels in transportation). The downstream markets consist of firms located and owned in the corresponding regions, and competition is perfect.[9] Electricity generation with conventional fossil-fueled technology leads to emissions of some pollutant that may have cross-border damages (e.g., CO_2). An alternative energy technology is available, such as solar panels, wind turbines, etc., that can produce electricity without emissions.

To calibrate the linear technology demand functions and the emissions consequences, we use simplified static versions of the calibrated electricity sector models in Fischer, Newell and Preonas (2014) for the US and Fischer, Huebler and Schenker (2014) for the EU.[10]

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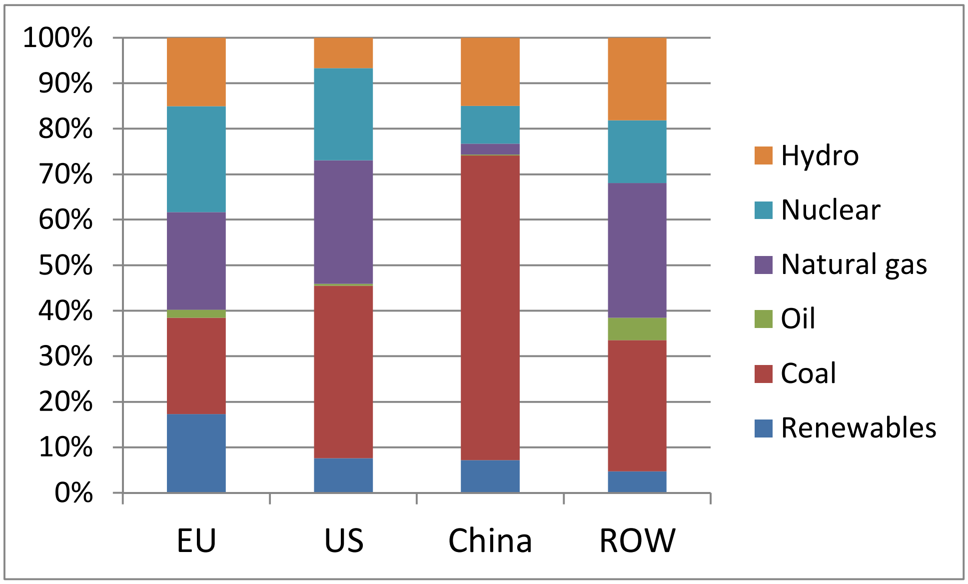
[9] The primary assumption is that the fossil supply curve is upward sloping and cost increases are fully passed through. This assumption is less realistic for China, where prices are regulated and adjusted infrequently.

[10] These models were designed for looking at endogenous technical change across two stages; to create a static model, we use the first stage only.

The data represent annual electricity production in a near-term horizon of 2015-2020. The downstream electricity market is composed of energy supply curves from coal, oil, natural gas, nuclear, hydro, and non-hydro renewables. The latter are our focus, and they include wind, biomass, solar, and others, with wind being the dominant source. These renewables represent 17% of EU electricity demand and 7% of US demand. All supply sources, as well as consumer demand, respond to changes in electricity and carbon prices. We back out from the system the implied demand for renewable energy capacity, as well as the emissions consequences. For example, in the baseline, the average emissions of non-baseload nonrenewable energy sources (essentially coal and gas, as the capacity of nuclear and hydro is fixed) is 13% higher in the US; however, when we calculate the marginal emissions rates from these sources in response to a small price change, they are twice as high in the US as in the EU.

For China and the ROW, we use the supply mix projected for 2020 in the 2013 International Energy Outlook. Lacking comparable data to calibrate their cost functions directly as had been done for the US and EU, we calibrate the slopes of the supply curves to match the same supply elasticities as in the US, as all three are more fossil-fuel reliant than the EU. We note that by 2020, while the EU and US electricity markets are projected to be similar in size, the Chinese power sector will be nearly twice as large, and ROW almost four times as large.

Figure 1: Projected baseline 2020 energy mix by region (IEO 2013)



Downstream outcomes, including the resulting demand for renewable energy, depend importantly on the downstream policy assumptions. We incorporate a downstream carbon price

τ_i that varies across regions, as well as a downstream subsidy to renewable energy. ROW is always assumed to have no policy.

For the upstream market, we draw on the wind turbine manufacturing sector, where the top four producers of wind turbines (located in the U.S. and Europe) supply roughly half the global market; from the top 10 producers, 70% of global production occurs in the U.S. (16%), Europe (38%), and China (17%). For this first series of simulations, we focus on the US and Europe (REN21). The top two producers, GE from the US and Vestas from Denmark, had 15.5% and 14% market shares, respectively, in 2012. In a Cournot model, these kinds of market shares occur when there about 7 firms; we round up to allocate 2 firms each to the US and China and 4 to Europe, to maintain roughly the correct producer market shares in our representation of imperfect competition. Since we perform sensitivity analysis to the degree of competition, in scenarios with "perfect competition" we will scale up firm numbers by a factor of 100, maintaining similar overall market shares.[11]

For example, for the EU and US, the calibrated downstream model calculates the following renewable energy demand functions:

$$x_{EU} = 6.04\times10^{11} + 1.43\times10^{9}\tau_{EU} + 3.65\times10^{12}(P + \eta_{EU} - P_0)$$
$$x_{US} = 2.99\times10^{11} + 5.06\times10^{9}\tau_{US} + 5.32\times10^{12}(P + \eta_{US} - P_0)$$

where P_0 is the global technology price in a baseline without subsidies. It is subsequently calibrated to reproduce the baseline quantities, and depends on the number of firms.[12]

Results

In the following scenarios, we explore quantitatively the role of key factors identified in the theoretical analysis. One set involves the value of the social cost of carbon (SCC), its valuation by producer countries, and the pricing of carbon in downstream markets. These variations explore the sensitivity of the optimal subsidies to the downstream market failure and

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[11] This is a reasonable approximation within the Cournot framework, and avoids having to introduce a new cost function as in the theory section.

[12] Any assumption about *c* has a 1-1 effect on this price, and subsequently an offsetting effect on the estimated intercept of the marginal operating cost curve for renewable energy, which in the baseline must equal $P_0^{kWh} - P_0$, so we let $c = 0$.

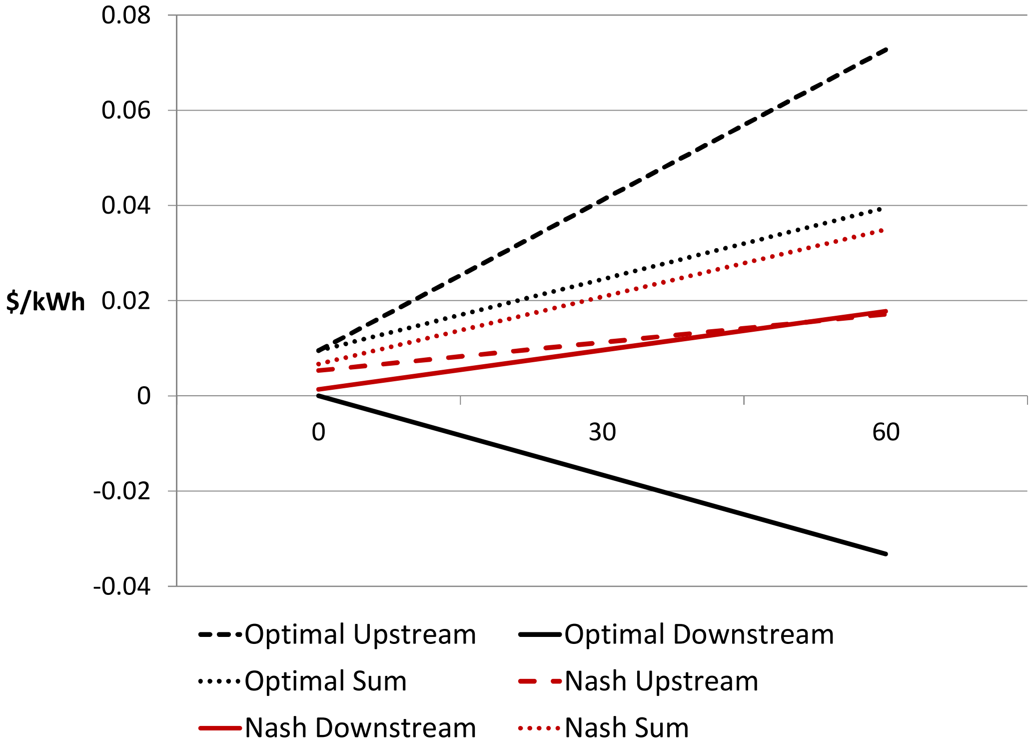
to pre-existing downstream regulations. Another issue relates to downstream market shares, the size of the export market, and the importance of the non-producing region. Third, we are interested in the degree of competition, and to what extent upstream market failures drive subsidies. Finally, we assess the welfare and distributional consequences of optimal and strategic subsidies and restrictions upon them.

Carbon externality and trade

Figure 1 reports optimal and strategic Nash subsidies for the EU as a function of the SCC when no region is taxing emissions. With no externality (SCC = 0) and heterogeneous countries, the optimal upstream subsidy internalizes the upstream externality, here about 1 cent / kWh. The Nash strategy for the EU has an upstream subsidy of roughly half that size, paired with a small downstream subsidy that does not quite make up the difference. As the SCC rises, there is a clear and growing deviation between the strategic and optimal subsidies. The global planner would call for larger upstream subsidies—and downstream taxes—as the SCC rises, as both strategies encourage more uptake of renewables and displacement of polluting outside the relatively clean EU. For a SCC of $30, the optimal upstream subsidy is about 4 cents / kWh, reflecting the value of the downstream eternality in ROW. The EU, on the other hand, does raise its upstream subsidy as the SCC rises, but less than is optimal, preferring to supplement with more downstream subsidies.

The sums of the subsidies in both the optimal and strategic cases rise accordingly with the SCC, as predicted in the theory (Proposition 5(a)); the difference is due to the response to imperfect competition, which strategic countries under-internalize (Proposition 1(b)).

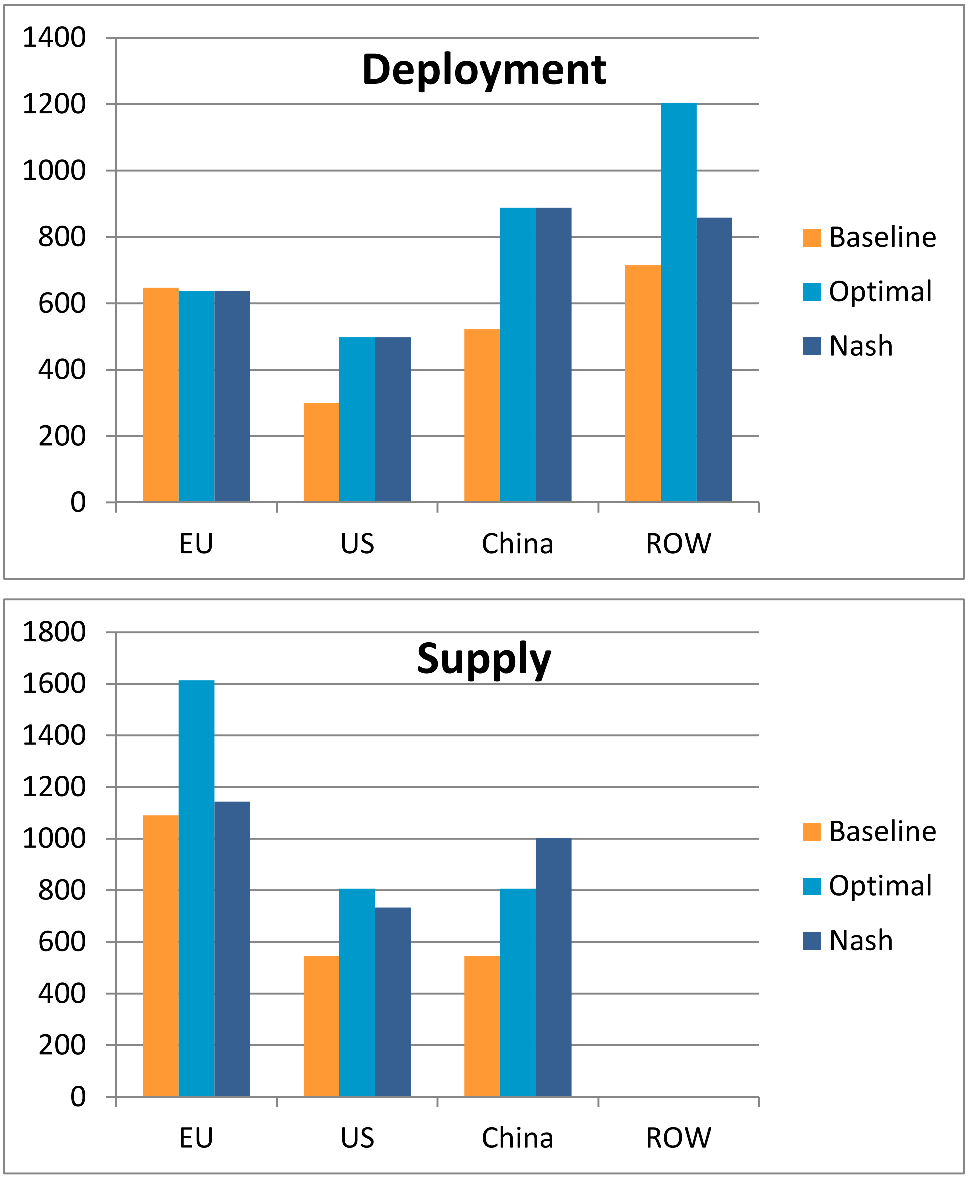
Figure 2: Optimal subsidies in the EU as a function of the SCC (no carbon taxes)



Role of ROW and exports in strategies

The next figures depict the difference in optimal and strategic outcomes for deployment and production of renewable energy technologies. They assume a SCC of $30, but no carbon taxes. Note that in both cases the EU experiences little change in renewable energy deployment, while the other regions increase substantially. Note also that in all the producer countries, there is no difference in the deployment outcomes between the optimal and Nash strategies. The difference lies in ROW, where the global planner's greater reliance on upstream subsidies leads to much greater deployment than the Nash outcome, where producers prefer higher global technology prices.

Figure 3: Deployment and supply by scenario (billions of kWh annual generation)



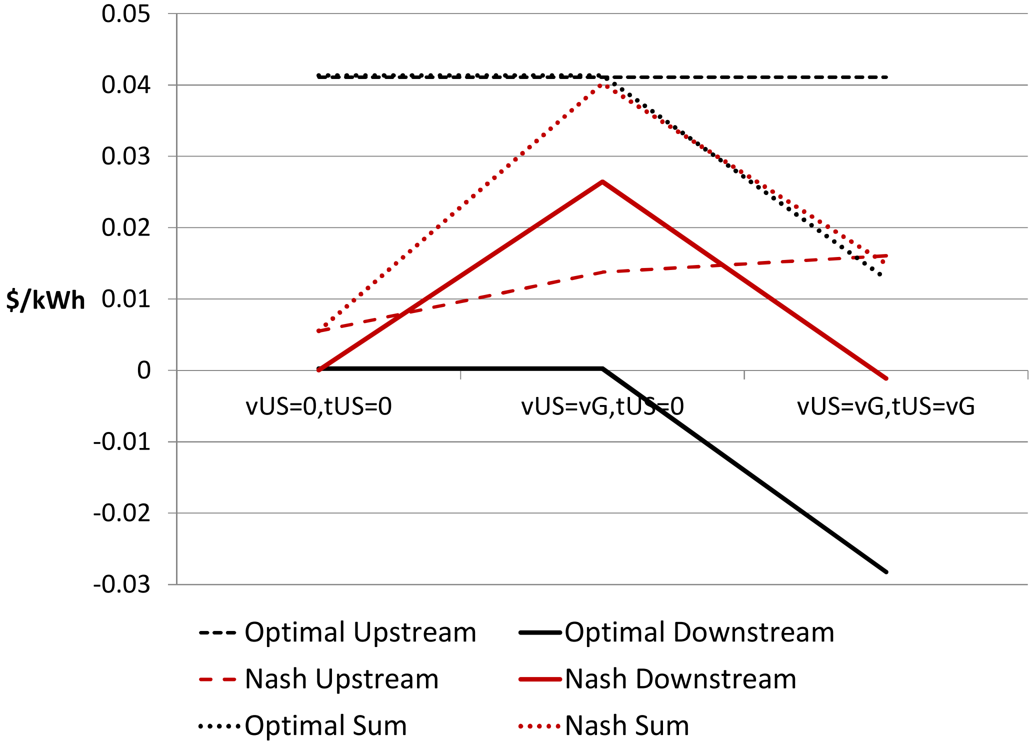
We see the strategies have different producer country impacts as well. The optimal subsidy policy maintains the baseline market shares (50% EU, 25% US and China each). The Nash equilibrium, however, shifts more production toward China, which is a larger consumer nation, and as a smaller net exporter, has less interest in withholding production to keep global prices high.

Downstream regulation

Suppose the EU has a carbon price equal to the SCC, assumed to be $30 / ton CO2. Figure 3 shows the effect of US valuation and regulation on optimal subsidies in the US. The global planner sets the upstream subsidy (assumed to be symmetric across producers) to balance both the upstream market failure and the external benefits in the non-regulating countries (recalling that for now ROW and the US have identical downstream markets). The valuation by the US does not affect the optimal subsidies, since the planner's valuation does not change. However, when the US prices carbon according to its social costs, the optimal downstream subsidy in the US now becomes a tax; since the US carbon prices gives an incentive to adopt renewable energy, taxing some of that adoption helps keep global technology prices lower to encourage adoption in ROW.

From the US perspective, a modest upstream subsidy is desired, and that increases as the US values carbon to a greater extent, as the changes in foreign emissions are valued. Downstream subsidies are positive only if the US values carbon reductions, but does not price carbon according to those values. Without carbon pricing, due to the terms-of-trade effects with exports to ROW, the sum of the strategic subsidies are less than that of the planner's subsidies in the US; however, with carbon pricing internalizing the downstream externality domestically, the sum of the Nash subsidies is slightly higher, due to the undertaxation of domestic deployment.

Figure 4: Optimal subsidies in the US as a function of US carbon valuation and pricing, when the EU taxes at the SCC $(t_{EU} = v_{EU} = v_G = \$30; t_{CN} = v_{CN} = 0)$



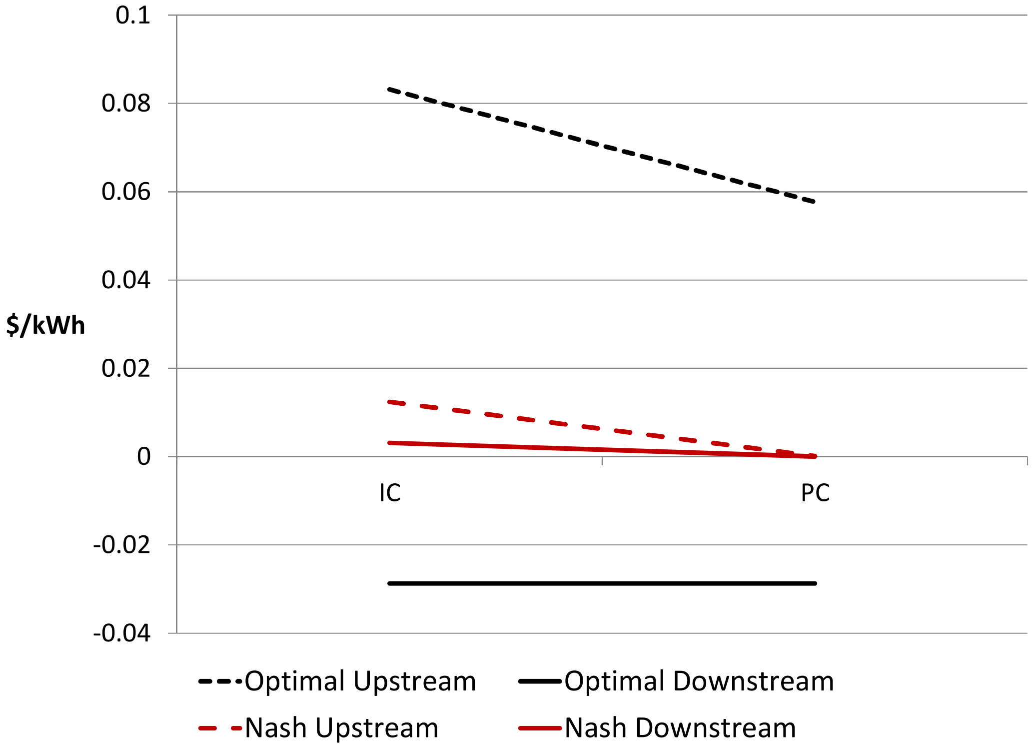
Interestingly, EU optimal subsidies do not respond significantly to changes in US valuation.

Unilateral subsidies and degree of competition

We next compare the case of imperfect competition, in which $n_{EU} = 4, n_{US} = n_{CN} = 2,$ with that of perfect competition, assuming $n_{EU} = 400, n_{US} = n_{CN} = 200.$ As previously mentioned, with no environmental externality, the optimal upstream subsidy is about 1 cent/kWh with imperfect competition. The upstream market failure also interacts with the environmental externality, as underprovision has additional social costs: the difference between the optimal upstream subsidies with and without imperfect competition rises to 1.6 cents/kWh with a SCC of $30/ton CO2, and 2 cents/kWh with a SCC of $60/ton CO2.

Another interesting case is that of unilateral policies, such as when only the EU implements carbon and renewable energy policies, which forces the global planner to take second-best decisions. Figure 4 depicts these optimal subsidies for the EU, when the EU has a carbon price equal to the SCC, while the US and ROW have no policies. Because of the larger external effects, the social planner wants a strong upstream subsidy, combined with a downstream tax, to suppress the global price and encourage more deployment outside the EU where the downstream electricity sectors are dirtier. With imperfect competition, the upstream subsidy is 2.4 cents/kWh higher.

Figure 5: Optimal unilateral EU subsidies and competition $(v_G = v_{EU} = t_{EU} = 30)$



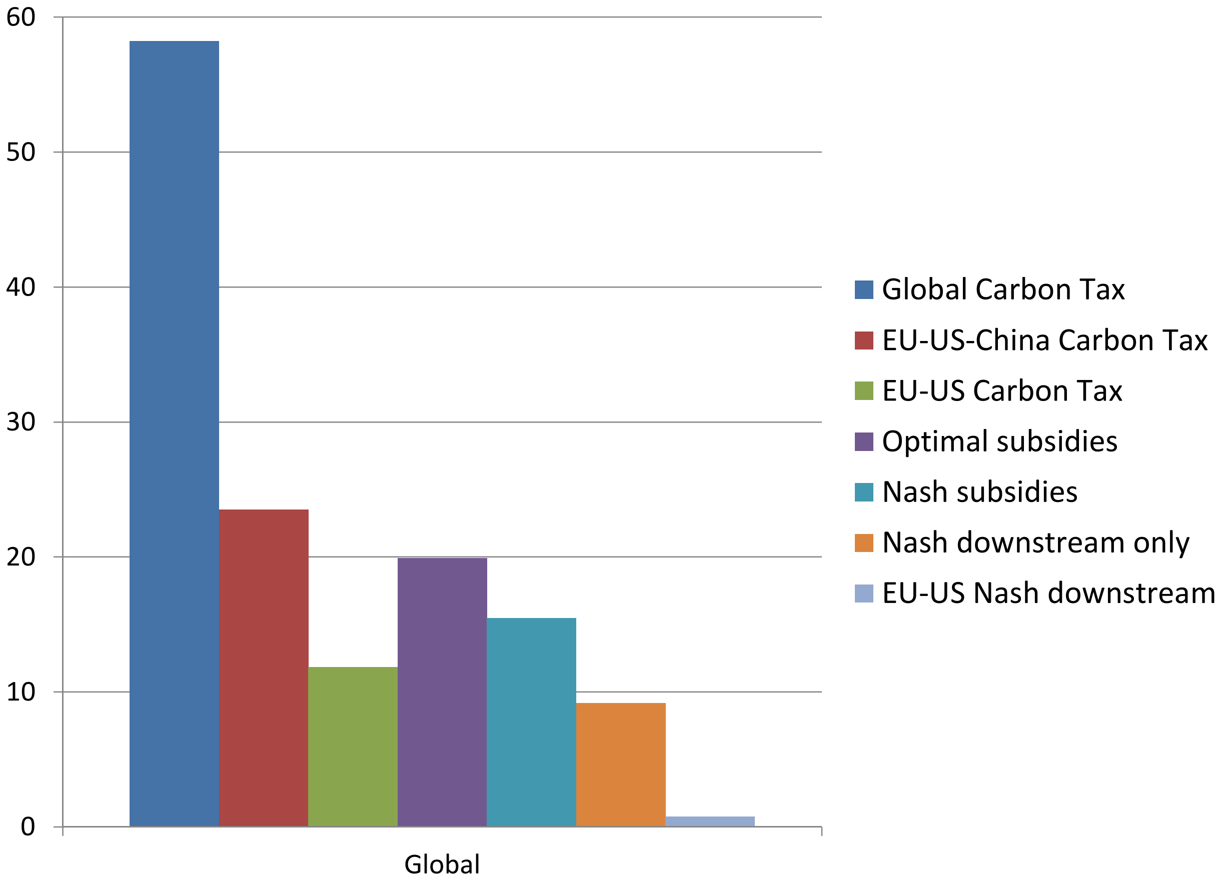
The EU, on the other hand, wants a modest upstream subsidy when there is imperfect competition, plus a very small downstream subsidy. Note that the sum of the global and EU-optimal subsidies are identical in this unilateral policy case, but the effects on the rest of the world are very different, since the EU does not shift deployment abroad in the same way.

Welfare effects of restrictions on subsidies

How do strategic subsidies and trade law constraints upon them affect welfare in a situation of market failures? We consider the case in which we have imperfect competition, and the SCC is $30. To get a sense of the scale of the benefits of intervention, implementing that SCC as a global carbon price (including ROW) would reap $60 billion in gains. Optimal subsidies implemented in the producer countries can generate a $20 billion improvement, almost as much as a carbon tax implemented only in the producer countries, and nearly twice the gains of a carbon price that only applied to the EU and US. The Nash equilibrium of strategic subsidies is somewhat smaller, but still achieves nearly $15 billion in global economic and environmental improvements.

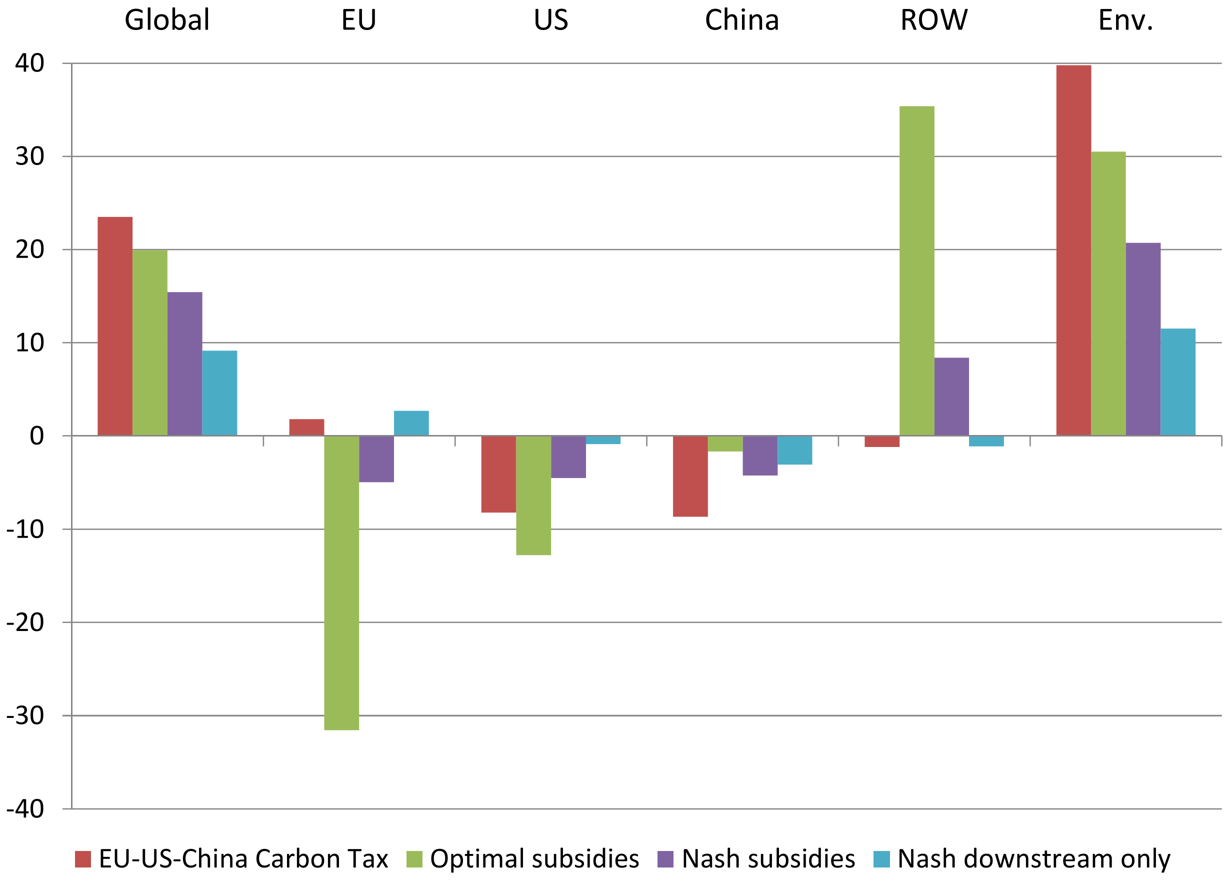
Now consider the effects of restrictions. If upstream subsidies are made unavailable, as represented by the Nash equilibrium with only downstream subsidies, the benefits fall to less than $10 billion. However, these are not that much lower than the benefits of a carbon tax that is restricted to the EU and US alone. Finally, if we limit interventions to downstream subsidies just in the EU and US, the benefits are negligible, since they draw resources away from the rest of the world where deployment has more value in reducing emissions.

Figure 6: Change in welfare from no policy; scenario with imperfect competition, all regions value at SCC of $30/ton CO2 price



The distributional effects of the policies, shown in Figure 6, are quite different as well. The globally optimal subsidies involve large transfers from producer to consumer countries, and moreso from the EU, the largest net exporter and where consumption is discouraged by a downstream tax. Nash subsidies cost producer countries, while benefiting ROW and generating even more environmental benefits than the optimal subsidies. Without upstream subsidies, producer countries are better off, but the environment and ROW are worse off.

Figure 7: Distributional effects of subsidies



Conclusion

This analysis has shown the importance of considering the global impacts of market failures when considering the value of market and trade interventions like subsidies—and the potential costs of placing restrictions upon them. For products with concentrated markets, emerging technologies with scale effects, or green goods with global cross-border environmental benefits, underprovision may be a real problem. In these cases, subsidies can help correct the market failures. In particular, upstream subsidies—by depressing global prices—tend to generate larger global benefits. However, it is these kinds of manufacturing subsidies that WTO rules tend to restrain. While producer countries may benefit from these restrictions, global welfare is higher with strategic subsidy competition.

In the case of climate change, when constraints are put on carbon pricing (such as due to principles of common but differentiated responsibilities for developing countries or political resistance in developed countries), technology policies like subsidies become important second-best tools. They are more effective to the extent they can reach all the major emitters, including developing and emerging economies and, toward that end, upstream subsidies become relatively valuable. Furthermore, strategic subsidies do not overcompensate for the external effects and restrictions on upstream subsidies then become counter-productive. Alternatively, the developed or producer countries could subsidize deployment in ROW to the same end, but their strategic incentives to do so would be even less, since they cannot guarantee those subsidies would benefit their own producers, as with upstream subsidies.

Most of this analysis relies merely on the assumptions that global supply curves for the green good are upward sloping and that downstream demand for the good is downward sloping. Thus, the qualitative results should be robust to other frameworks. While we have explored an application to renewable energy, the lessons should apply to a broad range of goods with spillover effects. For example, vaccines and therapies for communicable diseases can have global externalities while remaining under strict patent protection.

The larger caveats to the conclusions relate to other, unmodeled rationales for which restrictions on manufacturing subsidies might be warranted. A deadweight loss from the taxation needed to fund subsidies makes them a more costly tool; however, national governments should internalize these costs, as well as a global planner. In contrast, other market structure issues in which subsidies may lead to dynamic inefficiencies—like an ability to deter foreign entry and ultimately competition—are more likely to temper interest in loosening the restraints on industrial policy.[13] Indeed, these allegations have been made recently in the case of solar panels. More research is needed on the global effects of subsidies for green goods, as well as more thoughtful discussion about what role to make for them in international trade and environmental agreements.

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[13] On the other hand, Dixit and Kyle (1985) show that while protection for domestic entry promotion is generally bad from a global standpoint, subsidies for entry promotion are more beneficial, and countermeasures against them ineffective or harmful.

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Appendix

Analytical results

To avoid unnecessary complications for our core intuition, we generally make the following simplifications of symmetry among producing regions: $m_1 = m_2 = (1 - m_3)/2,$ and $n_1 = n_2 = n$.

Cournot competition

Proof of Proposition 1(a)

With a Cournot duopoly, the optimal policy is

$$\gamma_C^* = (a-c)/(2n), \quad \eta_C^* = 0$$

The symmetric Nash equilibrium, on the other hand, produces

$$\gamma_C^{\text{Nash}} = \frac{(a-c)(1+2n(1-m_3)+m_3(2-m_3))}{2n(1+2n+2m_3)} > 0$$
$$\eta_C^{\text{Nash}} = \frac{(a-c)m_3}{2n(1+2n+2m_3)} \geq 0.$$

Proof of Proposition 1(b)

The sum of these subsidies is less than the optimal upstream subsidy, to the extent that $m_3 > 0$:

$$\gamma_C^{\text{Nash}} + \eta_C^{\text{Nash}} = \frac{(a-c)(1+2n+2m_3-m_3{}^2)}{2n(1+2n+2m_3)} \leq \gamma_C^*$$

Furthermore, the upstream share is decreasing in *n* and m_3 :

$$\frac{\gamma_C^{\text{Nash}}}{\gamma_C^{\text{Nash}} + \eta_C^{\text{Nash}}} = 1 - \frac{2nm_3}{1+2n+m_3(2-m_3)} \geq \frac{1}{1+n}$$

Proof of Proposition 1(c)

When $m_3 = 0$, $\gamma_C^{\text{Nash}} = \gamma^*$ and $\eta_C^{\text{Nash}} = \eta^* = 0.$

Proof of Proposition 2(a)

Suppose that downstream subsidies are prohibited. The global optimum is unchanged, but the Nash equilibrium provides a smaller subsidy. We also solve for the optimal subsidies for the jointly maximized welfare of the producer states, and find that it is yet smaller:

$$\gamma_C^*\Big|_{\eta=0} = \frac{(a-c)}{2n}$$

$$\gamma_C^{\text{Nash}}\Big|_{\eta=0} = \frac{(a-c)(1+n(1-m_3))}{2n(1+n+m_3/2)} < \gamma_C^*$$

$$\gamma_C^{\text{Joint}}\Big|_{\eta=0} = \frac{(a-c)(1-2nm_3)}{2n(2+2n+m_3)} < \gamma_C^{\text{Nash}}\Big|_{\eta=0} < \gamma_C^*$$

This reveals the tension between the producer states incentives to restrict competition, their noncooperative incentives to protect market share, and global incentives to address the market failure of imperfect competition.

Proof of Proposition 2(b)

If upstream subsidies are prohibited, and one cannot subsidize downstream in the third country, then

$$\eta_C^*\Big|_{\gamma=0} = \frac{(a-c)2n}{(m_3+2n)^2+m_3(1-m_3)} = \gamma_C^*\frac{4n^2}{4n^2+4nm_3+m_3} < \gamma_C^*$$

$$\eta_C^{\text{Nash}}\Big|_{\gamma=0} = \frac{(a-c)(1+m_3)2n}{(m_3+2n)^2+2m_3(1-m_3)+(1+2n)^2} < \eta^*$$

Note that if the entire downstream market is in the third country, then

$$\eta_C^*\Big|_{\gamma=0} = \frac{(a-c)2n}{(1+2n)^2} = \eta_C^{\text{Nash}}\Big|_{\gamma=0}$$

Unilateral policies

If subsidies can only be implemented in one jurisdiction, then $\gamma_1^*\Big|_{\gamma_2=0,\eta_2=0} = (a-c)/n$. A strategic region 1, however, would subsidize downstream, not only upstream, with the sum still less than the constrained optimal subsidy:

$$\gamma_1\big|_{\gamma_2=0,\eta_2=0} = \frac{(a-c)\big(3+4n(1-m_3)+m_3(2-m_3)\big)}{4n(1+2n+m_3)} > 0$$

$$\eta_1\big|_{\gamma_2=0,\eta_2=0} = \frac{(a-c)(1+m_3)}{2n(1+2n+m_3)} > 0$$

$$\gamma_1\big|_{\gamma_2=0,\eta_2=0} + \eta_1\big|_{\gamma_2=0,\eta_2=0} = \frac{(a-c)(3-m_3)}{4n} < \gamma_1^*\big|_{\gamma_2=0,\eta_2=0}$$

Downstream externality

For the proof of optimal strategies without and with an externality, we derive the analytical solutions in Mathematica and report simplified results here.

Proof of Proposition 3(a) and Corollary

The effect of the third-party market is best seen with the assumption of symmetry across the producing countries: i.e., $m_1 = m_2 = (1-m_3)/2$. When $v_i = 0$, the symmetric Nash solution yields

$$\gamma_i^{\text{Nash}} = -\eta_i^{\text{Nash}} < 0$$

$$\eta_i^{\text{Nash}} = hm_3 \frac{b(a-c)}{(b+h)^2 + m_3(2(b+h) - hm_3)} > 0$$

Thus, we see the tax/subsidy shift is increasing in *h*, at least initially, and is strictly increasing in m_3. Furthermore, when $m_3 = 0$, symmetric countries have no subsidies in equilibrium.

Discussion of Asymmetric Firms

With no third-party country, the asymmetric Nash solution yields

$$\gamma_1^{\text{Nash}} = -\eta_1^{\text{Nash}} = \frac{(a-c)bh\Delta_m}{2(b+h)(b+h+h\Delta_m)} = \eta_2^{\text{Nash}} = -\gamma_2^{\text{Nash}}$$

$$Y^{\text{Nash}} - Y^* = -\frac{(a-c)bh{\Delta_m}^2}{2(b+h)(b+h+h\Delta_m)^2} < 0$$

where $\Delta_m = m_1 - m_2$ is the extent to which country 1 has a larger market share.

Proof of Proposition 5(a)

With the valuation of an environmental benefit, the analytical expressions for the Nash equilibrium subsidies are too elaborate to repeat here, but (without imposing any assumptions of symmetry) the sum of the upstream and downstream subsidies always yields $\gamma_i^{\text{Nash}} + \eta_i^{\text{Nash}} = v_i \mu_i$.

Proof of Proposition 5(c)

We show this for the case of symmetric producer countries that value the externality at the global value: i.e., $v_2 = v_1 = v_G;\, m_1 = m_2 = (1-m_3)/2;\, \mu_i = \mu.$ Simplifying the difference between the Nash and globally optimal upstream subsidies, we see

$$\gamma^{\text{Nash}} - \gamma^* = -m_3 \frac{b\big((a-c)hm_3 + (b+h(1+m_3))\mu v_G\big)}{(b+h(1+m_3))^2 - 2h^2 m_3{}^2} < 0;$$

$$Y^{\text{Nash}} - Y^* = \frac{m_3}{b+h}(\gamma^{\text{Nash}} - \gamma^*) < 0.$$

External Scale Effects

To be completed.