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Market power and global public goods*

Sebastian G. Kessing†

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Abstract

A global monopoly supplier country of green goods which are essential for the provision of global environmental public goods optimally subsidizes the export of such goods in an interior contribution equilibrium. This is not counterbalanced by an incentive to improve the terms-of-trade, since any price-induced transfers are off-set by contribution adjustments. By the same logic, a subsidy is costless for the monopoly supplier. The existence of a global monopoly supplier increases global public good supply relative to a competitive setting. The incentive to subsidize persists with impure public goods as long as the private co-benefits of green goods are sufficiently easy to substitute by other goods. Import-dependent countries may also benefit from a monopoly supplier. While they are strategically exploited to increase their contributions to the global public good, they do so at lower costs, and they benefit from increased contributions by the other importer countries.

JEL classification: H41, D60, Q54

Keywords: global public goods, market power, climate policy, global warming, terms-of-trade, China, Inflation Reduction Act, Net-Zero Industry Act

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1 Introduction

The last two decades have seen an increased concentration of the production of goods which are pivotal for a transition to a carbon-free economy in a single country, China. According to the International Energy Agency, China's share in the world's manufacturing capacity in polysilicons amounted to 79.4%, in solar cells to 85.1%, in solar modules to 74.7%, and to 96.8% in wafers in 2021 (IEA, 2022). Similarly, China's production capacity of lithium-ion batteries came to 75% of the global capacity in 2022, and it was responsible for 90% of anode and electrolyte production (BNEF, 2022). Moreover, it possessed 60% of global wind turbine manufacturing capacity in 2023 (GWEC, 2023).[1] Contrary to this development, China has been substantially increasing its greenhouse gas (GHG) emissions over recent years, whereas emissions have been substantially reduced in the advanced economies.[2] Other countries are increasingly worried about their green product import dependency and fear that China could exploit its market power to their detriment, and that this could also slow down the global fight against climate change. In the shadow of such potential threats, the United States have, with the Inflation Reduction Act, introduced large scale subsidies to reshore the production of such emission-reducing products. Similarly, the European Union is discussing its rules on state aid to enable similar subsidies. The recently revealed draft of the European Union's Net-Zero Industry Act aims to increase the share of domestically produced green tech to 40% of the own climate and energy targets.

[1]Chinese dominance in these green tech sectors has been supported by strong industrial policies. DiPippo et al. (2022) document that government industrial policy spending as a fraction of GDP in China exceeded that of other developed economies at least by a factor of three to four in 2019. Nahm (2021) contains a detailed description of the emergence of Chinese dominance in the solar and wind industry, including the extensive and multi-faceted government support. Bickenbach et al. (2024) document the comprehensive industrial policy measures in the Chinese battery electric vehicle and wind industry, respectively, arguing that these considerably exceed subsidies elsewhere.

[2]According to (IEA, 2023, p.20), " ... per capita emissions in the European Union have fallen strongly ... and (are) around 40% below those of China. China's per capita emissions exceeded those of the advanced economies as a group in 2020 and are now 15% higher". China accounted for two-thirds of the global increase in new operating coal power capacity in 2023, and it was responsible for 95% of world-wide new coal power construction. New coal-fired construction starting in China in 2023 is nearly quadruple relative to 2019, while no new coal-fired power plant construction has been started in any OECD country since 2019, see GEM (2023). CREA and GEM (2025) show that China's construction of new coal-power plants even reached a 10-year high in 2024.

Against the background of these empirical observations and the ongoing policy debates, this study investigates the strategic incentives of a monopoly supplier country of green goods, such as photovoltaics, batteries, or wind turbines, in a setting where countries non-cooperatively contribute to a global public good. These incentives are important since the monopolist's pricing policy generates inter-country transfers and changes the importers' contribution price which impact contributions and the equilibrium outcome. Moreover, the presence of a monopoly supplier implies that only its technology is relevant for the world wide technological constraint. As my analysis shows, the public good nature of green goods alters the strategic incentives of a monopoly supplier, provided that this country is sufficiently rich, and cares sufficiently about the global public good. In an interior contribution equilibrium, this country unambiguously subsidizes green exports in order to motivate importers to increase their contributions. Hence, with the mechanism identified in my study, a positive export tax is never optimal.

My baseline framework builds on the standard private provision model, see Bergstrom et al. (1986) for the seminal set-up and Buchholz and Sandler (2021) for its application to global public goods, while the trade perspective is limited to the necessary minimum.[3] To encompass impure public goods, the analysis is then recast in an environmental model of transboundary pollution. The optimality of the subsidy also emerges in this framework, as long as the degree of substitutability of the private co-benefits of green goods is sufficiently large.

In a seminal contribution, Markusen (1975) analyzed the role of transboundary externalities for optimal trade policy. He showed, in a setting without strategic interaction, how the optimal policy of a country with market power should take into account both, the corrective tax component to address the transboundary externality and the optimal tariff component to improve its terms of trade. According to his analysis, the optimal policy of a global monopoly supplier of green goods, which reduce global emissions, should balance the internalization considerations, which exert a downward pressure, with the optimum tariff incentives, which put upward pressure on the export tax. The present analysis shows for pure and impure global public goods that, in an interior equilibrium, the optimum tariff incentive disappears since any price-induced transfers are off-set by contribution adjustments. While Markusen (1975) encompasses the possibility that a subsidy is optimal, the present

[3] Compare Footnote 8 for a trade interpretation of the framework.

analysis implies that, in an interior contribution equilibrium, i) it should be larger in magnitude, since the countervailing optimum tariff effect is no longer operational, and, ii) a positive export tax can never be optimal. Moreover, global public good supply increases relative to a competitive setting.

The result can be traced back to the redistribution invariance property in private provision settings first pointed out by Warr (1983). While the importance of his result, and the substantial literature that further investigated this property and its limits, has been recognized in the global public goods literature, see Buchholz and Sandler (2021), it has received less attention in international trade, with Copeland and Taylor (1995), who consider inter-country transfers in a pure public goods model of global pollution and trade, being a notable exception.[4] The present study thus adds to the literature on transfers of resources or technology between countries in global public goods contexts, see Buchholz and Konrad (1994, 1995), Copeland and Taylor (1995), Ihori (1996), Buchholz et al. (2015), and Elsayyad and Morath (2016), which also has important implications for climate treaties, see Barrett (2006) and Harstad et al. (2019), among others. In the present study the monopoly supplier country strategically sets its price, and this endogenously generates a transfer to, and lower contribution costs for, the importers, whereas existing studies have focussed on explicit transfers of resources or technology between countries with existing differences in productivity or income. The present study makes the novel point that the implicit transfers generated by market power in international markets can change pricing incentives due to the strategic interaction in the provision of global public goods. If redistribution neutrality is operational, standard optimum tariff arguments may no longer apply.[5]

The study is organized as follows. Section 2 introduces the main argument in the baseline global public goods model, see Buchholz and Sandler (2021). Section 3 discusses extensions to the baseline model, whereas Section 4 shows that the results carry over to a standard environmental model of global pollution with impure public goods. Section 5 discusses the results and concludes.

[4]See Copeland and Taylor (2022) for a recent survey of the literature on trade and the environment, including the role of market power.

[5]The analysis is also relevant for other public goods where one contributing party has monopoly power over an essential input. Consider, for example, a specialized weapons system within a perfect military alliance, which is only available from one member. Since defense is a public good for all members, the incentive to exploit the monopoly vanishes due to the mechanism analyzed below.

2 The framework

There are $n+1$ countries $i = 0, 1, ..., n$. Countries have preferences $u^i(x^i, G)$, where x^i is private consumption and G are total emission reductions which constitute a global public good. Both goods are assumed to be strictly normal. The total emission reductions are the sum of the emission reductions by individual countries g^i, i.e., $G = \sum_{i=0}^{n} g^i$. Countries are endowed with an exogenous income m^i. Throughout the analysis, superscripts refer to the country, with superscripts 0 and j corresponding to the monopoly supplier and a generic importer country, respectively. Subscripts denote partial derivatives with respect to the subscript variable.

My analysis departs from the usual assumption that countries possess a given local, potentially different, technology to reduce emissions. Instead, I make two key assumptions that determine the structure and the results in my model. First, emission reductions require the purchase of a particular good. The purchase of one unit of this good generates one unit of g^i. The second key assumption is the determination of the price at which this emission-reducing good is available to individual countries in the world market. Country 0, called the monopoly supplier, is assumed to be the only producer of this good, possibly due to a leadership in technology or lower costs. The good is produced in a competitive industry, and the marginal cost of producing the good is constant and equal to c. All other countries $i = 1, ...n$ rely on imports from the monopoly supplier country to engage in emission reductions and are price-takers.[6] Because of this dependency, the monopoly supplier can effectively determine the price of emission reductions in all other countries p. This may be implemented by setting an appropriate tax or subsidy on the exports of the emission-reducing good. The price p is uniform across importer countries reflecting the fact that price discrimination will be difficult to establish given potential resale.[7] The monopoly supplier first chooses the world market price p for emission-reducing goods, and then all countries simultaneously choose their contributions to the global

[6] While there may be a domestic alternative technology in each importer country, i.e., more expensive or less advanced solar panels etc., the domestic alternative is assumed to be irrelevant due to its substantial cost disadvantage.

[7] The government of country 0 may also manipulate its domestic price. However, the relevant marginal contribution cost for the monopoly supplier is always the marginal cost c, so that the monopoly supplier's optimization problem, the equilibrium outcome and the monopoly supplier's optimal policy are independent of the domestic price. By the same logic, a general production subsidy for the green good in the supplier country amounts to a subsidy for the importers.

public good. The sequential structure is a natural one and allows straightforward comparative statics of the equilibrium allocation with respect to the price. Moreover, the equilibrium in the sequential game also constitutes an equilibrium in the simultaneous move game in which the monopoly supplier decides both, the price and its contribution, simultaneously with the contribution decision of the other countries. Finally, the private good x is internationally homogenous with its price normalized to one, and the international trade balance automatically adjusts.[8]

Taking into account their respective constraints for given prices, all countries $i = 0, ...n$ solve the standard private provision problems,

$$\max_{x^i, G} u^i\left(x^i, G\right)$$
$$\text{s.t. } x^i + pG \leq m^i + pG^{-i}, \text{for } i = 1, 2, ..., n, \tag{1}$$
$$x^i + cG \leq m^i + \Pi^0 + cG^{-i}, \text{for } i = 0, \tag{2}$$
$$G - G^{-i} \geq 0, \text{for all } i,$$
$$x^i \geq 0, \text{for all } i$$

where $G^{-i} = \sum_{k=0,k\neq i}^{n} g^k$ is the total emission reduction by all other countries, and $\Pi^0 \equiv (p - c)\, G^{-0}$ is the additional rent of the monopoly supplier country. The budget constraint of the monopoly supplier (2) differs from those of the importers (1), since this country additionally receives revenues from export taxes, and the relevant contribution prices are c and p, respectively. The solutions to these problems implicitly yield the best responses and characterize the Nash equilibrium.

My further analysis relies on an aggregative game approach, see Cornes and Hartley (2007) and Buchholz and Sandler (2021). This allows straightforward investigation of the equilibrium repercussions of changes in the world market price of emission-reducing goods. For an importer the price of one unit of g is p. Thus, $x^j = m^j - pg^j$, so that $g^j = \frac{1}{p}\left(m^j - x^j\right) = a^j\left(m^j - x^j\right)$, with $a^j \equiv 1/p$. Denoting by $a^0 \equiv 1/c$ the monopoly supplier's productivity, and assuming symmetric importers in terms of preferences and incomes, the aggregate budget constraint implies

$$G = ng^j + g^0 = na^j\left(m^j - x^j\right) + a^0\left(m^0 + \Pi^0 - x^0\right). \tag{3}$$

[8]One may think of this as a rudimentary Ricardian trade model with two goods and homothetic preferences, where all importer countries specialize on producing only the general consumption good, whereas the monopoly supplier country produces both goods. In a free trade equilibrium, world market prices equal the autarky prices in the monopoly supplier country ($p = c$), see Feenstra (2015, p.2-3), who, in the context of the general Ricardian set-up, also sketches this incomplete specialization case.

Since $a^0\Pi^0 = a^0(p-c)ng^j = na^0(m^j - x^j) - na^j(m^j - x^j)$, this simplifies to

$$G = na^0\left(m^j - x^j\right) + a^0\left(m^0 - x^0\right). \qquad (4)$$

Equation (4) may also be written as $\sum_{i=0}^{n} m^i = cG + \sum_{i=0}^{n} x^i$, which says that the world's endowment equals world private good consumption plus world public good consumption, where the latter is valued at the marginal cost of converting the private good into the public good using the monopoly supplier's technology. The price p charged by the monopoly supplier drops out as it is irrelevant for this underlying constraint. It enters (4) only indirectly, insofar as it affects countries' consumption choices and thus the global allocation. This highlights the transfer nature of a monopoly price deviating from marginal costs, and this property substantially simplifies the analysis of the global private provision equilibrium and its comparative static properties. The real resources that have to be spent for the public good contributions made by the importers are not affected by the price p that is demanded by the monopolist. Note, that this is different from situations where countries' own investments, or technology transfers between countries, affect the marginal rate of transformation within individual contributing countries which make use of their own technology. In the monopoly situation, the global budget constraint only depends on the monopoly supplier's technology, and this constraint is independent of the price set by the monopolist or the country composition of contributions.

For positive equilibrium contributions, on each country's income expansion path in x^iG space, which is denoted $e^i(G, a^i)$, the marginal rate of substitution between the private and the public good is equal to the price ratio, i.e., $\frac{u^i_{x^i}}{u^i_G} = a^i$, where $u^i_{x^i}$ and u^i_G are the partial derivatives of utility with respect to private and public good consumption, respectively. Thus, $x^i = e^i(G, a^i)$. Due to non-inferiority of both goods, the expansion paths are strictly increasing in G, and I assume that $e^i(0, a^i) = 0$. In a Nash equilibrium $(x^0, ..., x^n, G)$, in which all countries contribute, all countries i will be on their respective expansion paths $e^i(G, a^i)$. The aggregate constraint (4) can then be turned into the interior equilibrium condition

$$cG = n\left[m^j - e^j\left(G, a^j\right)\right] + \left[m^0 - e^0\left(G, a^0\right)\right]. \qquad (5)$$

Differentiating yields $cG_{a^j} = -n\left[e^j_G G_{a^j} + e^j_{a^j}\right] - e^0_G G_{a^j}$. This can be solved as

$$G_{a^j} = \frac{-ne^j_{a^j}}{c + ne^j_G + e^0_G} > 0. \qquad (6)$$

The sign follows from the positive slope of the expansion paths, so that $e^j_G > 0$ and $e^0_G > 0$, and from the fact that normality implies $e^j_{a^j} < 0$, i.e., a decrease in the price of the emission-reducing good, which increases a^j, reduces the consumption of the private good. I state this as my first proposition.

Proposition 1 *In an interior Nash equilibrium a decrease in the price charged by the monopoly supplier leads to an increase in global public good provision.*

A reduction in the monopoly supplier's price has two effects. First, it generates an income transfer from the monopoly supplier to the importer countries. For the monopoly supplier this transfer is explicit, whereas for the importers it is implicit and corresponds to the income effect of the price change. Warr (1983) demonstrated that, in an interior equilibrium, a transfer does not change total public good provision, and does not affect the utility of the parties involved. Second, the price reduction makes contributions to the public good less expensive for all importer countries. The substitution effect of the price reduction further raises the importers' contributions so that the total quantity of the public good is increased.

Consider now what happens to the utility of the monopoly supplier country as it manipulates the price of the emission-reducing good p. The equilibrium utility achieved by the monopoly supplier is $u^{0^*} = u^0\left(e^0\left(G\right), G\right)$, so that

$$u^{0^*}_{a^j} = u^0_{x^0} e^0_G G_{a^j} + u^0_G G_{a^j} = G_{a^j}\left[u^0_{x^0} e^0_G + u^0_G\right] > 0. \tag{7}$$

This is my next result.

Proposition 2 *The utility of the monopoly supplier in an interior equilibrium is decreasing in the price charged by the monopoly supplier. The optimal policy of the monopoly supplier is to subsidize its exports of emission-reducing goods.*

The intuition is again straightforward and relates to the two effects of changing the price of the emission-reducing good. While a reduction in the price leads to an income transfer from the monopoly supplier to the importers, this does not hurt the monopoly supplier country. The income transfer will be offset one-to-one by a reduction in its contribution, which will be fully compensated by increased contributions by the importers receiving the transfer. Thus, this income transfer is fully neutral. Intuitively, the transfer reduces the monopoly supplier's resources to contribute to the global public good and expands those of the importers, which decreases the contributions by the former and increases those by the latter. Moreover, the substitution effect of the price reduction additionally boosts the equilibrium quantity of the public good, which benefits the supplier country. The increase is driven by higher contributions by the importers in response to the subsidized price.

Proposition 2 implies that the monopoly supplier has an incentive to subsidize the emission-reducing good to reduce prices below marginal costs. In contrast to markets for private goods, where a monopoly supplier country optimally taxes exports to improve its terms of trade, here, the monopoly supplier has an incentive to reduce prices. This country will deliberately worsen its terms of trade. The result goes beyond Markusen (1975) who first argued that countries with market power can use a tariff to address cross-border externalities. According to his analysis, countries should combine optimum tariff considerations and cross-border internalization aspects. Proposition 2 shows that, with strategic interaction, the optimum tariff concerns can become irrelevant, and that export subsidies are unambiguously optimal in an interior equilibrium with positive cross-border externalities.[9]

The effects of the export subsidy on global public goods provision and on the welfare of the monopoly supplier are reminiscent of the literature on technology transfers in private provision situations, i.e., the fact that it may be advantageous to improve other countries' technological capabilities. They also relate to the benefits of transferring resources to countries with superior emission-reducing technology, see Buchholz and Konrad (1995) and Ihori (1996), among others. Here, however, the transfer and the lower contribution costs arise endogenously from market power and the corresponding strategic self-interested policy of the monopoly supplier.

The result also relates to the findings of Copeland and Taylor (1995) for an explicit transfer between two countries in their general equilibrium trade model of transboundary pollution, endogenous national environmental regulation (as a function of income), and with global environmental quality being a pure public good. These authors show that an inter-country transfer does not affect either country's welfare or the global environmental quality. However, the transfer moves

[9]If the monopoly supplier does not care about the global public good, it will set the standard optimum tariff (an export tax) equal to the inverse of the rest of the world's demand elasticity. If it cares about the global public good, but not sufficiently to contribute itself, it would additionally take the possibility to correct other countries' behavior into account according to the Markusen (1975) analysis. Only if it is a contributor in an equilibrium with $p = c$, the strategic incentives driving Propositions 1 and 2 are operational.

the location of pollution emissions away from the recipient to the donor. The location change of pollution parallels the consequences of the transfers arising here from strategic pricing of the monopoly supplier, with the additional effect of even further contribution increases due to the price reduction.

As a consequence of Propositions 1 and 2, in any interior equilibrium, the monopoly supplier will at least subsidize its exports, and reduce the own contributions concomitantly, up to the point where it seizes to contribute. While it is likely that the corresponding export price defines the optimal policy, it may be optimal to reduce the import prices for the importing countries even further. In a corner equilibrium, in which all importers contribute, but the monopoly supplier does not[10], the effect of increasing a^j, i.e., a further reduction in import prices p, is

$$u^{0^*}_{a^j} = u^0_{x^0}\left[-\frac{G}{a^{j^2}} + (p-c)\,G_{a^j}\right] + u^0_G G_{a^j}. \tag{8}$$

It is directly evident from the comparison of (8) to (7) that, once the monopoly supplier country seizes to contribute to the global public good itself, its incentives to reduce the price are strongly diminished. While there is still a positive effect from the increase in public good provision, given by the last term in (8), there are two additional negative effects. First, the subsidy is no longer costless, and affects all infra-marginal units, i.e., the total level of G, given the country's monopoly position. Moreover, also the expansion of total public goods provision is costly to the extent that $p < c$, which is a consequence of the export subsidy. In a corner solution, the monopoly supplier country cannot compensate the transfer implicit in an increased subsidy by further reductions of its own contributions. Thus, while increasing the subsidy continues to generate higher contributions by the importers, this subsidy suddenly becomes rather costly. I summarize this as my next result.

Proposition 3 *The optimal policy of the monopoly supplier country subsidizes the emission-reducing good at least up to the point where it seizes to contribute to the public good itself.*

Finally, it directly follows from Proposition 1 and Proposition 3 that the total level of public good provision is higher with a monopoly supplier relative to a com-

[10] In such an equilibrium the monopoly supplier's utility is $u^{0^*} = u^0\left(m^0 + (p-c)\,G, G\right)$, the total quantity of the public good is $G = na^j\left(m^j - e^j\left(a^j, G\right)\right)$, the comparative static effect, analogous to (6), is $G_{a^j} = \frac{n\left[\left(m^j - x^j\right) - a^j e_{a^j}\right]}{1 + na_j e^j_G} > 0$, and $cu^0_{x^0} > u^0_G$.

petitive setting in which all counries produce the essential green good themselves at cost c and contribute to the public good at this price.

Consider now the utility of an importer country in an interior equilibrium. It is well-known that an exogenous cost-reduction for an individual country may benefit or hurt it, given that such a country benefits from the lower costs, but is strategically exploited, see Cornes and Hartley (2007). Here, at least for $n > 1$, the situation is different, given that all importer countries face the lower price. This strengthens the possibility that importer countries benefit from the higher contributions by the other importer countries.[11] Consider the utility of an importer country $u^{j^*} = u^j \left(e^j \left(G, a^j \right), G \right)$, and its reaction to a price change

$$u^{j^*}_{a^j} = u^j_{x^j} \left[e^j_{a^j} + e^j_G G_{a^j} \right] + u^j_G G_{a^j}. \tag{9}$$

The sign of this expression is ambiguous. The last term is the direct effect of the public good increase. By Proposition 1, this term is positive. The first term, however, consists of two elements, which work in opposite directions. The first element is the response to relative prices. An increase in a^j is a decrease in p which triggers higher contributions g^j and lower private consumption x^j. This element is negative and corresponds to the strategic exploitation effect. The second element is the private consumption response due to the income effect of the public good increase. This is positive. Thus, the combined first term is undetermined, so that the total effect is undecided. However, using (6), and exploiting the fact that in an interior equilibrium $a^i = u^i_x / u^i_G$ for all i, allows to write

$$u^{j^*}_{a^j} = \frac{u^j_{x^j} e^j_{a^j} \left[c + e^0_G - \frac{n}{a^j} \right]}{c + n e^j_G + e^0_G}. \tag{10}$$

Evaluating this at $p = c$, yields the next result.

Proposition 4 *An importer country will benefit from a marginal export subsidy if* $n > 1 + \frac{e^0_G}{c}$.

This shows that, for given $n > 1$, importer countries will benefit from a marginal export subsidy if private consumption of the monopoly supplier does not react too

[11]Intuitively, if the contributions by the $n-1$ other importers under the subsidized price exceed the contributions of the n other countries (including country 0) for $p = c$, the new budget set with the subsidized prices strictly dominates the original budget set, since G^{-j} is larger and the price of G is lower. This is sufficient for the importer countries to be better-off.

strongly to the public good increase triggered by the marginal export subsidy. In this case, the negative exploitation effect is insufficient to outweigh the benefits of higher public good provision. Each importer enjoys a direct positive effect and a positive income effect from the increased contributions by the other importers in response to the lower price. The importance of the slope of the income expansion path of the monopoly supplier is also intuitive, given its role for the reaction of total public goods supply to the export subsidy. The larger its magnitude, the smaller the increase. This increase in public goods generates the possibility that all countries, including the importers, are made better-off.

3 Extensions and robustness

Before discussing impure public goods in Section 4, I consider the importance of the simplifying assumptions made in Section 2 and discuss potential extensions.

Asymmetric importer countries. The results of propositions (1)-(3) do not depend qualitatively on the symmetry assumption with respect to preferences and income. With asymmetric countries, the condition for an interior equilibrium corresponding to (5) reads

$$cG = \left[m^0 - e^0\left(G, a^0\right)\right] + \sum_{i=1}^{n}\left[m^i - e^i\left(G, a^i\right)\right], \tag{11}$$

and the effect of a price reduction corresponding to (6) is

$$G_{a^j} = \frac{-\sum_{i=1}^{n} e^i_{a_j}}{c + e^0_G + \sum_{i=1}^{n} e^i_G} > 0. \tag{12}$$

The importers' responses to lower prices differ quantitatively, but not qualitatively, so that public good provision still increases, and, as a consequence, subsidizing exports remains optimal for the monopoly supplier.

Non-contributing countries. The results are robust to the inclusion of non-contributing countries. Redistribution neutrality will typically break down if the redistribution involves non-contributing countries, see Bergstrom et al. (1986). However, export subsidies on emission-reducing goods imply that transfers only accrue to contributing countries. Non-contributors do not benefit from lower prices, so that redistribution invariance is preserved. If lower prices additionally turn some non-contributors into contributors, this further increases public good provision.[12]

Local conditions. My analysis assumed that one unit of the emission-reducing good translated one-to-one into contributions to the global public good for all countries alike. However, the contribution costs may additionally depend on local conditions, such as the local climate or the level of economic development. Assume that for each country i, one unit of the emission-reducing good generates b^i, $b^i > 0$, units of the public good, so that for an importer the effective price of one unit of g is p/b^j. Thus, $x^j = m^j - pg^j/b^j$, and $g^j = \frac{b^j}{p}(m^j - x^j) = a^j b^j (m_j - x_j)$. The income expansion paths may now be defined as $e^i = e^i(G, z^i)$, with $z^i \equiv a^i b^i$, and $e^i_{z^i} < 0$, $e^i_G > 0$. Assuming symmetry among the importers in terms of preferences, incomes, and local conditions, i.e., b^j is the same for all importers, equation (6) becomes

$$G_{a^j} = \frac{-n\left[a^0 b^0 b^j e^j_{z^j} + (b^j - b^0) a^j b^j e^j_{z^j} - (b^j - b^0)(m^j - e^j(G, z^j))\right]}{1 + n(b^j - b^0) e^j_G + n a^0 b^0 e^j_G + a^0 b^0 e^0_G}. \tag{13}$$

For $b^j > b^0$, i.e., if importers are more effective at turning the emission-reducing good into contributions, by (13), public good provision in an interior equilibrium still increases in response to a price reduction ($G_{a^j} > 0$), so that Propositions (1)-(3) also hold. For $b^j < b^0$, i.e., if importer countries are less effective, public good provision will react positively only if the productivity differences are not too pronounced, and Propositions (1)-(3) will then continue to hold. However, if local conditions make it substantially more challenging for importers to turn the emission-reducing good into contributions, this may no longer be the case.

Two producer countries Global market shares for individual producer countries in some markets for key inputs to reduce GHG emissions may not be fully adequately approximated by the monopoly assumption. Assume now that there is a second country, country 1, which also produces the green good at marginal costs c, and has the same preferences and income as country 0. Consider the following dynamic game with homogeneous products Bertrand competition.[13] In Stage 1, both producer countries simultaneously set their prices p^0 and p^1, respectively. The country with the lower price receives the entire demand and the demand is split

[12]Similarly, a price increase which turns importers into non-contributors, and thus into non-importers, precludes the possibility that the monopoly supplier could benefit from further raising the price, which confirms that an export subsidy is the optimal policy.

[13]While homogeneous products Bertrand competition would not result in a mark-up in a setting with private goods, it avoids the additional complications of introducing product differentiation or quantity setting.

evenly if both choose the same price. In stage 2, all countries simultaneously choose their contributions. Both supplier countries will have an incentive to import from the other producer if the other country subsidizes its product. However, if, in a free trade equilibrium, both countries contribute to the global public good, both countries will have an incentive to reduce their price and contribute less, at least until they stop contributing. In the equilibrium both countries choose the same subsidized price, $p^0 = p^1 < c$. Thus, also with a second supplier, the subsidization incentive exists.

Minimum and gratuitous contributions The monopoly supplier may be constrained to employ some minimum amount of green goods as some kind of requirement to be the monopolist, i.e., to acquire and to maintain the technological expertise and scale required to be the market leader. In this case, the monopoly supplier would reduce its contribution to the global public good down to this constraint.[14] Similarly, with recent technological improvements and scale economies in production, some emission reductions may 'come for free', since green technologies are already cost competitive in a limited number of sectors, or in regions with the appropriate climatic conditions. All countries would make use of such possibilities. My analysis then only applies to the costly contributions to reduce emissions, which go beyond such cost-free contributions. In such an extension, the monopoly supplier country would only reduce its costly contributions to zero but continue to provide those which 'come for free'.[15]

[14]Domestic demand-side subsidies seem to have played a role in the establishment of Chinese dominance in many green tech sectors at some point. For example, the Chinese photovoltaic (PV) industry was originally an export-led industry. After the financial crisis, in an environment of weaker international demand, China's central government established own demand side policies from 2009 onwards, which guaranteed the survival of its industry and laid the ground for the emergence of its dominant international position today. Since 2015, the demand side programs have been phased out in several steps, see Nahm (2021).

[15]IRENA (2024) documents that the levelized cost of energy for renewables has fallen considerably over recent years. This is in line with the empirical observation that China has started to substantially increase its roll-out of green technologies as these have become more cost-competitive. For example, despite Chinese dominance in production, its yearly capacity additions in PV energy generation amounted only to 50 GW from 2016-2022, on average. Average capacity additions in 2023 and 2024, however, were 217 GW and 277 GW, respectively. 56% of the total Chinese capacity at the end of 2024 were only added in these last two years, see IRENA (2025).

4 Impure public goods

The analysis has so far been cast in the standard framework of the pure private provision model used in the global public goods literature, see Buchholz and Sandler (2021). This section investigates whether the key results can also be derived in an impure public goods model which parallels a standard environmental model of transboundary pollution.[16] The formulation follows the characteristics approach in the private provision literature to model such settings, see Kotchen (2005, 2006), or Vicary (2009), on which I base the development of my argument.

Countries' preferences are represented by $u^i = u^i(X^i, G)$, where G continues to be global environmental quality, and X^i is now a private characteristic. Preferences are assumed to be strictly normal in both characteristics, X^i and G. The private characteristic X^i can be derived either from the consumption of the dirty good y which generates a global negative externality, or by the clean good z according to the relationship $X^i = \alpha z^i + \beta y^i$, where $\alpha > 0$ and $\beta > 0$ are parameters. This implies that, except for efficiency differences, the clean good and the dirty good are perfect substitutes in terms of the private characteristic. The analysis thus directly fits the case of green versus dirty energy consumption (electricity from photovoltaics versus electricity from a fossil-fuel power plant) or the use of traditionally composed and produced cement, which causes CO2 emissions, versus "green" cement, which does not generate CO2 in its production. Following the analysis of this standard setting, the assumption of perfect substitutability is relaxed further below.

Each country's consumption of the dirty good y^i translates proportionally into damage $D^i = \gamma y^i$, where, for ease of exposition, I set $\gamma = 1$, so that $D^i = y^i$. The consumption level of the global public good is $G = \bar{G} - D$, where $\bar{G}$ is an exogenous level of the global public good without human intervention, and $D = \sum_{i=0}^{n} D^i = \sum_{i=0}^{n} y^i$ is the total damage (emissions) by all countries combined.

The clean good z is again only produced by the monopoly supplier country 0 at constant marginal costs c, the dirty good by all countries, i.e., there is incomplete international specialization so that the monopoly supplier exports the clean good and imports the dirty good. The dirty good is the numéraire and the price of the clean good is denoted by p. The monopoly supplier country first sets this price by

[16] The relationship between the standard private provision model, also called the subscription model by some authors, and the common pool or congestion model approach is discussed by Cornes and Sandler (1996) and Vicary (2011), among others.

appropriate export taxes or subsidies, all countries then simultaneously decide on their consumption choices. As in Section 2, m^i denotes the exogenous income of country i, so that the budget constraint for an importer country is $m^j = pz^j + y^j$. I assume throughout that $\beta p > \alpha$, which prevents the case where clean consumption always dominates dirty consumption. Moreover, I focus on interior equilibria, i.e., countries consume positive amounts of both marketable goods, and I assume that all countries have the same preferences and incomes.[17]

While countries are ultimately interested in the private characteristic X^i and global environmental quality G, these quantities are steered via their choices of clean and dirty consumption z^i and y^i. If an importer decides only to consume the clean good, the private characteristic is $X^j = \frac{\alpha m^j}{p}$. This is its minimum private characteristic X^j. If an importer only consumes dirty, it will consume its maximum private characteristic $X^j = \beta m^j$. Thus, all importers choose their private consumption characteristic on the interval $\left[\frac{\alpha m^j}{p}, \beta m^j\right]$, and this choice also determines the global public good level given the emissions of all other countries. A higher private consumption characteristic X^j requires more dirty good consumption and less clean good consumption, and thus a lower level of G. By consuming more of the green good z^i instead of the dirty good y^i, a country contributes to the global public good. Since contributions also generate private co-benefits, the public good is impure.

The maximization problem of each importer country is

$$\max_{X^j, G} u^j\left(X^j, G\right)$$

s.t.

$$m^j = pz^j + y^j, \tag{14}$$

with $G = G^{-j} - y^j$, where $G^{-j} \equiv \bar{G} - D^{-j}$, and D^{-j} denotes the damage done, i.e., dirty consumption by all other countries except country j. Using $X^j = \alpha z^j + \beta y^j$ and $y^j = G^{-j} - G$, the budget constraint (14) becomes $m^j + \pi^{jG} G^{-j} = \pi^{jX} X^j + \pi^{jG} G$, where $\pi^{jX} \equiv \frac{p}{\alpha}$ and $\pi^{jG} \equiv \frac{p\beta - \alpha}{\alpha}$ are the 'prices' of the characteristics, see Vicary (2009). The characteristics 'price' ratio $\pi^j \equiv \frac{\pi^{jX}}{\pi^{jG}}$ determines the constant slope of the budget constraint in $X^j G$ space, and it is a function of the price of the clean good p, with $\pi^j_p = \frac{-\alpha}{[pb - \alpha]^2} < 0$. An increase in p makes the clean good relatively more

[17]See Vicary (2009) for an encompassing analysis of this framework including the corner solution cases. Note that this formulation does not allow for the option of directly contributing to the public good, as in Kotchen (2006).

expensive, so that, for a given increase in the public good characteristic, a country has to give up more of the private characteristic.

From the solution of the maximization problem, one can trace out the expansion path in X^jG space, where the first order condition at an interior solution requires $\frac{u^j_{X^j}}{u^j_G} = \pi^j$ on this path.[18] Given normality of both characteristics X^j and G, the income expansion path in X^jG space defines a function $X^j = E^j(G, \pi^j)$, with $E^j_G > 0$, and I assume $E^j(0, \pi^j) = 0$. An increase in π^j rotates this expansion path to the left, i.e., $E^j_{\pi^j} < 0$, which implies for importer countries that $E^j_{\pi^j}\pi^j_p > 0$. A rise in the price of the clean good reduces clean consumption and increases dirty consumption which increases consumption of the private characteristic.

The decision problem for the monopoly supplier is analogous, but the budget constraint (14) is replaced by the constraint

$$m^0 + n(p - c) z^j = cz^0 + y^0. \tag{15}$$

Using $X^0 = \alpha z^0 + \beta y^0$, this can be reformulated as $m_0 + n(p-c) z^j + \pi^{0G} G^{-0} = \pi^{0X} X^0 + \pi^{0G} G$, with $\pi^{0X} \equiv \frac{c}{\alpha}$ and $\pi^{0G} \equiv \frac{\beta c - \alpha}{\alpha}$, so that the characteristics 'price' ratio is $\pi^0 \equiv \frac{\pi^{0X}}{\pi^{0G}} = \frac{\frac{c}{\alpha}}{\frac{\beta c - \alpha}{\alpha}}$. This ratio does not directly depend on p. In an interior equilibrium the monopoly supplier will be on its income expansion path in X^0G space where optimality requires $\frac{u^0_{X^0}}{u^0_G} = \frac{\pi^{0X}}{\pi^{0G}} = \pi^0$. Thus, this income expansion path is independent of p. The optimal X^0 can be expressed as a function of the global public good only $X^0 = E^0(G)$. By normality $e^0_G > 0$, and I assume $E^0(0) = 0$.

Consider now the equilibrium. Since the level of the global public good inversely relates to total damage, I study the equilibrium starting from the aggregate feasibility requirement for total damage. This naturally leads to an aggregative game approach which parallels my analysis in the pure public good case. Total damage equals global consumption of the dirty good, so that

$$D = n\left[m^j - pz^j\right] + m^0 + n(p - c) z^j - cz^0. \tag{16}$$

This can be rearranged to

$$D = n\left[m^j - cz^j\right] + m^0 - cz^0. \tag{17}$$

The price of the dirty good disappears from the global feasibility constraint. Thus, the direct impact of the price of the clean good washes out at the world level. Just

[18] The solution gives the demand functions for X and G as functions of π^j and m^j. Solving both for m^j, setting them equal and rearranging yields the path.

as in the pure public good case analyzed in Section 2, the price charged by the monopoly supplier only has indirect effects via the price's impact on the demand for clean consumption. This reflects the transfer nature of revenues or subsidies which are generated by a price deviating from marginal cost. Intuitively, the global feasibility constraint requires that, for any given vector of clean good consumption, the world's total spending on the dirty good, and thus total damage, equals the world endowment minus what it costs to produce the world's clean good consumption. The world's costs for a cleaner environment only depend on the costs in the monopoly supplier country to produce the clean good, and this fundamental condition remains unaffected by the price charged.

In an interior equilibrium, where all countries consume positive amounts of both marketable goods, all countries must be on their respective expansions paths in X^iG space. This allows to express clean consumption of the importers and the monopoly supplier as $z^j = z^j\left(E^j\left(G,\pi^j\right),p\right)$ and $z^0\left(E^0\left(G\right),p\right)$, respectively, see Appendix. Substituting these into (17), the equation is turned into an equilibrium relationship

$$D = n\left[m - cz^j\left(E^j\left(G,\pi^j\right),p\right)\right] + m^0 - cz^0\left(E^0\left(G\right),p,z^j\right). \tag{18}$$

This allows to consider how total damage D, and thus G, depends on the clean good's price. Given the additional effect of z^j on z^0 caused by a change in p, see Appendix, it is useful to consider the effects at $p = c$. This yields the next proposition.

Proposition 5 *At price equal to marginal cost ($p = c$), increasing the export price of the clean good increases global damage in an interior impure public good equilibrium, i.e.*

$$D_p|_{p=c} = \frac{-nc\left[z^j_p + z^j_{X^j}E^j_{\pi^j}\pi^j_p\right] - cz^0_p}{1 - ncz^j_{X^j}E^j_G - cz^0_{X^0}E^0_G} = \frac{ncE^j_{\pi^j}\pi^j_p}{c\beta - \alpha + ncE^j_G + cE^0_G} > 0. \tag{19}$$

Proof. See Appendix. ■

The result that total damage is increasing in the price charged by the monopoly supplier for the clean good is intuitive and directly parallels Proposition 1 in the pure public good case. This comparative static result now directly allows to investigate the effects of a price increase on the welfare of the monopoly supplier, again starting from the benchmark of price equal to marginal costs. The equilibrium utility of the monopoly supplier is given as $u^{0^*} = u^0\left(E^0\left(G\right),G\right)$, so that

$$u^{0^*}_p\big|_{p=c} = u^0_{X^0}E^0_G\, G_p|_{p=c} + u^0_G\, G_p|_{p=c} < 0, \tag{20}$$

since, by (19), $G_p|_{p=c} = G_D \; D_p|_{p=c} = - \; D_p|_{p=c} < 0$. This can be summarized as the next proposition.

Proposition 6 *At price equal to marginal costs ($p = c$), a reduction of the price charged by the monopoly supplier country increases its welfare in an interior impure public good equilibrium.*

Thus, the incentives for the monopoly supplier to subsidize the price below marginal costs also exist in an impure global public goods setting. The subsidy increases the importers' clean good consumption, while the monopoly supplier substitutes clean consumption by dirty consumption. This allows it to benefit from higher global public good consumption and from higher consumption of the private characteristic.

In the current impure public good setting, a country contributes to the global public good by consuming less dirty and more green goods. This is costly given that one \$ spent on the dirty good generates β units of the private characteristic, whereas one \$ spent on the clean good generates $\frac{\alpha}{p}$ units, and $\beta > \frac{\alpha}{p}$. Given perfect substitutability, the importer countries can contribute to the global public good at a constant price in terms of foregone private consumption. This parallels the pure public good model. It is thus intuitive that the optimality of a subsidy policy for a monopoly supplier carries over to the impure public good setting.

To gain insights into the role played by perfect substitutability, consider a simple extension. Let the private characteristic X^i now be generated according to the constant elasticity of substitution relationship $X^i = \left[\alpha \left(z^i\right)^\rho + \beta \left(y^i\right)^\rho\right]^{\frac{1}{\rho}}$, with the elasticity of substitution $\eta \equiv \frac{1}{1-\rho}$. Since I am interested in the case where the clean good and the dirty good are substitutes, I consider the case were $0 < \rho < 1$. For $\rho \to 1$, this converges to the case of perfect substitutability discussed so far. An importer's maximization problem with respect to X^j and G stated above is now characterized by a non-linear budget constraint

$$0 = X^j - \left[\alpha \left(\frac{1}{p}\left[m^j - \left(G^{-j} - G\right)\right]\right)^\rho + \beta \left(G^{-j} - G\right)^\rho\right]^{\frac{1}{\rho}} \equiv H\left(X^j, G\right). \qquad (21)$$

For appropriate parameter assumptions about β, p, α and ρ (the analogue to the requirement $\beta p > \alpha$ in the case where z^i and y^i linearly aggregate into X^i), this constraint defines a convex set in $X^i G$ space over which the countries maximize.[19]

[19]The parameters must insure that $h(G) = \left[\alpha\left(\frac{1}{p}\left[m^j - \left(G^{-j} - G\right)\right]\right)^\rho + \beta\left(G^{-j} - G\right)^\rho\right]^{\frac{1}{\rho}}$ is a

For the monopoly supplier the constraint is analogous except that c takes the place of p and that its income is $\hat{m}^0 \equiv m^0 + n(p-c)z^j$. Along the budget constraint in X^iG space the characteristics 'price' ratio $\pi^i \equiv \frac{H^i_{X^i}}{H^i_G}$ is no longer constant as in the case of perfect substitutability, since H^i_G depends on G. In an interior equilibrium, each country will now be on its expansion path characterized by $\frac{u^i_{X^i}}{u^i_G} = \frac{H^i_{X^i}}{H^i_G} = \pi^i$. Note that this implies that the income expansion path of the monopoly supplier will now also depend on the price p via π^0, since H^0_G is now a function of p, and thus $\pi^0 \equiv \frac{H^0_{X^i}}{H^0_G} = \frac{1}{H^0_G}$ is also a function of p, with $\pi^0_p < 0$ since H^0_G is increasing in p. Thus, the expansion path of the monopoly supplier must now be written as $X^0 = E^0(G, \pi^0)$ with $E^0_{\pi^0} < 0$, so that $E^0_{\pi^0}\pi^0_p > 0$. Focussing on an interior equilibrium with all expansion paths characterized by $E^i_G > 0$ allows again applying the aggregative game approach. The equilibrium condition (18) becomes

$$D = n\left[m - cz^j\left(E^j\left(G, \pi^j\right), p\right)\right] + m^0 - cz^0\left(E^0\left(G, \pi^0\right), p, z^j\right). \tag{22}$$

For the comparative static effect of a change in the price charged by the monopoly supplier country one can now derive the following.

Proposition 7 *Let* $X^i = \left[\alpha\left(z^i\right)^\rho + \beta\left(y^i\right)^\rho\right]^{\frac{1}{\rho}}$, *with* $0 < \rho < 1$, *and let all countries be symmetric in terms of preferences and income, and let an interior impure public good equilibrium exist, in which all countries are located on an upward-sloping income expansion path in* X^iG *space, then, at price equal to marginal costs* ($p = c$)*, an increase in the export price of the clean good increases global damage* D*, i.e.,*

$$D_p|_{p=c} = \frac{-ncz^j_{X^j}E^j_{\pi^j}\pi^j_p - cz^0_{X^0}E^0_{\pi^0}\pi^0_p}{1 - ncz^j_{X^j}E^j_G - cz^0_{X^0}E^0_G} > 0. \tag{23}$$

Proof. See Appendix. ■

Intuitively, if the clean and the dirty good are substitutes, the outcome is similar to the outcome with perfect substitutes. Beyond the effect on the importers who decrease dirty consumption in response to the price increase, there is now an additional income effect from the marginal monopoly rents which, due to imperfect substitutability, pushes the monopoly supplier to increase dirty consumption.

The monopoly supplier's equilibrium utility is $u^{0^*} = u^0\left(E^0\left(G, \pi^0\right), G\right)$, so that

$$\left.\frac{\partial u^{0^*}}{\partial p}\right|_{p=c} = u^0_{X^0}\left[E^0_G\, G_p|_{p=c} + E^0_{\pi^0}\pi^0_p\right] + u_G\, G_p|_{p=c}. \tag{24}$$

concave function. Moreover, the function should exhibit a downward-sloping section to allow for an interior solution as assumed below.

The monopoly supplier is directly hurt by the lower level of public good consumption ($u^0_G\, G_p|_{p=c} < 0$). It also suffers from the indirect effect of lower public good consumption on private consumption ($u^0_{X^0} E^0_G\, G_p|_{p=c} < 0$). These two effects were the only effects present in the case of perfect substitutability as summarized in Proposition 6. However, there is now an additional counterveiling effect ($u^0_{X^0} E_{\pi^0} \pi^0_p > 0$) which pushes for higher private consumption due to imperfect substitutability and increases utility. This term is decreasing in ρ and is equal to zero for perfect substitutability. Thus, if ρ is sufficiently close to one, the overall effect will be negative. This is summarized in my last proposition.

Proposition 8 *At price equal to marginal costs ($p = c$), a reduction of the monopoly supplier country's export price increases its welfare in an interior impure public good equilibrium if the clean and the dirty good are sufficiently close substitutes.*

The importance of the degree of the substitutability is intuitive. If the green good allows to consume other important private characteristics, which cannot be perfectly substituted by other goods, the monopoly supplier's incentive to subsidize its exports of the green product will be suppressed. Think about the example of a vaccine against a transmittable disease which is only available from a single country. It is typically very difficult to substitute the direct benefits of a vaccinated population by other private goods. This can make it unattractive for this country to sell the vaccine at a subsidized prize to other countries and reduce the degree of vaccination in the own population. On the other hand, energy produced without emissions has no particular characteristic that cannot be delivered by energy produced with emissions.[20] The key insight is that, in an interior equilibrium, it is not the relative importance of the global public good that determines whether the strategic incentive to subsidize exists. Rather, the degree of substitutability of the private benefits from green and dirty consumption matter for the optimality of subsidies.

5 Discussion and conclusion

The key result that in an interior contribution equilibrium a monopolist has an incentive to subsidize beyond what would be prescribed by the classic transboundary externality argument put forward by Markusen (1975) may be surprising at first

[20]This may not be true if there are psychological benefits, such as the joy of consuming green.

sight. However, the findings are rather intuitive given the redistribution invariance result of Warr (1983). The loss in tax revenue from the export subsidy results in a transfer from the monopoly supplier country to the importer countries via the income effect of lower prices. Given redistribution invariance, this transfer does not affect the equilibrium outcome, i.e., public and private good consumption by all parties remain unchanged, and the transfer does not make any country better or worse-off. The implicit transfer is therefore cost-free for the monopoly supplier country. By the same logic, redistribution invariance destroys any incentive for the monopoly supplier country to exploit its market power to improve the terms of trade in its favor. At the same time, reduced prices for emission-reducing goods in the world market trigger higher emission-reducing efforts by all importer countries, which increases total emission reductions. This makes the monopoly supplier better-off and increases total public good provision relative to the competitive setting. The same mechanism is at work in a standard environmental model with transboundary pollution, so that the subsidization incentives will also exist if the global public good is impure. This will be the case as long as the private co-benefits of contributions are sufficiently easy to be substituted by non-green goods. Importer countries can also be better off with a monopoly supplier relative to a competitive setting. They face lower prices and benefit from the increased provision by the other importers. However, they are strategically exploited by the monopoly supplier country which reduces its contributions to their detriment.

Taken at face-value, the results call into question whether there is a strong case for public subsidies by current importer countries to reshore production of green products, given the incentives of a monopoly supplier. Even if the monopoly supplier country's scope for expanding the level of global public goods via subsidized export prices is limited by a rather low level of its own contributions in the competitive benchmark, the monopoly supplier will always have an incentive to worsen its terms of trade at the margin, as long as it is a contributer in the free trade benchmark. Consequently, importer countries' fears of being exploited by high prices set by the monopoly supplier may be less warranted for emission-reducing goods. Ceteris paribus, the case for industrial policy for green goods may be weaker than for non-green products. For such goods, the strategic contribution interaction eliminates the classic rent-shifting potential of such policies. Moreover, reshoring subsidies can also become more costly if they must not only cover the cost difference but also cover the gap to the lower price chosen by the monopoly supplier.

However, there are also important instances where the results do not apply, and further arguments beyond the present analysis exist, which must be weighed before drawing policy conclusions. First, if the monopoly supplier does not contribute to the public good to begin with, the key mechanism which generates the strategic subsidization incentive will not be operational. This will be the case if the monopoly supplier country's preferences are such that it cares substantially less about the public good than the importers, or if this country is substantially poorer than the importers, see Buchholz and Sandler (2021).[21] Second, the analysis has shown that the degree of substitutability of private co-benefits of green goods can be important. If private co-benefits are difficult to substitute, the subsidization incentives are reduced and can eventually disappear. The joint production of the private co-benefits then commits the monopoly supplier not to set lower prices. It is therefore useful to assess the substitutability of private benefits from particular externality-generating products to gauge whether strategic incentives to subsidize are likely to exist or not. Third, going beyond the aspects discussed in the present analysis, there may be other economic arguments which speak in favor of green subsidies, see Andres (2023), for example. Classic industrial policy arguments may be particularly strong for green products and are likely to become even more important due to consumer preferences, technological advances, or tighter environmental constraints. Finally, policy-makers in importer countries should also consider political and geo-strategic reasons, why too much dependence on a single importer may not be desirable.

6 Appendix

Proof of Proposition 5

Before considering the effect of changing p on the equilibrium of the impure

[21]The empirical observation of the joint occurrence of China's market dominance for many products which are essential for the transition to a carbon-free global economy with China's rising per capita GHG emissions (in absolute terms but also relative to the key importers, which show falling emissions), and with its continued investment in emission-intensive energy production is fully in line with the present analysis. However, the same observation could result from a situation where China does not sufficiently care about the global public good, or is still too poor to be a contributor, and where low Chinese prices of green tech products arise from fierce competition and industrial policy measures carried out for more classic reasons.

public goods model, consider how clean consumption z^j and z^0 depend on p and X^i, respectively. Inserting the respective budget constraints $m^0+n(p-c)z^j = cz^0+y^0$, and $m^j = pz^j + y^j$ into $X^i = \alpha z^i + \beta y^i$, we have

$$z^j = \frac{\beta m^j - X^j}{\beta p - \alpha} = \frac{\beta m^j - E^j(G,\pi^j)}{\beta p - \alpha} = z^j\left(E^j\left(G,\pi^j\right),p\right),$$

$$\begin{aligned} z^0 &= \frac{\beta}{\beta c - \alpha}\left[m^0 + n(p-c)z^j\right] - \frac{X^0}{\beta c - \alpha} \\ &= \frac{\beta}{\beta c - \alpha}\left[m^0 + n(p-c)z^j\right] - \frac{E^0(G)}{\beta c - \alpha} = z^0\left(E^0(G),p,z^j\left(E^j\left(G,\pi^j\right),p\right)\right), \end{aligned}$$

with $z^j_{X^j} < 0$ and $z^0_{X^0} < 0$. For any country, a higher private consumption characteristic implies less green good consumption. Turn to the equilibrium condition (18)

$$D = n\left[m - cz^j\left(E^j\left(G,\pi^j\right),p\right)\right] + m^0 - cz^0\left(E^0(G),p,z^j\left(E^j\left(G,\pi^j\right),p\right)\right).$$

Differentiating with respect to p, using $G_D = -1$, and rearranging gives

$$D_p = -nc\left[z^j_p + z^j_{X^j}\left(E^j_{\pi^j}\pi^j_p - E^j_G D_p\right)\right] - c\left[z^0_p - z^0_{X^0}E^0_G D_p + z^0_{z^j}\left(z^j_p + z^j_{X^j}\left(E^j_{\pi^j}\pi^j_p - E^j_G D_p\right)\right)\right]$$

Moreover, at $p = c$, $z^0_{z^j} = 0$, so that

$$D_p|_{p=c} = -nc\left[z^j_p + z^j_{X^j}\left(E^j_{\pi^j}\pi^j_p - E^j_G\, D_p|_{p=c}\right)\right] - c\left[z^0_p - z^0_{X^0}E^0_G\, D_p|_{p=c}\right], \text{ or}$$

$$D_p|_{p=c} = \frac{-nc\left[z^j_p + z^j_{X^j}E^j_{\pi^j}\pi^j_p\right] - cz^0_p}{1 - ncz^j_{X^j}E^j_G - cz^0_{X^0}E^0_G}$$

With the linear aggregation of the clean and the dirty good into the private characteristic, we have $z^j_{X^j} = -\frac{1}{\beta p-\alpha}$, $z^0_{X^0} = -\frac{1}{\beta c-\alpha}$, $z^j_p = -\frac{\beta^2 m^j - \beta X^j}{(\beta p-\alpha)^2} = -\frac{\beta z^j}{\beta p-\alpha}$, $z^0_p = \frac{\beta n z^j}{\beta c-\alpha} = \frac{\beta n\left(\beta m^j - X^j\right)}{(\beta c-\alpha)(\beta p-\alpha)}$. For $p = c$, we thus have

$$D_p|_{p=c} = \frac{\frac{ncE^j_{\pi^j}\pi^j_p}{\beta c - a}}{1 + \frac{ncE^j_G}{\beta c-\alpha} + \frac{cE^0_G}{\beta c-\alpha}} = \frac{ncE^j_{\pi^j}\pi^j_p}{\beta c - \alpha + ncE^j_G + cE^0_G} > 0$$

The denominator is positive since $\beta c - \alpha > 0$, $E^0_G > 0$ and $E^j_G > 0$, and the numerator is also positive since $E_{\pi^j}\pi^j_p > 0$, as was shown in the main text.■

Proof of Proposition 7

Substituting the countries' budget constraints in terms of clean and dirty consumption into the private characteristic CES aggregation gives

$$X^j = \left[a\left(z^j\right)^\rho + \beta\left(m^j - pz^j\right)^\rho\right]^{\frac{1}{\rho}}, \text{ and}$$

$$X^0 = \left[\alpha \left(z^0\right)^\rho + \beta \left(\hat{m}^0 - cz^0\right)^\rho\right]^{\frac{1}{\rho}},$$

where $\hat{m}^0 \equiv m^0 + n\,(p - c)\,z^j$. Solving these for z^j and z^0, respectively, one can find $z^j_p = -\frac{z^j}{p}$ and $z^0_p = \frac{nz^j}{c}$. Moreover, $z^j_{X^j} < 0$ and $z^0_{X^0} < 0$. The equilibrium relationship for total damage is

$$D = n\left[m - cz^j\left(E^j\left(G, \pi^j\right), p\right)\right] + m^0 - cz^0\left(E^0\left(G, \pi^0\right), p, z^j\left(E^j\left(G, \pi^j\right), p\right)\right).$$

Differentiation with respect to p and evaluating at $p = c$, where $z^0_{z^j} = 0$ and $z^0_p = -nz^j_p$, taking into account $G_D = -1$, and that now π^0 is a function of p yields

$$D_p|_{p=c} = -nc\left[z^j_p - z^j_{X^j}\left[E^j_G\, D_p|_{p=c} + E^j_{\pi^j}\pi^j_p\right]\right] - c\left[z^0_p + z^0_{X^0}\left[E^0_{\pi^0}\pi^0_p - E^0_G\, D_p|_{p=c}\right]\right], \text{ or}$$

$$D_p|_{p=c} = \frac{-nc\left[z^j_p + z^j_{X^j}E^j_{\pi^j}\pi^j_p\right] - c\left[z^0_p + z^0_{X^0}E^0_{\pi^0}\pi^0_p\right]}{1 - ncz^j_{X^j}E^j_G - cz^0_{X^0}E^0_G} = \frac{-ncz^j_{X^j}E^j_{\pi^j}\pi^j_p - cz^0_{X^0}E^0_{\pi^0}\pi^0_p}{1 - ncz^j_{X^j}E^j_G - cz^0_{X^0}E^0_G} > 0$$

By the upward-sloping income expansion paths $E^j_G > 0$, $E^0_G > 0$. Moreover, $z^j_{X^j} < 0$ and $z^0_{X^0} < 0$, so that the numerator is positive. The denominator is also positive since $z^j_{X^j} < 0$, $E^j_{\pi^j}\pi^j_p > 0$, $z^0_{X^0} < 0$, and $E^0_{\pi^0}\pi^0_p > 0$.■

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