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Environmental Protection for Sale: Strategic Green Industrial Policy and Climate Finance

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Abstract Industrial policy has long been criticized as subject to protectionist interests; accordingly, subsidies to domestic producers face disciplines under World Trade Organization agreements, without exceptions for environmental purposes. Now green industrial policy is gaining popularity as governments search for low-carbon solutions that also provide jobs at home. The strategic trade literature has largely ignored the issue of market failures related to green goods. I consider the market for a new environmental good (like low-carbon technology) whose downstream consumption provides external benefits (like reduced emissions). Governments may have some preference for supporting domestic production, such as by interest-group lobbying, introducing a political distortion in their objective function. I examine the national incentives and global rationales for offering production (upstream) and deployment (downstream) subsidies in producer countries, allowing that some of the downstream market may lie in nonregulating third-party countries. Restraints on upstream subsidies erode global welfare when environmental externalities are large enough relative to political distortions. Climate finance is an effective alternative if political distortions are large and governments do not undervalue carbon costs. Numerical simulations of the case of renewable energy indicate that a modest social cost of carbon can imply benefits from allowing upstream subsidies.

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1 Introduction

Green industrial policy (GIP) is the use of government interventions to support domestic industries that have environmental benefits. GIP has emerged as a primary policy tool to develop clean energy alternatives that can help reduce reliance on energy sources that emit greenhouse gases. Rationales for GIP are manifold: the development of new technologies and industries can create jobs and economic opportunities and combat climate change at the same time. Furthermore, such industries may need assistance to become competitive, both because they are "infant" industries still innovating, developing support networks and scale economies, and also because their environmental benefits are not properly priced by the market (Rodrik 2014).

Carbon dioxide (CO_2) in particular is an underpriced externality. As of 2015, only 12% of global emissions were included in a carbon pricing scheme (World Bank 2015), and of those, the average price was \$8 per ton,[1] well below common estimates of the social cost of carbon (SCC), which the US Environmental Protection Agency puts in the range of \$40 per ton (Interagency Working Group on Social Cost of Carbon, United States Government 2015). At the same time, fossil fuels enjoy substantial subsidies in most parts of the world (International Energy Agency (IEA) 2015). The general policy preference for subsidies over emissions prices is evident in renewable energy policies: nearly 100 countries and countless subnational jurisdictions offer financial incentives for renewable energy (IEA/IRENA 2015), whereas fewer than 40 countries and roughly 20 subnational jurisdictions—all of which also rely on renewable energy support—are using or planning to implement carbon pricing (World Bank 2015).

The policies range from downstream measures to support deployment to upstream incentives for R&D and manufacturing. Downstream measures create markets for upstream industries to serve; upstream measures support domestic industries directly. The distinction is important, both from an economic and legal perspective. With international trade, the policies have different effects on global clean technology prices, and thus on the deployment opportunities for export markets (Fischer et al. 2016b). The World Trade Organization (WT) agreements create restrictions on industrial policies that distort trade, particularly subsidies. Although downstream subsidies can generally be designed in a nondiscriminatory fashion, upstream policies by definition offer preferential treatment to domestic producers. The WT attests that its rules do not impede supporting the deployment and diffusion of green technologies (World Trade Organization (WTO) 2011), but multiple disputes have come to WT panels over the solar PA, wind power equipment, and boxful sectors, particularly regarding subsidies or local content requirements for deployment benefits (Charnovitz and Fischer 2015; Cosbey and Mavroidis 2014).[2] Importantly, the Agreement on Subsidies and Countervailing Measures (Subsidies Code) lacks exceptions for environmental reasons; thus, subsidy

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[1] Own calculations based on data from World Bank (2015).

[2] Examples: European Union—Certain Measures on the Importation and Marketing of Biodiesel and Measures Supporting the Biodiesel Industry (Complainant: Argentina, 2013); India—Certain Measures Relating to Solar Cells and Solar Modules (Complainant: United States, 2013); European Union and Certain Member States—Certain Measures Affecting the Renewable Energy Generation Sector (Complainant: China, 2012); Canada—

policy may have less leeway than tariff-related measures, since the General Agreement on Tariffs and Trade (GATT) does carve out specific exceptions for transboundary externalities like human health or resource conservation (Rubini 2012).

Economists have long made a strong case against industrial policy, noting the potential for beggar-thy-neighbor protectionism, opportunities for rent seeking, and the difficulty in picking winners (Rodrik 2014). Should exceptions be made in the Subsidies Code for addressing global environmental challenges? Or can alternative policies—like encouraging technology-producing countries to extend climate finance to develop markets for deployment in developing countries—substitute for upstream measures?

This paper extends the work on strategic subsidies by Fischer (2016) to look specifically at the question of politically motivated green industrial policy and climate finance as an alternative. This intersection is highly novel. Export and production subsidies have been studied in the strategic trade literature, largely building on early work by Spencer and Brander (1983) and Brander and Spencer (1985), who demonstrate that countries with imperfectly competitive industries that export to a third market can raise their joint profits if they commit to limiting production by agreeing to avoid subsidies. These studies tend to focus on the strategic interest of the producer countries, ignoring questions of global welfare or correcting market failures. Fischer (2016) points out that from a global welfare perspective, strategic countries tend to *under*provide production subsidies that can correct upstream market failures (like imperfect competition or network externalities) and downstream externalities.[3] In an application to renewable energy, she finds that the global emissions externalities are far more consequential than market power by technology firms. That pattern of market failures thus does not make a case that restricting the use of upstream subsidies enhances global welfare. By contrast, the "protection for sale" theory initiated by Grossman and Helpman (1994, 1995) explains excess protectionism with a model of industry group lobbying that distorts the government's objective function away from pure welfare. In contrast to the upstream market failures of imperfect competition or network externalities, which lead to underproduction, this political distortion leads to *over*production, which does set the stage for multilateral agreements limiting subsidies to improve global welfare. However, this literature has traditionally ignored transboundary environmental spillovers.[4]

Renewable energy is an interesting application because of its central role in green industrial policy, its potential to generate spillover benefits, the multiple policy levers brought to bear, and the multiple objectives expressed (Fischer and Preonas 2010). The European Parliament, in adopting the 20/20/20 Directive, justified the renewable energy targets as "promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, especially in rural and isolated areas …, [increasing] export prospects, social cohesion and employment opportunities … [for

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Footnote 2 continued
Measures Relating to the Feed-in Tariff Program (Complainant: European Union, 2011); Canada—Certain Measures Affecting the Renewable Energy Generation Sector (Complainant: Japan, 2010); China—Measures Concerning Wind Power Equipment (Complainant: United States, 2010).

[3] Fischer et al. (2014, 2016a) consider strategic subsidy policies with environmental consequences in somewhat different frameworks among Cournot duopolies (with no third market). Other well-known studies in the environmental economics literature have considered strategic policy responses to trade and market structure (e.g., Barrett 1994; Conrad 1993), and a recent study by but they have ignored the important distinction between upstream providers of abatement technologies and downstream sectors deploying them (Greaker and Rosendahl 2008).

[4] An exception is Margolis et al. (2005), who look at invasive species issues.

small] independent energy producers" (European Union (EU) 2009, 16).[5] In 2012, the value of EU interventions for renewable energy exceeded the value of all the emissions trading allowances allocated for the year.[6] Renewable energy is also contentious in trade: in addition to the above-mentioned disputes, both the United States and the European Union have initiated antidumping measures against Chinese solar panels in recent years. Meanwhile, climate finance plays a growing part in international architectures: the Paris Agreement included commitments to delivering climate finance to developing countries of at least \$100 billion per year by 2025, with a large portion devoted to low-carbon energy.[7]

The next section describes the model framework. Theoretical results isolate the environmental and political market failures. Then the model is parameterized to represent global production and deployment of renewable energy technologies and explore optimal policy strategies. Both sections reveal important trade-offs between allowing and restricting the use of upstream subsidies. For green goods, allowing upstream subsidies may be useful, especially if political distortions are large relative to the environmental benefits. For brown goods, restrictions on upstream subsidies are either useful, if political distortions are large, or ineffectual, as strategic countries may not want to use them otherwise. These restrictions can be costly, however, when external environmental benefits are important, and climate finance may only be a successful alternative if clean technology-exporting countries have strong special interests lobbying their governments to support foreign markets.

2 Model Framework

The model focuses on the market for a green manufactured good, a clean technology such as a wind turbine or solar panel. There are three regions, all of which are consumers of the green good, in the sense of deploying the clean technology in their downstream electricity sectors. Two of the regions are also home to producers of the good. Markets are decentralized, and the products are assumed to be identical. This static, partial equilibrium model is kept simple to capture the essential features of the trade and environmental problem.[8]

Governments in each producing region $i = \{1, 2\}$ may offer to subsidize downstream deployment by η_i and/or to subsidize the production of the upstream technology firms by γ_i.

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[5] As further evidence of the broad link between GIP and employment objectives, during the Great Recession, the European Union devoted 59% of its stimulus to green projects, while individual member states and the United States each allocated on average about 11% of their stimulus packages, and China spent 38% on green projects; globally, 9% of green stimulus was spent on renewable energy specifically (Robins et al. 2009).

[6] 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 (pp. i–ii). For 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 (also cited in Fischer 2016).

[7] Climate finance is distinct from the technology transfer envisioned in the Kyoto Protocol. Glachant et al. (2016) explore strategic incentives to transfer less polluting technologies to trade partners when the downstream industries adopting them compete (albeit imperfectly) through international trade.

[8] Since a green good represents a relatively small sector in the economy, we decline to model general equilibrium effects. Brander and Spencer (1985) show that with an additive utility function including a perfectly competitive numeraire good, the results carry through in a general equilibrium model with terms of trade. We also avoid dynamic effects; policies that stimulate upstream innovation, like R&D subsidies, generally have the same cost-reducing effect as upstream subsidies, over the longer term. We discuss some important caveats related to unmodeled scale economies and learning spillovers in the conclusion.

The third region's government makes no interventions (for example, a developing country without climate policy obligations), leaving $\eta_3 = 0$—that is, unless the producer countries agree to subsidize deployment there by f_i (such as through contributions to climate finance or clean energy foreign aid), in which case $\eta_3 = f_1 + f_2$. This latter policy option will be considered as an alternative when upstream policies are disallowed. Note that contributions differ from export subsidies, since they apply to all consumption in the third market, not just the exports of the region offering the support. Contributions also differ from technology transfer, which typically relates to the transfer of intellectual property and expertise; hence, we prefer the term climate finance to characterize this set of policies.

The demand side of the model follows Fischer (2016), as repeated here. Let us assume the following linear demand functions for the clean technology in each region, where m_i is a measure of downstream market share of region i (and $\sum_i m_i = 1$).[9]

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

Total demand is $X = x_1 + x_2 + x_3$, which 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 $A = a + \bar{\eta}$, where $\bar{\eta} = \sum_i m_i \eta_i$.

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

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

The upstream market is characterized by price-taking firms with an upward-sloping aggregate supply curve in each producer region. This assumption allows us to focus on the market failures related to the downstream external benefits and the political economy, rather than other potential issues like imperfect competition or scale economies, which have been analyzed in Fischer (2016).[10] Since we want to think about an international trade context with multiple producer regions and allow for asymmetric policies and thereby asymmetric costs, a market structure that gives positive producer surplus is required. The earlier strategic trade literature and Fischer (2016) used Cournot competition with constant marginal costs, but with perfect competition and price-taking firms, constant marginal costs and zero profits mean the least-cost producer would serve the entire market. Thus, let us assume upward-sloping marginal costs of domestic production, such as can arise from production lines of heterogeneous producers with limited capacities (as in Laffont and Tirole 1996).[11]

Consider a representative, price-taking firm in each region; marginal costs are linear in output y_i. Let total costs for region i be $(c + hy_i)y_i$, leading to marginal costs with intercept c and slope $2h$. Recognizing that equations for region 2 are the mirror image of those for

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[9] 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.

[10] Fischer (2016) explores the interactions with imperfect competition and finds the welfare costs from that market failure to be small relative to the costs of the downstream externality. Still, it is worth mentioning that those upstream market failures pull in the opposite direction from the political distortion in this paper; imperfect competition and scale externalities lead to underproduction, while the political distortion leads to overproduction.

[11] An alternative structure would be heterogeneous firms with imperfect substitutability (as in Melitz 2003). However, representative supply curves are in better keeping with our numerical parameterization, which relies on linear demand functions and the assumption of identical products. The important aspect is simply that we have positive producer surplus, which makes strategic countries want to engage in industrial policy, in order to influence the terms of trade.

region 1, let us lay out the model from the perspective of region 1. Domestic industry profits in region 1 are

$$\pi_1 = (P + \gamma_1 - (c + hy_1))\, y_1$$

From the first-order conditions for each firm $\partial\pi_1/\partial y_1 = P + \gamma_1 - (c + 2hy_1) = 0$; with $P = A - B(y_1 + y_2)$, we have in equilibrium

$$y_1 = \frac{(A - c + \gamma_1) + \frac{B}{h}\frac{(\gamma_1 - \gamma_2)}{2}}{2(B + h)}; \quad Y = \frac{A - c + \bar{\gamma}}{B + h}$$

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

$$\begin{aligned} P &= (c - \bar{\gamma})\,\frac{B}{B + h} + A\frac{h}{B + h} \\ &= (c - \bar{\gamma})\,\frac{b}{b + h} + (a + \bar{\eta})\frac{h}{b + h} \end{aligned}$$

(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 region: $\gamma_2 - \gamma_1 \leq h(A - c + \gamma_1)/B$. Since we will look at symmetric equilibria, this always holds, but in general it requires a positive h).

Total revenues are the cost of the upstream and downstream subsidy payments for a producer region: $TR_i = -\gamma_i Y_i - \eta_i x_i$. Conventional economic surplus in region i is thus the sum of domestic upstream profits, Π_i, domestic downstream surplus, CS_i, and net revenues, TR_i.

Consumption of the clean technology in the downstream markets leads to global external benefits, E_G. The external benefits generated in region i are proportional to its consumption of the product, and the unit benefit μ_i may differ by the region of consumption. Total external benefits are given by $E_G = \mu_1 x_1 + \mu_2 x_2 + \mu_3 x_3$. For example, suppose the global benefits are from climate mitigation and the environmental good is renewable energy technologies. The deployment (consumption) of renewable energy technologies displaces emissions from fossil energy by factor μ_i in region i, and those factors differ according to the market for electricity generation in each region. An additional question is the value that individual governments place on the global external benefit: since the benefits of local consumption are global, we consider that individual governments place their own value on those benefits, which may be lower than that of a global planner ($v_i \leq v_G$). Since some countries do choose to use the global social cost of carbon in their policy planning (e.g., Interagency Working Group on Social Cost of Carbon, United States Government 2015), we do not restrict v_G to be the sum of the individual regional values.

Finally, governments may have heightened concerns about the clean technology industry's success because of the associated jobs, wages, and exports. Let us model this concern by adding weight ω in the domestic objective function to total domestic production of the technology. Though we will not model the underlying influences explicitly, preferences for establishing and maintaining global market share may arise from a model of lobbying by industry interest groups, as was well established by Grossman and Helpman (1994). The choice of upstream output as the metric of interest for the governing politicians has several advantages as compared to other options like industry profits. First of all, output represents a metric of interest for a broader array of stakeholders lobbying government than just firm shareholders; labor interest groups, associated industries in the supply chain, and environmental groups are arguably more interested in the scale than in the profitability of production.[12] Second, this choice renders the theoretical results and intuition very straightforward. Because aggregate profits are closely related to output, the qualitative results of production overweighting are the same as profits overweighting: governments supporting industry profits will expand subsidies and expand their production.[13] Given that both the character of government distortion and its weight are unobservable, some small loss of potential nuance is outweighed by the benefits of transparency. Lastly, the scale of the weight on output can be easily put into the perspective of existing support mechanisms.

To summarize, governments place a value on economic surplus with weight 1; global downstream externalities, E_G, with weight v_i, and domestic upstream production scale with common weight ω. The objective function for the government of producer region i is thus

$$W_i = \Pi_i + CS_i + TR_i + v_i E_G + \omega y_i$$

From the perspective of a global social planner, however, welfare is

$$W_G = \Pi_1 + \Pi_2 + TR_1 + TR_2 + CS_1 + CS_2 + CS_3 + v_G E_G.$$

3 Optimal and Strategic Subsidies

The strategic subsidy choice is 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, such as direct subsidies, tax breaks, and low-cost land or financing. In the second stage of the game, international supply and demand find equilibrium.

We compare the optimal subsidy strategy of a global planner with the Nash equilibrium among the regional governments. In essence, although the firms are price takers, their governments have market power, and they compete like a duopoly. Each actor maximizes its welfare function with respect to the policy levers it controls, recognizing the market equilibrium response to subsidies, and 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; that is, $\{\partial W_G/\partial \gamma_1 = 0, \partial W_G/\partial \eta_1 = 0, \partial W_G/\partial \gamma_2 = 0, \partial W_G/\partial \eta_2 = 0\}$. We will consider the case of symmetric producer regions and thus restrict the optimal upstream subsidies to be symmetric, to allow better comparison with the noncooperative equilibrium. We also consider the case in which upstream subsidies are restricted to zero, but contributions to deployment in the third market can be made: $\{\gamma_1 = 0, \gamma_2 = 0, \partial W_G/\partial \eta_1 = 0, \partial W_G/\partial \eta_2 = 0, \partial W_G/\partial f_1 = 0, \partial W_G/\partial f_2 = 0\}$.

In the Nash game, each producing region 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, $\{\partial W_1/\partial \gamma_1 = 0, \partial W_1/\partial \eta_1 = 0, \partial W_2/\partial \gamma_2 = 0, \partial W_2/\partial \eta_2 = 0\}$

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[12] Common models of industry lobbying assume concentrated industries with individual firms perceiving benefits from their own lobbying. This paper implicitly considers that several kinds of groups (and not just firms) may organize to lobby for their special interests. This choice seems realistic for representing the landscape of clean energy interests, which include not only equipment manufacturers but also installers, researchers, financers, environmental consumer groups, construction services, and utilities. (Solar Energy Industries Association is a good example of a blended interest group, with the stated mission "to promote, protect and expand solar energy across America"). The focus on upstream scale over profits is then also more compatible with the assumption of competitive firms.

[13] The main difference is that with profits overweighting, the two subsidies would be increasing in a nonlinear fashion, rather than in a linear fashion as presented here. Thus, some second-order effects would be introduced.

all must hold. In the case where upstream subsidies are restricted and contributions used instead, we consider $\{\gamma_1 = 0, \partial W_1/\partial\eta_1 = 0, \partial W_1/\partial f_1 = 0, \gamma_2 = 0, \partial W_2/\partial\eta_2 = 0, \partial W_2/\partial f_2 = 0\}$.

The subsidies have direct and indirect effects on welfare through changes in output and consumption. Note that from the decentralized problem, $\partial\Pi_i/\partial y_i = 0$ and $\partial CS_i/\partial x_i = 0$, holding prices fixed, and all price changes amount to global transfers on the margin $(\partial W_G/\partial P = \sum_i \partial\Pi_i/\partial P + \sum_i \partial CS_i/\partial P = \sum_i y_i - \sum_i x_i = 0)$. Consider the planner's problem with respect to region 1. Differentiating global welfare in its general form with respect to the upstream subsidy, we see

$$\begin{aligned}\frac{dW_G}{d\gamma_1} &= \frac{\partial\Pi_1}{\partial\gamma_1} + \frac{\partial TR_1}{\partial\gamma_1} + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{d\gamma_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{d\gamma_1} + \frac{\partial TR_2}{\partial x_2}\frac{dx_2}{d\gamma_1}\\ &\quad + \frac{\partial TR_2}{\partial y_2}\frac{dy_2}{d\gamma_1} + v_G \sum_i \frac{\partial E_G}{\partial x_i}\frac{dx_i}{d\gamma_1}\\ &= y_1 - y_1 - \eta_1\frac{dx_1}{d\gamma_1} - \eta_2\frac{dx_2}{d\gamma_1} - \gamma_1\frac{dy_1}{d\gamma_1} - \gamma_2\frac{dy_2}{d\gamma_1} + v_G\sum_i \mu_i\frac{dx_i}{d\gamma_1}\\ &= \sum_i (v_G\mu_i - \eta_i)\frac{dx_i}{d\gamma_1} - \sum_i \gamma_i\frac{dy_i}{d\gamma_1} = 0\end{aligned}$$

Similarly, with respect to the downstream subsidy,

$$\begin{aligned}\frac{dW_G}{d\eta_1} &= \frac{\partial CS_1}{\partial\eta_1} + \frac{\partial TR_1}{\partial\eta_1} + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{d\eta_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{d\eta_1}\\ &\quad + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{d\eta_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{d\eta_1} + v_G\sum_i \frac{\partial E_G}{\partial x_i}\frac{dx_i}{d\eta_1}\\ &= x_1 - x_1 - \eta_1\frac{dx_1}{d\eta_1} - \gamma_1\frac{dy_1}{d\eta_1} - \eta_2\frac{dx_1}{d\eta_1} - \gamma_2\frac{dy_1}{d\eta_1} + v_G\sum_i \mu_i\frac{dx_i}{d\eta_1}\\ &= \sum_i (v_G\mu_i - \eta_i)\frac{dx_i}{d\eta_i} - \sum_i \gamma_i\frac{dy_i}{d\eta_i} = 0\end{aligned}$$

Thus, the planner wants a combination of subsidies to internalize the environmental externality, such that the last bracketed term equals zero. Note that since the planner is indifferent to the location of revenue transfers, a choice of contributions for deployment in the third region will look like $dW_G/d\eta_3$.

From the individual region's perspective, the subsidy choices are somewhat different:

$$\begin{aligned}\frac{dW_1}{d\gamma_1} &= y_1 + \frac{\partial\Pi_1}{\partial P}\frac{dP}{d\gamma_1} + \frac{\partial CS_1}{\partial P}\frac{dP}{d\gamma_1} - y_1 + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{d\gamma_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{d\gamma_1}\\ &\quad + v_1\sum \frac{\partial E_G}{\partial x_i}\frac{dx_i}{d\gamma_1} + \omega\frac{dy_i}{d\gamma_1}\\ &= (y_1 - x_1)\frac{dP}{d\gamma_1} + \sum_i v_1\mu_i\frac{dx_i}{d\gamma_1} - \eta_1\frac{dx_1}{d\gamma_1} + (\omega - \gamma_1)\frac{dy_1}{d\gamma_1} = 0\end{aligned}$$

$$\begin{aligned}\frac{dW_1}{d\eta_1} &= \frac{\partial\Pi_1}{\partial P}\frac{dP}{d\eta_1} + x_1 + \frac{\partial CS_1}{\partial P}\frac{dP}{d\eta_1} - x_1 + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{d\eta_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{d\eta_1}\\ &\quad + v_1\sum_i \frac{\partial E_G}{\partial x_i}\frac{dx_i}{d\eta_1} + \omega\frac{dy_i}{d\eta_1}\end{aligned}$$

$$= (y_1 - x_1)\frac{dP}{d\eta_1} + \sum_i v_1\mu_i\frac{dx_i}{d\eta_1} - \eta_1\frac{dx_1}{d\eta_1} + (\omega - \gamma_1)\frac{dy_1}{d\eta_1} = 0$$

$$\frac{dW_1}{df_1} = \frac{\partial\Pi_1}{\partial P}\frac{dP}{df_1} + \frac{\partial CS_1}{\partial P}\frac{dP}{df_1} - x_3 + \frac{\partial TR_1}{\partial x_1}\frac{dx_1}{df_1} + \frac{\partial TR_1}{\partial y_1}\frac{dy_1}{df_1} + v_1\sum_i\frac{\partial E_G}{\partial x_i}\frac{dx_i}{df_1} + \omega\frac{dy_i}{df_1}$$

$$= (y_1 - x_1)\frac{\partial P}{\partial f_1} - x_3 + \sum_i v_1\mu_i\frac{dx_i}{df_1} - \eta_1\frac{dx_1}{df_1} - g_1\frac{dx_3}{df_1} + \omega\frac{dy_1}{df_1} = 0$$

In each case, the first term reflects incentives to influence the terms of trade, to the extent the region is a net exporter. These terms differ across the policies, since $dP/d\gamma_i < 0$ while $dP/d\eta_i > 0$ and $dP/df_i > 0$. The remaining terms reflect the region's value of the additional environmental benefits relative to the additional revenue costs as quantities adjust, as well as any perceived benefit from expanding production. Notably, in the case of the contributions, the lost revenue to the government from the transfer abroad imposes a direct negative term; thus, for contributions to be positive, there must be sufficient benefits in terms of trade, environmental improvement, and/or having a larger market.

4 Strategic Upstream and Downstream Subsidies

To begin, let us ignore the option of contributions to foreign deployment and consider optimal strategies targeting only domestic production and deployment. All results are derived in the "Appendix" using our linear functional forms, which provide straightforward relationships for the equilibrium price and quantity responses embedded in the previous equations. For the most part, we consider equilibria with symmetric producer countries to focus on the role of the third market and the different market distortions. Let $\{\gamma_i^{Nash}(v_i, \omega), \eta_i^{Nash}(v_i, \omega)\}$ be the Nash upstream and downstream subsidies, respectively, for region i given its valuation of external benefits and the political distortion. Optimal upstream and downstream subsidies are given by $\{\gamma_i^*(v_G), \eta_i^*(v_G)\}$.

4.1 Strategic Subsidies Without Environmental Benefits

First, we consider the strategic incentives in the absence of environmental spillovers. These benchmark subsidies can then be compared with subsidies in the presence of global environmental externalities.

Proposition 1(a) *If $v_G = 0$, then the optimal policy is to have no subsidies ($\gamma_i^* = \eta_i^* = 0$).*

In the absence of any market failures, no intervention is necessary (this obvious result is stated formally only for symmetry with the subsequent results).

Proposition 1(b) *If $v_i = 0$, then in the Nash equilibrium, the sum of the upstream and downstream subsidies equals the extra weight on production in the objective function $\left(\gamma^{Nash}(0, \omega) + \eta^{Nash}(0, \omega) = \omega\right)$. If $\omega = 0$, then the Nash equilibrium has producer countries taxing upstream and subsidizing downstream by an equivalent amount, to the extent that they are net exporters to the third market: $\left(\gamma_i^{Nash}(0, 0) = -\eta_i^{Nash}(0, 0) < 0,\ i = \{1, 2\}\right)$. If $\omega > 0$, symmetric producer countries subsidize downstream and may tax or subsidize upstream.*

Without a downstream externality and without any distortion to the domestic welfare function, governments still have an incentive to intervene in the market for green goods.

Both taxing upstream and subsidizing downstream serve to drive up global technology prices and capture rents from the third region. Furthermore, since marginal production costs are increasing within a region, there may be some incentive to shift the cost of production to the other producing region.[14] 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 desire to subsidize upstream producers comes from caring more about upstream producers than about downstream consumers. Thus, governments are willing to let global prices be driven down to some extent because the upstream subsidy directly benefits the producing firms at home. For the net effect to be positive, the upstream subsidy requires $\omega > \eta_i^{Nash}(0, 0)$.

Corollary *In a symmetric-region duopoly with no third market, strategic downstream subsidies are zero, and strategic upstream subsidies are* ω.

If neither region is a net exporter, there is no incentive to influence the terms of trade, only an incentive to expand the scale of the upstream producers.

Note that if $\omega = 0$, the symmetric duopoly replicates the social optimum with no subsidies. However, if the downstream demand functions differ, the duopoly equilibrium will deviate from the social optimum. For example, if one region has a larger downstream consumption market share ($m_1 > m_2$), all else equal, it will tax downstream and set an equal subsidy upstream, while the exporting region will do the opposite but at different levels. The net effect of the taxes/subsidies is to reduce total output.[15]

It is worth noting that in this framework, upstream subsidies are negative unless there is a significant distortion in the regional government's objective function. This result differs from that with imperfectly competitive firms with Cournot competition upstream, in which case strategic upstream subsidies are positive (Fischer 2016). However, the common point among both of the perfectly and imperfectly competitive frameworks is that regions tend to provide upstream subsidies that are *lower* than optimal (because of the lack of concern for the third-party region), and a distortion like overweighting production in the government's objective function is required for a prohibition of positive upstream subsidies to be welfare enhancing from a global perspective.

4.2 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. At the social optimum, we want the price to equal the marginal social cost in each downstream region: $P_{D,i}^* = c + hY - v_G \mu_i$. Since the externality is downstream, this would suggest implementing the subsidies downstream ($\eta_i^* = \mu_i v_G, \forall i$). However, if a third-party region 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 $\gamma_1^* = \gamma_2^* = v_G \mu$ alone suffice to achieve the optimum. But when marginal benefits differ, a combination of upstream and downstream subsidies is needed to maximize welfare.

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[14] This result stands in contrast to that with Cournot-competing producers with constant marginal costs, where a positive upstream subsidy is strategically optimal (Fischer 2016). In that case, the upstream subsidy helps expand market share and profits, without raising production costs. Here, capturing more market share incurs a deadweight loss from higher total production costs.

[15] To contrast, in the case of Cournot competition and no third market, the Nash equilibrium finds the average of the upstream subsidies equal to the planner's upstream subsidy, even with asymmetric regions (Fischer 2016).

We find the following results with strategic subsidies:

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

With an external environmental benefit from downstream consumption, the planner wants the total subsidy in each region to equal the social marginal benefit; that is, $\gamma^* + \eta_i^* = v_G\mu_i,\ \forall i$. If subsidies cannot be implemented in the third-party region, the optimal strategy is to use the uniform upstream subsidy to reflect the third region's external benefit, while downstream subsidies (or taxes) are used in the producer countries to adjust net subsidy.[16]

Proposition 3 *In the Nash equilibrium, the sum of the subsidies equals the marginal benefit as valued by that region, plus the government's weight on production:* $\gamma_i^{Nash} + \eta_i^{Nash} = v_i\mu_i + \omega,\ i = \{1, 2\}$.

The individual subsidies combine the cost-shifting components defined in the subsection above with an external benefit component that is positive and increasing in proportion to v_i.[17] 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, we can write the Nash subsidies $\{\gamma_i^{Nash}(v_i, \omega), \eta_i^{Nash}(v_i, \omega)\}$as separable functions of the Nash subsidies without an external benefit $\{\gamma_i^{Nash}(0, \omega), \eta_i^{Nash}(0, \omega)\}$ plus a component $\{\chi_i^{up}(v_i), \chi_i^{down}(v_i)\}$that is a function of the external benefit, independent of ω, where $\chi_i^{up} + \chi_i^{down} = \mu_i v_i$. I.e., for $i = \{1, 2\}$, $\gamma_i^{Nash}(v_i) = \gamma_i^{Nash}(0) + \chi_i^{up}(v_i)$ and $\eta_i^{Nash}(v_i) = \eta_i^{Nash}(0) + \chi_i^{down}(v_i)$.

Corollary *Without a third region, in a symmetric Nash equilibrium, the noncooperative subsidies replicate the social optimum if each region values environmental changes at the global marginal benefit and* $\omega = 0$.

This follows from Proposition 3; 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, the countries combine upstream and downstream subsidies in such a way that the total subsidies equal those desired by the planner for each region, assuming they adopt the global valuation of the externality. In this case, the planner is indifferent as to where to target the subsidies because only the sum matters.

Proposition 4 *With a third region, a symmetric Nash equilibrium provides lower environmental gains than is optimal to the extent that* $m_3 > 0$ *and* $\mu_3 > 0$, *even if* $v_i = v_G$, *unless* ω *is sufficiently large.*

Although strategic countries may care about the global costs of foreign emissions, the incentive to maintain higher export prices remains (through higher downstream subsidies and lower upstream subsidies than the planner would prefer), resulting in global underprovision of the green good. This underprovision is further exacerbated to the extent that global gains are undervalued locally. The exception is if the preference for domestic production is sufficiently strong that it drives upstream subsidies high enough to induce more global reductions. In this sense, the political economy distortion can be a friend to the environment.

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[16] This result is of course also the case with Cournot competition as the number of firms gets arbitrarily large (Fischer 2016).

[17] This result also has the same flavor of that with Cournot competition as the number of firms gets arbitrarily large. In that case, the upstream subsidy converges to zero and the downstream subsidy to v_i (Fischer 2016).

4.3 Contributions to Climate Finance

If upstream policies are prohibited, an alternative mechanism is to encourage the producer regions to contribute to financing deployment in the rest of the world (ROW). In a sense, contributions subsidize exports; however, they also subsidize the exports of the competitor, so another type of free-riding problem exists.

We derive the following results:

Proposition 5 *The social planner is indifferent between subsidizing deployment in ROW and subsidizing upstream manufacturing.*

The social planner merely seeks to ensure that the net subsidy in each region equals the marginal external benefit. If the planner cannot set that subsidy directly in the third region, it can do it either through the upstream subsidy or through climate finance.

Proposition 6 *In the Nash equilibrium, with no environmental externality and no policy restrictions, strategic countries would subsidize upstream but tax downstream if they could also tax ROW deployment.*

Taxing ROW deployment is essentially a way of raising revenues and returning rents from the third region. The domestic downstream tax is perfectly offset by the upstream subsidy. To the extent that governments overweight producer surplus, the upstream subsidy will be even higher. Obviously, such a policy (taxing foreign consumption) is not feasible, but it illustrates the strategic incentives.

The following set of propositions reveals that producing countries do not have an inherent interest in subsidizing foreign deployment, just as they will not provide positive upstream subsidies, unless the political distortion or external benefit is sufficiently large. Furthermore, when that is the case, they still prefer to subsidize at home rather than abroad, to keep more rents at home.

Proposition 7(a) *If upstream interventions are not allowed and there are no political or environmental distortions, strategic countries in the Nash equilibrium would tax downstream consumption at home to the extent that the ROW has market share, and they would also like to tax ROW consumption.*

Proposition 1(b) found that in the absence of other market failures, strategic countries would like to tax upstream production to the extent that the ROW has market share. Thus, when that upstream policy lever is removed, the countries would like to tax all downstream consumption, although in this case they are restricted to home and ROW. With that desire, and the additional incentive of shifting more rents from ROW through the tax directly, the strategically optimal domestic downstream subsidy is negative.

Proposition 7(b) *If upstream interventions are not allowed, symmetric strategic countries will subsidize both downstream consumption at home and in ROW only if the overweighting of production or their value of the external benefit is sufficiently large.*

Both concern about domestic production and concern about the global environment lead the producing region to want to expand the global market for its upstream producers. However, these concerns must be sufficiently large to overcome the incentives from Proposition 1(a) to tax downstream deployment. The "Appendix" demonstrates this result for the case in which the marginal external benefits of deployment are equal across countries; from that point, increasing μ_3 alone would increase foreign contributions and decrease domestic deployment subsidies, in order to shift more deployment where it is more valuable.

Proposition 7(c) *Domestic downstream subsidies are strictly larger than foreign contributions if the marginal external benefits are equal.*

Strategic countries would prefer to subsidize at home more than abroad, for the same environmental effects. However, if the external benefits in ROW are sufficiently large, more support will be allocated to foreign contributions.

To summarize the theoretical results, we have found that for goods without environmental benefits, restrictions on upstream subsidies are either useful (if $\omega > 0$) or ineffectual (if $\gamma^{Nash} < 0$). For green goods, allowing upstream subsidies may be useful, *especially* if $\omega > 0$, since political distortions can encourage regions to subsidize upstream, offering benefits to ROW, which they would not do sufficiently otherwise. Climate finance, on the other hand, will only be a good substitute measure for upstream subsidies if $\omega > 0$ and producing countries do not undervalue the global external benefits.

5 A Numerical 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.

The downstream side of the numerical model is based on that of Fischer (2016). It represents the producer-consumer regions of Europe, the United States, and China, as well as and consumption in the rest of the world. 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 representative firms located and owned in the corresponding regions, and competition is perfect.[18] Electricity generation with conventional fossil-fueled technologies (coal, oil, and gas-fired generation) leads to emissions of CO_2, a global pollutant. Renewable energy technologies, such as solar panels and wind turbines, produce electricity without emissions. Hydropower and nuclear capacity are available but are assumed not to benefit from the subsidy policies (although they may benefit indirectly from CO_2 taxes if implemented).

The baseline supply mixes for all regions are drawn from the projections for 2020 in the 2013 International Energy Outlook (IEO) for the United States, OECD Europe,[19] China, and ROW (U.S. Energy Information Administration (EIA) 2013).[20] Nonhydro renewables (wind, biomass, solar, etc.) are aggregated, with wind being the dominant source. These renewables represent 18% of European electricity demand and 8% of US demand in the baseline. All technology demand functions are linear and based on simplified static versions of the calibrated electricity sector models in Fischer et al. (2013) for the United States and in Hübler et al. (2015) for the European Union.[21] The slopes for the different sources of

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[18] 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.

[19] Though the membership is somewhat different, the IEO projections for OECD Europe are similar in scale to those of the European Union in Hübler et al. (2015). This choice is made based on available data and for consistency with the global scale of generation in 2020.

[20] Although updated IEOs are available, they include recent, more ambitious climate policy pledges that are difficult to remove from the baseline to consider a reference scenario without additional policies.

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

electricity are taken from the first stages of these models, notionally representing annual electricity production in a near-term horizon of 2015–2020. With different supply curves and different generation mixes, incremental renewables displace fossil energy to different extents; for example, the marginal emissions rates from displacing nonrenewable sources are roughly twice as high in the United States as in the Europe.

For China and ROW, the slopes of the supply curves are calibrated to match the same supply elasticities as in the United States, in the absence of data to calibrate them directly, and China and ROW have levels of fossil fuel reliance more like US than European levels. We note that by 2020, the US and European electricity markets are projected to be similar in size to each other, while the Chinese power sector will be approaching twice as large, and ROW nearly three times as large.

The model incorporates the downstream subsidies in the nonhydro renewable energy demand functions, including η_{EU}, η_{US}, η_{CN}, and $\eta_{ROW} = f_{EU} + f_{US} + f_{CN}$.[22] The result is a series of linear downstream demands for renewable energy technology, as a function of the after-subsidy prices. All subsidies are represented in levelized terms, as \$/kWh of generation.

The upstream market follows that of the analytical section, which differs from Fischer (2016). Since wind is the dominant technology, the allocation of the upstream renewable technology supply is stylized on the global wind turbine manufacturing sector. Nine of the top ten producers are from the United States and China (one is from India), and they provide 70% of global production (Renewable Energy Policy Network for the 21st Century (REN21) 2013). Of these ten producers, Europe has roughly twice the market share of the United States and China. Thus, the model allocates half of baseline global renewable energy supply to the European Union and one quarter each to the United States and China. The baseline technology price (measured in \$/kWh generated) is assumed to equal the lowest of the electricity prices among the downstream markets (\$0.09/kWh), such that renewable energy is competitive in the baseline. The supply curves are assumed to begin at the origin and run through the baseline supply quantity at the baseline technology price.

5.1 Scenarios

The scenarios explore three main policy combinations:

1. upstream and downstream subsidies are both available;
2. upstream interventions are restricted and only downstream subsidies are available; and
3. downstream subsidies are combined with contributions to climate finance for deployment in ROW.

The optimal and Nash subsidies are solved for a range of values of the SCC. When it is not in a region's interest to make positive climate finance contributions, we constrain contributions to be nonnegative. Each case is valued assuming either no political distortion or assuming $\omega = \$0.05$/kWh, which is a similar scale to production subsidies for wind in the US and Europe.

6 Results

To focus on the role of upstream subsidies, let us first compare the optimal subsidies to the Nash subsidies without and with the overweighting of production. Then, the effects of

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[22] The model can allow carbon prices τ_i that vary across regions, but these scenarios are not explored in this paper.

restrictions on upstream subsidies and the effectiveness of contributions to ROW deployment as an alternative will be analyzed.

In the next cases, the results assume that regions value CO_2 at the global SCC. This assumption avoids the issue of undervaluation and keeps the focus on the distortion from overweighting.

Figure 1 depicts the optimal upstream subsidies (denoted *) and the Nash subsidies, both without any political distortion (no additional notation) and with the overweighting of production (denoted +), as a function of the SCC, when the three producer countries are free to choose both γ_i and η_i. Note that Europe (EU), the largest net exporter, picks the lowest subsidy, followed by the United States (US) and China. The optimal subsidies are uniformly higher than the Nash subsidies in the absence of overweighting (as predicted by the theory). With the degree of overweighting chosen, the Nash subsidies are higher than the optimal subsidies until the SCC gets large (\$120/ton CO_2). Thus, overweighting can be a friend to the environment, but it can in a sense be too friendly: at lower values of the SCC, the optimal subsidy is closer to zero than the Nash subsidies. Thus, we see that absent a global externality, the WTO has a strong case to place restrictions on upstream subsidies.

To what extent, then, are contributions a useful alternative to addressing an externality when upstream subsidies are restricted? First, consider the incentives to provide them. Figure 2 plots the Nash contributions when they are completely unconstrained.

We see that—with the exception of the Europe when it overweights production—the producer countries would like to tax foreign deployment unless the SCC is quite high (this behavior allows them to transfer rents from export markets, raising revenues and offering larger subsidies at home). With contributions restricted to be nonnegative in subsequent scenarios, we find that only Europe is willing to contribute at a SCC of \$80/ton CO_2, and no one is willing to contribute at a SCC of \$40 or less.

We can understand these results by exploring the net subsidies in the various equilibria. Figure 3 shows the total effective subsidies ($\eta_i + \bar{\gamma}$) for Europe and ROW in the standard, overweighting, and optimal cases, as a function of the SCC, when upstream subsidies can be freely chosen and no direct contributions are made to foreign deployment. At these SCC levels, optimal total subsidies for relatively clean Europe are smaller than the Nash combinations, especially with overweighting of production, while optimal total subsidies for

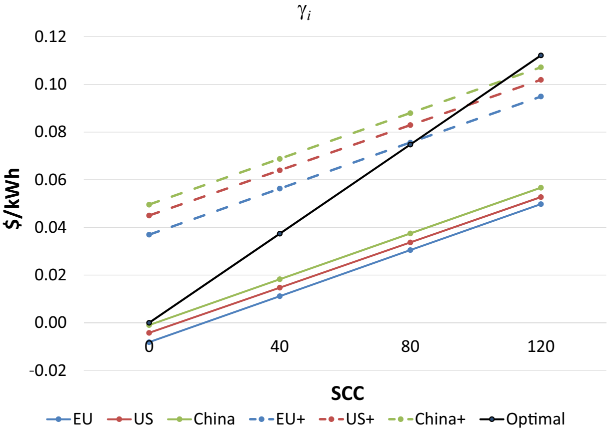

Fig. 1 Optimal and strategic upstream subsidies as function of SCC

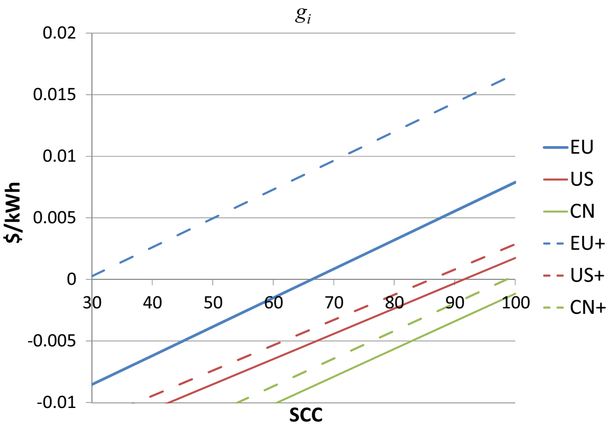

Fig. 2 Strategic contributions to ROW deployment

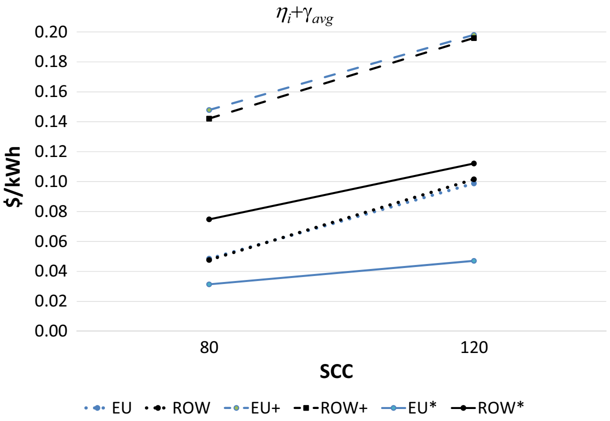

Fig. 3 Total effective subsidies when upstream subsidies are unconstrained

ROW are higher than in the standard Nash equilibrium but lower than with overweighting of production.

Figure 4 shows the total subsidies when only downstream subsidies and climate finance are allowed (η_i, in this case). With these restrictions, the Nash subsidies for the producer regions are below the optimal subsidies, even with overweighting, because of the loss of the upstream subsidy. With overweighting, however, contributions can lead to higher-than-optimal subsidies in ROW.

What are the welfare consequences of restrictions on upstream subsidies or the use of contributions? Figures 5 and 6 compare the welfare change from no policy of the Nash equilibria, as a share of the welfare improvement from optimal subsidies, for an SCC of $40 (roughly the central value for the global SCC used by the US government; Interagency Working Group on Social Cost of Carbon, United States Government 2015) and $80.

In Fig. 5, with an SCC of $40, we observe a large welfare loss from regions freely choosing subsidies when they overweight production. In that case, disallowing upstream subsidies eliminates the loss and leads to a small welfare gain. On the other hand, in the absence of the

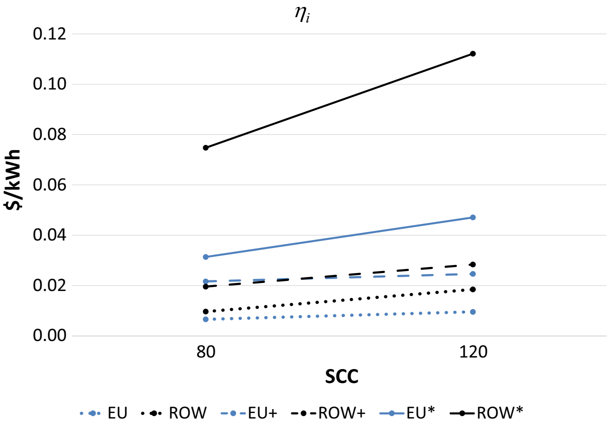

Fig. 4 Total effective subsidies with downstream subsidies and contributions to ROW deployment

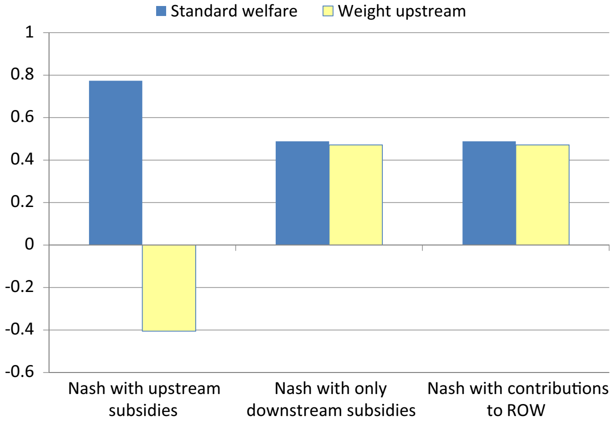

Fig. 5 Welfare change (as share of change with optimal subsidies) by policy tools and political distortions; SCC = $40

political distortion, the restriction on subsidy policy leads to a loss of nearly half the gains from the unrestricted Nash policy response. At this SCC, no producer region is willing to offer positive contributions toward foreign deployment, even with political distortions. With overweighting of production scale, producer regions constrained from offering upstream subsidies provide higher downstream subsidies, resulting in a slight welfare loss.

With an SCC of $80 (Fig. 6), restrictions are no longer beneficial with our political distortion. Recall from Fig. 1 that in this situation, upstream subsidies are too high with political distortions and too low without; however, in both cases, having strategic upstream subsidies is better than having none. With this valuation of the SCC, Europe provides positive climate finance, but only in the case of political distortion. Those contributions to foreign deployment achieve nearly the same global welfare as allowing upstream subsidies, which are excessive in the presence of the political distortion. Absent that distortion, however, welfare is significantly higher allowing for upstream subsidies. The results with an SCC of $120 are similar, with a larger fraction of the potential gains being captured by policies with either upstream subsidies or climate finance contributions.

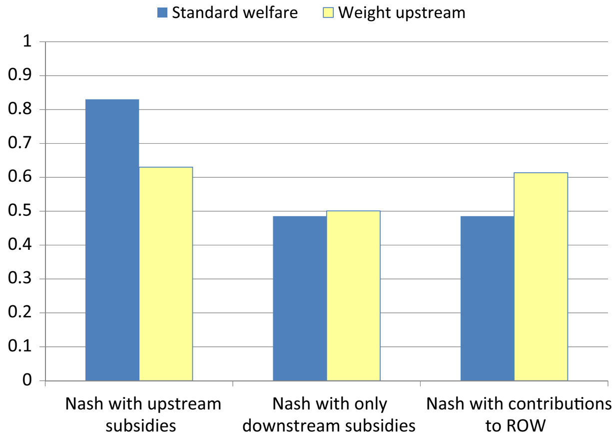

Fig. 6 Welfare change (as share of change with optimal subsidies) by policy tools and political distortions; SCC = \$80

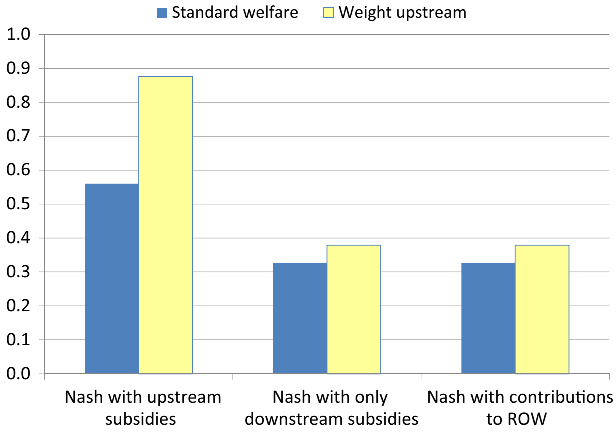

Fig. 7 Welfare change (as share of change with optimal subsidies) by policy tools and political distortions; SCC = \$80, but $v_i = \$40$

All of the preceding scenarios assume that governments value global emissions at the global SCC; suppose they undervalue the global benefits of the green technologies? Figure 7 considers this case when the SCC is \$80 but countries value the benefits at \$40. With undervaluation, Nash strategies using upstream subsidies achieve most of the potential welfare gains from subsidies, whether or not there is a political distortion. Restricting the use of upstream subsidies forgoes a majority of those welfare gains, and climate finance is unable to recapture any, since at a carbon value of \$40, no one is willing to contribute support to deployment in ROW.

7 Conclusion

Green industrial policy raises important questions about the interaction between environmental and free-trade goals as applied to goods with global external benefits. In particular, this analysis reveals rationales both for allowing and for restricting the use of upstream subsidies. In the absence of uninternalized environmental benefits, restricting upstream subsidies either does no harm (since strategic countries may not want to use them anyway) or provides global welfare benefits by impeding domestic political distortions from interfering with trade. On the other hand, such restrictions can do more harm than good if the environmental benefits outweigh the political distortion. Indeed, if governments undervalue the global external benefit, the political distortion can be a friend to the environment, if countries are free to use all subsidy tools.

Given restrictions on upstream subsidies, an alternative policy in which producer countries finance deployment in third-party markets can recoup some of the lost welfare. However, this option is most effective when those producer countries both perceive a high value in the global environmental benefit and have a high degree of political distortions to their trade policies.

These issues are particularly relevant for climate policies and markets for low-carbon technologies. The Paris Agreement codifies an international system of differentiated and voluntary climate policy formation, and the slow progress of emissions pricing means that most emissions are not internalized by energy markets. In the face of carbon leakage, countries that take into account the SCC may continue to eschew carbon pricing in favor of technology policies, which benefit from much greater public support. Toward that end, the most valuable policies are those that will lower the cost of low-carbon technologies for the entire world, but particularly for developing countries whose energy demand growth far outstrips that anticipated among developed nations. Here, upstream subsidies clearly meet that objective, as can contributions to climate finance as well. The disadvantage of climate finance is that such contributions benefit domestic industry only in part, and in practice, these shares are further diluted by the large portfolio of activities foreseen by the Green Climate Fund, of which clean energy deployment is just a part. Strategic countries thus prefer upstream subsidies, and the key question is whether some leeway for green industrial policy should be provided in trade rules, in an attempt to harness these selfish incentives for the global good.

Underlying this analysis is the standard assumption that global supply curves for the green good are upward sloping and that downstream demand for the good is downward sloping. As such, the qualitative results should be robust to other applications. However, some aspects relevant to emerging clean technologies have not been included. In particular, characteristics that might render the supply curve downward sloping—such as scale economies, learning-by-doing, and international innovation spillovers—could change the results, as then downstream subsidies can have the effect of lowering global prices as well. Fischer (2016) considers both imperfect competition and global scale economies; in this case, downstream deployment policies can bring down global technology policies. However, as both of these market failures originate in the upstream market, upstream policies are still more effective interventions. Furthermore, strategic regions tend to underprovide such interventions. The protection for sale framework still provides the most robust explanation for caution in giving leeway for industrial policy; on the other hand, taking into account the global benefits from addressing these other market failures—of which the external environmental benefits are the largest—we may well want to think of cautious ways of making room for green industrial policy.

Appendix: Analytical Results

To avoid tedious algebraic manipulations, the optimal and Nash solutions are solved in Mathematica using the linear functional forms, and the results are reported here. To provide core intuition without unnecessary complications, the reported results generally assume symmetric producer countries. The notebook file with proofs is available from the author upon request.

No Downstream Externality

Proof of Proposition 1(b) We can simplify the expressions for the welfare derivations with our functional forms and solve for the Nash equilibrium. The effect of the third-party market is best seen with the assumption of symmetry across the producing countries: that is, $m_1 = m_2 = (1 - m_3)/2$.

When $\omega > 0$, the symmetric Nash solution is

$$\begin{aligned} \eta_i^{\text{Nash}}(0, \omega) &= m_3 \frac{hb(a - c + w)}{Z} > 0 \\ \gamma_i^{\text{Nash}}(0, \omega) &= -\eta_i^{\text{Nash}} + \omega \end{aligned}$$

where $Z = (b + h)^2 + m_3 h(2(b + h) - hm_3)$

Furthermore, $\gamma^{\text{Nash}} > 0$ if

$$\omega > m_3 \frac{hb(a - c)}{Z}.$$

Thus, the larger the third-party market share, the higher is this threshold for wanting a positive upstream subsidy.

When $v_i = 0$, and $\omega = 0$, the symmetric Nash solution yields

$$\begin{aligned} \eta_i^{\text{Nash}}(0, 0) &= m_3 \frac{hb(a - c)}{Z} > 0 \\ \gamma_i^{\text{Nash}}(0, 0) &= -\eta_i^{\text{Nash}} < 0 \end{aligned}$$

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

Discussion of Asymmetric Firms

For this case of $m_3 = 0$ and $\omega = 0$, with no third-party region, the asymmetric Nash solution yields

$$\begin{aligned} \gamma_1^{\text{Nash}} &= -\eta_1^{\text{Nash}} = \frac{(a - c)bh\Delta_m}{2(b + h)(b + h + h\Delta_m)} = \eta_2^{\text{Nash}} = -\gamma_2^{\text{Nash}} \\ Y^{\text{Nash}} - Y^* &= -\frac{(a - c)bh\Delta_m^2}{2(b + h)(b + h + h\Delta_m)^2} < 0 \end{aligned}$$

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

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 Although the value of an individual subsidy is a complicated expression, without relying on the symmetry assumptions, with our functional forms, $\eta_i^{\text{Nash}} + \gamma_i^{\text{Nash}} = u_i v_i + \omega$.

For example of the individual subsidies, when $v_i = v, i = \{1, 2\}$,and $\mu_i = \mu$, $\forall i$, the symmetric Nash solution yields

$$\eta_i^{\text{Nash}}(v) = \eta_i^{\text{Nash}}(0) + \frac{vub(b + h(1 + m_3))}{Z} > 0$$
$$\gamma_i^{\text{Nash}}(v) = \gamma_i^{\text{Nash}}(0) + vu - \frac{vub(b + h(1 + m_3))}{Z} < 0$$

Proof of Proposition 4 This result essentially requires $\mu_3 > 0$ and $m_3 > 0$. We show the result for the case of symmetric producer countries that value the externality at the global value (that is, $v_2 = v_1 = v_G$ and $m_1 = m_2 = (1 - m_3)/2$), and when the marginal external benefit is the same across countries ($\mu_i = \mu\, \forall i$), so the location of deployment does not matter. The difference in global deployment is a function of the difference between the Nash and globally optimal upstream subsidies, as well as the political distortion:

$$Y^{\text{Nash}} - Y^* = \frac{m_3(\gamma^{Nash} - \gamma^*)}{b + h} + \frac{(1 - m_3)}{b + h}\omega$$

If $\omega = 0$, then $\gamma^{Nash} < \gamma^*$ and $Y^{Nash} < Y^*$. If the political distortion is large enough, deployment may be even higher with the Nash equilibrium among strategic countries. However, if $\mu_3 > \mu$, there is the additional problem that strategic countries deploy too little abroad, reducing the external benefits achieved under the Nash equilibrium.

Contributions to Climate Finance

Proof of Proposition 5 If the planner cannot use upstream subsidies, the optimal contributions, split equally, are

$$f_i^* = \frac{\mu_3 v_G}{2}$$

and the optimal downstream subsidies in producing countries remain the same.

Proof of Proposition 6 In the unconstrained (subscript u) symmetric Nash equilibrium with $v = 0$,

$$\eta_u^{Nash} = -m_3 \frac{bh(a - c + \omega)}{Z_2} < 0$$
$$\gamma_u^{Nash} = \omega - \eta_u^{Nash} > 0$$
$$f_u^{Nash} = -\frac{b(b + h)(a - c + \omega)}{Z_2} < 0$$

where $Z_2 = (3(b + h) - hm_3)\,(b + h - hm_3) > 0$.

Proof of Proposition 7 In the restricted (subscript r) symmetric Nash equilibrium with $\mu_i = \mu,\ \forall i$,

$$\eta_r^{Nash} = \frac{-m_3 bh(a-c) + (3(b+h) - 2hm_3)(\omega + 2\mu)}{Z_2}$$

$$f_r^{Nash} = \frac{-b(2b+h)(a-c) + b(b+2h-hm_3)(\omega+2\mu)}{Z_2}$$

$$= \eta_r^{Nash} - \frac{b(a-c+\omega+2\mu)}{3(b+h)-hm_3}$$

If $\mu_3 \neq \mu, \quad f_r^{Nash} > \eta_r^{Nash}$ if

$$\mu_3 > \mu + \frac{b(a-c+\omega+2v\mu)}{v(b+h+hm_3)}$$

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