Green Technology Transfers
and Border Tax Adjustments

Alain-Désiré Nimubona and Horatiu A. Rus[1]

Abstract

We develop a two-country general equilibrium model of foreign assistance tied to environmental clean-up in the presence of transboundary pollution. The recipient country generates pollution as a by-product in the production of a 'dirty' good, which it consumes as well as exports to the donor country. In contrast to the literature which typically treats aid as a monetary transfer, we assume that foreign aid consists in a transfer of environmental technology that lowers the cost of public clean-up in the recipient country. We highlight the fact that the marginal propensities to consume the polluting good in the donor and recipient countries are driving the terms of trade effect at work in our model. The environmental and welfare outcomes are influenced by the direct, terms of trade and abatement effects of the transfer. We show that such tied aid may be Pareto improving if the clean-up effect of the foreign aid is strong enough to compensate for the donor's monetary and terms of trade losses. We finally analyze the effects of the green transfer combined with an appropriate border tax adjustment. Contrary to intuition, we find that green technology transfers and border tax adjustments are not complements.

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[1]Department of Economics, University of Waterloo, 200 University Drive, Waterloo, ON, Canada N2L 3G1 (animubon@uwaterloo.ca, hrus@uwaterloo.ca)

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1. Introduction

From transboundary local pollutants to global pollutants, a large host of environmental problems have international repercussions. At the same time, there exist significant differences between the stringency of environmental policies adopted by countries with different degrees of development around the world, as documented in the 'environmental Kuznets curve' literature. This creates obvious difficulties when it comes to issues requiring international policy coordination. While potential pollution haven or carbon leakage effects arising from diverging environmental standards could be mitigated by increasing the abatement capacity of the global South, developing countries can hardly afford to cover the full cost of addressing these environmental problems. In such a context, and especially if the pollutant is transboundary or global, *green foreign assistance* in various forms may be optimal.

This paper looks at the environmental and welfare impact of a particular type of tied green aid and border tax adjustments in the case of transboundary pollution. The recipient country is the net exporter of a dirty good and finances its (potentially incomplete) public abatement of pollution via environmental taxes, while the donor country internalizes its own pollution in an efficient manner. A fraction of the unabated pollution from the recipient affects the donor, creating a cross-jurisdictional linkage between the two economies and a motive for the latter to provide the former with 'green assistance.' The paper analyzes the effectiveness of a transfer of green technology between the donor and the recipient and presents conditions under which the transfer increases abatement, decreases pollution and raises welfare in the two countries. The results depend on the interplay between the direct, terms of trade and clean-up effects of the transfer and are a function of the cost of the donation, as well as the effectiveness of the donated green technology vis-à-vis the environmental benefits. The conditions for a 'normal' transfer outcome in which the donor loses and the recipient gains, a transfer paradox in which the donor gains and the recipient loses, and a Pareto improving outcome in which both countries gain in welfare terms are also discussed.

The welfare effects of various forms of foreign assistance have been studied extensively.

Foreign aid can be unconditional or conditional (tied), and the existing literature differentiates between several different types of the latter form of assistance. Procurement tying - aid conditional on government purchases - is analyzed for instance in Kemp and Kojima (1985), Schweinberger (1990) and Hatzipanayotou and Michael (1995). Policy tying - aid conditional on the implementation of certain policies - is assumed in Lahiri and Raimondos-Møller (1997). Project tying - aid destined to finance certain projects - is considered in Schweinberger and Woodland (2008) and Chao and Yu (1999). This paper assumes a specific form of project tying of international assistance by modelling a green technology transfer which lowers the unit costs of abatement in the recipient. This form of environmental aid addresses the moral hazard issue associated with cash transfers, while also circumventing the fungibility of aid problem. Moreover, such technical environmental assistance is the actual form taken by many projects around the world. Figure 1 below[1] is based on OECD data on official development assistance to over 180 different recipient countries and regions worldwide and destined for general environmental protection. It shows that technical assistance is an important component of this type of aid. Moreover, besides the so-called 'free-standing' technical assistance projects, which for instance in 2006 were the single largest category of green aid, most projects classified in the other categories include a technical assistance component.

Concrete examples of such projects are particularly numerous in Germany, which generally considers the transfer of technical know-how as a key component of its bilateral development assistance activities. One of the more prominent such ventures is the Profitable Environmental Management Project (PREMA), which has assisted many small and medium-sized companies in developing countries in their efforts to improve their environmental performance. The federally owned German Organization for Technical Cooperation (GTZ) has also provided technical environmental assistance to many developing countries to facilitate the implementation of Rio commitments, the convention on biological diversity (CBD), the convention to

[1] From OECD's International Development Statistics, Development Assistance Committee (DAC). See http://www.oecd.org/dataoecd/50/17/5037721.htm, accessed May 14, 2010.

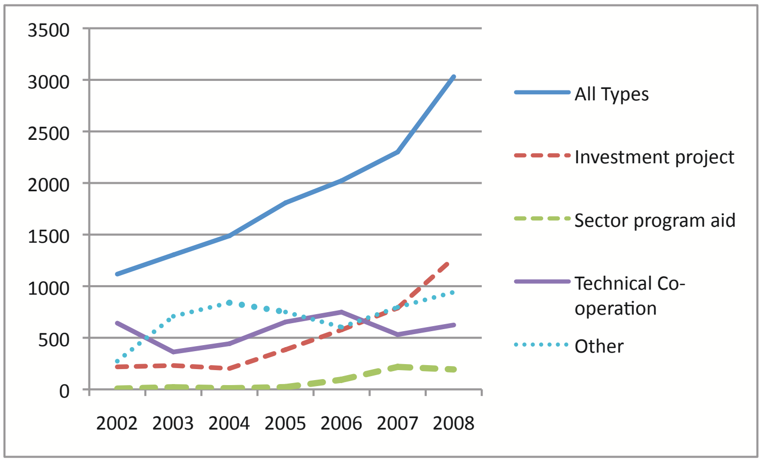

Figure 1: Types of Foreign Aid for General Environmental Protection (mil. USD, OECD)

combat desertification (CCD), the Montreal protocol, etc.[2] Technology transfer and assistance to developing countries are also among the areas where there was progress at the 2010 Cancun Climate Conference.[3]

To preview the main results of the paper, a green technology transfer is effective at increasing the amount of public pollution abatement in the recipient country and leads to better overall environmental outcomes when the clean-up effect of the transfer dominates any positive price effect. Strong environmental benefits lead to a Pareto-improving outcome of the transfer, even when - unlike in the received literature - the two countries have different marginal propensities to consume the dirty good and even when the recipient is the exporter of this good. When a border tax adjustment is however used in conjunction with an effective technical assistance, there may be less public abatement of pollution in the recipient and both the environmental and the welfare outcomes worsen for both countries. Moreover, the 'normal' transfer effect of donor immiserization and recipient enrichment is more likely to be obtained. The next section provides background information and reviews the existing liter-

[2] See http://www.un.org/esa/agenda21/natlinfo/countr/germany/eco.htm, accessed August 11, 2010. Also see Schweinberger and Woodland (2008), p. 310 for some additional examples.

[3] See 'A Surprising Success', *The Economist*, December 11, 2010.

ature on the effectiveness of foreign assistance and border tax adjustments in dealing with pollution abatement.

2. Background and literature review

It is widely accepted that carrot and/or stick-type policy instruments are required in order to correct many inter-jurisdictional environmental externalities. From the first Earth Summit held in Stockholm in 1972 to Rio in 1992, Copenhagen in 2009 and Cancun in 2010, international negotiations on environment issues have consistently emphasized the crucial role of green foreign aid. Articles 2 and 12 of the Stockholm Declaration, for example, urge developed countries to increase international technical and financial assistance available for environmental protection in developing countries (Roberts et al., 2009). In order to implement chapter 33 of Agenda 21, the sustainable development plan crafted in preparation for the Rio summit, developed countries pledged $141.9 billion to help their developing counterparts tackle global as well as local environmental issues (UNCED, 1992). At the Copenhagen climate summit in December 2009, participants also agreed to establish the 'Copenhagen green climate fund' to support projects, programmes, policies and other activities in developing countries related to climate change mitigation (UNFCC, 2009). The $100 billion fund was confirmed at the recently concluded global climate talks in Cancun in December 2010. In addition to this long-term finance, other projects such as Reduced Deforestation and Forest Degradation (REDD+) are to be based in developing countries and financed by the developed countries. Indeed, the sustained growth in the total amount of green aid disbursed annually has been accelerating in recent years, as illustrated by the cumulative trend depicted in Figure 1 above. At the same time, Border Tax Adjustments are envisaged in both the EU Emissions Trading System (ETS) and the proposed American Clean Energy and Security Bill (Waxman-Markey), as punitive instruments meant to ensure a 'level playing field'. Given these trends, it is important to gain a better understanding of the effects of technology transfers to developing countries.

The received literature on foreign environmental aid builds on and introduces foreign aid into the trade and environment literature that studies the interaction between trade and pollution policies.[4] In particular, Chao and Yu (1999) use a parsimonious framework to establish that aid tied to environmental clean-up can be welfare improving for both countries, when the beneficial environmental effect exceeds the terms of trade deterioration for the dirty-good importing recipient, and when the terms of trade improvement exceeds the direct negative effect of the transfer for the donor. Hatzipanayotou, Lahiri and Michael (2002) describe a non-cooperative game in which the recipient of untied aid chooses the fraction it allocates to abatement as well as its pollution tax, while the donor chooses the level of aid. They show that higher perceived transboundary pollution may lead to better environmental outcomes via increased transfers. Hatzipanayotou, Lahiri and Michael (2008) analyze a pollution policy game without foreign aid, in which the degree of cross-border pollution affects the strategic policy response of the two countries, as well as the pollution and welfare outcomes. In another recent paper, Schweinberger and Woodland (2008) develop a framework in which foreign aid tied to public abatement may lead to a crowding out of private abatement and a subsequent worsening of pollution both in the short and the long run.

This paper resembles Chao and Yu (1999) from a modelling standpoint, as it looks at the environmental and welfare effects of tied aid aimed at increasing pollution abatement in the recipient country. Also, like Chao and Yu (1999), Hatzipanayotou, Lahiri and Michael (2002) and Schweinberger and Woodland (2008) it considers both private and public abatement of pollution.[5] Unlike these papers and given the stylized facts on the trend of foreign environmental assistance already presented, we model the transfer as technological assistance. In a

[4] Seminal papers on the interaction between trade and pollution policies include Copeland (1991) and Copeland and Taylor (1995). For a book-length treatment, also see Copeland and Taylor (2003).

[5] Both types of abatement are important. According to the OECD, total pollution abatement and control expenditures ranges between 1 and 3 % of the GDP in OECD member countries, and the ratio of public to private expenditures varies greatly by country and pollutant type. The most recent report is for 2002 and can be found at: http://www.oecd.org/dataoecd/41/57/4704311.pdf.

framework similar to Chao and Yu (1999), Haibara (2002) also studies the welfare impact of international technical assistance, which he assumes to be directed towards reducing polluting emissions. Like Haibara (2002), we find that technical assistance is superior to financial aid in addressing pollution problems. However, our model is different in many significant respects. First and foremost, we explicity model the channel by which technical assistance affects abatement activities and we assume that technical assistance has a positive economic cost in the donor country. Moreover, we add in transboundary pollution, which provides a direct motive for aid. Although foreign environmental assistance is often characterized by a mix of altruistic and self-interested considerations of the donor country, the latter type are better supported by actual donor behaviour (e.g. Hassler, 2002).[6] This cross-border externality creates an additional link between the two jurisdictions beside international trade, and - as we argue further below - it allows for a Pareto optimal outcome in a more natural scenario in which the recipient, rather than the donor, is the net exporter of the dirty good in equilibrium.[7] The paper also differs from Chao and Yu (1999) and Haibara (2002) in two other ways. First, it allows marginal propensities to consume the polluting good to vary across the donor and the recipient countries, which is consistent with existing empirical evidence.[8] Second, it considers the role of a border tax adjustment (BTA) as a policy instrument complementary to the green technology transfer. While the early papers on BTAs such as Bhagwati and Srinivasan (1973) and Grossman (1980) look at the trade distorting effects and implications of different tax

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[6] As an illustration, Hassler (2002) cites the case of the Swedish self-interested environmental assistance granted to other Baltic states such as Estonia, Latvia and Lithuania. Declaratively aimed at addressing general environmental issues of high importance for those countries, the Swedish green aid was disproportionately geared towards transboundary problems such as wastewater treatment, reduction of emissions from point sources and nuclear safety.

[7] It is widely accepted that OECD countries as a whole are net importers of embodied CO_2 emissions, while developing countries as a whole are net exporters (Peters and Hertwich, 2008) .

[8] Naito (2003) cites empirical evidence showing above-unity levels of the income elasticity of demand for energy, which translate into higher expenditure shares on polluting goods in countries with higher average incomes. See p. 162.

rates, there is also a growing sub-literature on BTAs in the context of environmental regulatory differences, spawned by papers such as Barthold (1994) and Poterba and Rotemberg (1995). Recent contributions include Fischer and Fox (2009) and Dissou and Eyland (2009), which explore the effectiveness and the partial and general equilibrium effects of border tax adjustments, respectively.

The rest of the paper is organized as follows. The next section describes the model. Section four looks at the environmental and welfare effects of the green technology transfer. Section five analyzes the merits of a border tax adjustment as a complementary policy instrument available to the donor, while section six summarizes and concludes.

3. The Model and Some Preliminaries

Suppose there are two countries, the donor and the recipient, producing a polluting good x and a non-polluting numeraire y. The recipient country exports the polluting good x and imports good y. The production processes of x and y as well as the clean-up activities use several factors of production. We denote by v the factor endowments, and by v^p and v^g the potentially non-disjoint vectors of factors devoted to the production and pollution abatement processes, respectively.[9]

Polluting firms abate their emissions privately until their marginal costs of abatement are equal to a given emission tax t set by the government. We assume that the emission tax in the donor country is stringent enough to give sufficient incentives for polluting firms to abate all emissions. However, the emission tax is low in the recipient country and e amount of unabated pollution emissions is generated there in equilibrium.[10] Pollution is transboundary. Denote by $z = \theta_1 e$ the amount of domestic emissions that affect the recipient country and $z^* = \theta_2 e$

[9] For comparability, much of our notation throughout follows closely that of Chao and Yu (1999).

[10] The developing recipient sets its emission tax at a lower level than the developed donor since they weigh the different components of their welfare functions differently: while the donor has a higher marginal willingness to pay for abatement than the recipient, the reverse is true for the marginal utility of income.

the amount of emissions that crosses the border to affect the donor country ($\theta_1, \theta_2 > 0$). When $\theta_1 \neq \theta_2$ pollution is local, and when $\theta_1 = \theta_2$ we are dealing with global pollution as a special case.

Since private abatement does not completely eliminate the environmental damage in the recipient country, a public agency also carries out some clean-up activities. We denote by g the amount of public pollution abatement, where $g \leq e$.[11] Given this g amount of pollution abatement, the residual levels of pollution affecting the recipient country and the donor country are $(z - \theta_1 g)$ and $(z^* - \theta_2 g)$, respectively. The unit cost of this public clean-up is $c^g\Big(w\left(p,t\right), A\Big)$, where $w\left(p,t\right)$ is a vector of factor returns and A is the total cost of foreign assistance. The vector of factor returns, $w\left(p,t\right)$, is a function of the price of the polluting good (p) and the emission tax (t). The amount of foreign technology transfer A lowers the marginal cost of public clean-up in the recipient country, i.e. $c^g_A < 0$. The total factor demand of public pollution abatement v^g is equal to gc^g_w, while the total cost of public clean-up is gc^g.

Moreover, we assume that the total cost of public clean-up is covered using revenues from the emission tax:

$$gc^g\Big(w\left(p,t\right), A\Big) = t\left(\theta_1 e + \alpha\theta_2 e\right) = tz' \ , \tag{1}$$

where α $(0 \leq \alpha < 1)$ is the fraction of transboundary pollution affecting the donor country which is internalized by the recipient of aid and p is the relative price of the dirty good x. As emphasized by Brett and Keen (2000) as well as Schweinberger and Woodland (2008), the assumption of earmarking pollution tax revenues for abatement purposes is supported by substantial empirical evidence. Therefore, z' represents the total amount of pollution internalized due to the presence of the emission tax. When $\alpha = 0$, the recipient country does not internalize any of its emissions affecting the donor country. Totally differentiating (1)

[11] For model simplicity, public abatement is not an explicit option here for the donor. First, the donor is already internalizing all self-produced pollution. Secondly, public clean-up of transboundary pollution is indirect and would be difficult to implement (e.g. acid rain).

yields:

$$c^g dg = tdz' - gc_p^g dp - gc_A^g dA \; . \tag{2}$$

This equation suggests that the change in public environmental clean-up depends on the changes in tax revenues and goods prices, as well as on the effectiveness of foreign assistance at reducing the cost of abatement.

The recipient country's budget constraint calls for total expenditures E on private goods x and y to be equal to the sum of revenues from production R and tax revenues:

$$E\left(p, z - \theta_1 g, u\right) = R\left(p, t, g\right) + tz', \tag{3}$$

where $E\left(p, z - \theta_1 g, u\right) = \min\left\{d_y + pd_x : u = \phi\left(d_x, d_y\right) + \psi\left(z - \theta_1 g\right)\right\}$ and $R\left(p, t, g\right) =$ $= \max\left\{y + px - tz' : \left(y, x, z'\right) \in T\left(v^p\right)\right\}$, are the expenditure and revenue functions for the recipient economy, respectively. d_x and d_y denote the demand for goods x and y, respectively, $T(v^p)$ is the production technology for the private goods and u is the consumers' utility. We assume that the latter is additively separable in goods and pollution, and that pollution is harmful ($\psi_z < 0$). Notice that the transfer has no direct impact on revenues in the recipient. Totally differentiating (3) yields the change in the recipient country's welfare:

$$E_u du = -M dp - E_z dz + tdz' + \left(\theta_1 E_z - c^g\right) dg \; , \tag{4}$$

where $M = d_x - x < 0$ is the recipient country's export of good x to the donor, $E_u = 1$ by choice of units and E_z is the marginal willingness to pay for a unit reduction in pollution in the recipient. Equation (4) indicates that foreign aid affects social welfare in the recipient country through the terms-of-trade effect as well as its effects on the levels of local pollution, pollution that is internalized, and environmental clean-up.

As for the donor country, its budget constraint is as follows:

$$E^*\left(p, z^* - \theta_2 g, u^*\right) = R^*\left(p\right) - \gamma A \; , \tag{5}$$

where γ corresponds to the marginal cost of the environmental technology transfer for the donor $(0 < \gamma)$[12] and "$*$" denotes the same variables as previously but for the donor country. Since there is no (unabated) pollution generated in the donor country, the revenue function $R^*(p)$ depends only on the commodity price p. One can determine the change in the donor country's welfare by totally differentiating (5):

$$E_u^* du^* = -\gamma dA + M dp - E_{z^*}^* dz^* + \theta_2 E_{z^*}^* dg \ , \tag{6}$$

where $M = x^* - d_x^* < 0$ is the donor's import of good x from the recipient, and we set $E_u^* = 1$ by choice of units. Equation (6) shows that the change in the donor country's welfare depends on the direct effect of the transfer on income, on the terms-of-trade effect, as well as on the change in pollution level and in environmental clean-up in the recipient country, since pollution in the recipient country is transboundary.

The world goods market clearing requires that the recipient country's export of good x be equal to its counterpart's import of the same good:

$$E_p(p, z - \theta_1 g, u) + E_p^*(p, z^* - \theta_2 g, u^*) = R_p(p, t, g) + R_p^*(p) \ . \tag{7}$$

Indeed, from the above revenues and expenditures functions we obtain the demand of x as $E_p = d_x$ $(E_p^* = d_x^*)$ and the supply of x as $R_p = x$ $(R_p^* = x^*)$. Totally differentiating (7) yields:

$$S_{pp} dp = R_{pg} dg - E_{pu} du - E_{pu^*}^* du^* - E_{pz} d(z - \theta_1 g) - E_{pz^*}^* d(z^* - \theta_2 g) , \tag{8}$$

where $S_{pp} = E_{pp} + E_{pp}^* - R_{pp} - R_{pp}^* < 0$, since $E_{pp}\left(= \frac{\partial d_x}{\partial p}\right) < 0$, $E_{pp}^*\left(= \frac{\partial d_x^*}{\partial p}\right) < 0$, $R_{pp}\left(= \frac{\partial x}{\partial p}\right) > 0$, and $R_{pp}^*\left(= \frac{\partial x^*}{\partial p}\right) > 0$, $R_{pg}\left(= \frac{\partial x}{\partial g}\right) < 0$, $E_{pu}\left(= \frac{\partial d_x}{\partial u}\right) > 0$, $E_{pu^*}^*\left(= \frac{\partial d_x^*}{\partial u^*}\right) > 0$, $E_{pz}\left(= \frac{\partial d_x}{\partial z}\right) > 0$, and $E_{pz^*}^*\left(= \frac{\partial d_x^*}{\partial z^*}\right) > 0$. It is worth mentioning that $\frac{\partial x}{\partial g} < 0$ follows from the

[12] We leave γ unrestricted from above here, since plausible scenarios can be imagined for both $\gamma \leq 1$ (e.g. the cost to the donor may be less than the benefit for the recipient, for instance when the development of the cleaner technology has positive spillovers) and $\gamma > 1$ (e.g. as opportunity cost when superior competing purchase offers exist for the technology, for instance from third countries where the marginal benefit exceeds the one in the recipient).

fact that public clean-up activities crowd out the production of good x to a certain extent. Moreover, $\frac{\partial d_x}{\partial z} > 0$ $\left(\frac{\partial d_x^*}{\partial z^*} > 0\right)$ implies that an increase in the level of pollution leads to an increase in demand for commodity x in order to compensate for the lost utility.[13]

Using Sheppard's lemma we can write the level of the internalized pollution z', as well as the pollution levels in the recipient and donor countries z and z^*, as follows:

$$z' = \theta_1 e + \alpha\theta_2 e = -R_t \tag{9}$$

$$z = \theta_1 e = -\frac{\theta_1}{\theta_1 + \alpha\theta_2} R_t \tag{10}$$

$$z^* = \theta_2 e = -\frac{\theta_2}{\theta_1 + \alpha\theta_2} R_t \ . \tag{11}$$

As assumed above, the recipient country internalizes only a fraction α of the transboundary pollution, as opposed to the full amount affecting its own residents.

The changes in these pollution levels correspond to:

$$dz' = -\left(R_{tp}dp + R_{tg}dg\right) \tag{12}$$

$$dz = -\frac{\theta_1}{\theta_1 + \alpha\theta_2}\left(R_{tp}dp + R_{tg}dg\right) \tag{13}$$

$$dz^* = -\frac{\theta_2}{\theta_1 + \alpha\theta_2}\left(R_{tp}dp + R_{tg}dg\right) \ , \tag{14}$$

where $R_{tp} = -\frac{\partial z}{\partial p} = -\frac{\partial z}{\partial x}\frac{\partial x}{\partial p}$ and $R_{tg} = -\frac{\partial z}{\partial g} = -\frac{\partial z}{\partial x}\frac{\partial x}{\partial g} = -c_t^g$ capture the responses of the level of pollution in the recipient country to an increase in the price of x and the amount of public abatement efforts, respectively. It is straightforward to see that $R_{tp} < 0$ whenever x is a normal good (a higher price of x increases its output), and $R_{tg} > 0$ if factor intensities of dirty good production x and public abatement g are such that they compete for some of the same resources.[14]

[13] The indifference curves between a good x and the bad z have a positive slope. See Copeland (1994) and Chao and Yu (1999).

[14] $R_{tg} < 0$ if the production of x and public abatement efforts g do not compete for resources at all. We consider the first scenario (i.e. $R_{tg} > 0$) to be more plausible, which is also consistent with Chao and Yu (1999).

With the equations (2), (4), (6), (8), (12), (13), and (14), we form a system of seven equations in seven unknowns: g, u, u^*, p, z', z and z^*. The system contains two policy instruments: one for the donor country, i.e. the amount of tied foreign aid, and the other for the recipient country, i.e. the level of the emission tax. The following section uses this system to analyze the welfare effects of green foreign aid in the recipient and donor countries.

4. The Effects of Green Technology Transfers

Like all foreign aid, green technical assistance has both a direct effect on consumption decisions and an indirect effect via changes in the goods prices.The papers obtaining the 'aid paradox' of donor enrichment and recipient immiserization generally assume that the donor is experiencing a terms of trade (ToT) gain that outweighs the direct negative welfare effect of the transfer. In the aid for pollution abatement case à la Chao and Yu (1999) what is then needed is the somewhat particular assumption that the donor exports the dirty good in equilibrium. With transboundary pollution this is no longer a requirement: the donor country may be importing the dirty good from the recipient of aid and may still gain due to strong environmental benefits. In view of the evidence suggesting that the manufacturing center of gravity is shifting to the global South, we regard this as the more likely scenario.

Let us first examine the terms-of-trade effect of tied aid. This effect can be found by substituting relations (2), (4), (6), (12), (13), and (14) into (8) to obtain:

$$\frac{dp}{dA} = \frac{\theta_1 E_z \left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m_x - m_z)}{G} + \frac{\left[\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right) + (c^g + tR_{tg})\frac{\gamma}{gc^g_A}\right]m^*_x}{G} - \\ - \frac{\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)m^*_{z^*}}{G} - \frac{[pR_{pg} + (c^g + tR_{tg})\,m_x]}{G}, \quad (15)$$

where $m_x = pE_{pu}$ ($m^*_x = pE^*_{pu^*}$) represents the marginal propensity to consume good x in the recipient (donor) country,[15] $m_z = \frac{pE_{pz}}{E_z}$ ($m^*_{z^*} = \frac{pE^*_{pz^*}}{E^*_{z^*}}$) corresponds to the degree of

[15] Actually $m_x = \frac{pE_{pu}}{E_u}$, but E_u is normalized to one.

substitution between good x and pollution z, and

$$G = \frac{c^g + tR_{tg}}{gc_A^g} \cdot \Bigg\{ (pS_{pp} - tm_x R_{tp}) + M\left(m_x^* - m_x\right) + \left(tR_{tp} + gc_p^g\right) \cdot \left(\frac{pR_{pg}}{c^g + tR_{tg}} + m_x\right) + \\ + \Big[\theta_1 E_z \left(m_z - m_x\right) + \theta_2 E_{z^*}^* (m_z^* - m_x^*)\Big] \cdot \left[\left(1 + \frac{R_{tg}}{\theta_1 + \alpha\theta_2}\right) \cdot \frac{tR_{tp} + gc_p^g}{c^g + tR_{tg}} - \frac{R_{tp}}{\theta_1 + \alpha\theta_2}\right] \Bigg\},$$

with $G > 0$ according to the stability conditions detailed in Appendix A.

The first term on the right-hand side of (15) corresponds to the indirect price effects of aid, via the ensuing increase in the quality of the environment and savings on abatement. As the green technology transfer generates savings in terms of abatement expenses in the recipient, the demand for good x increases according to m_x. At the same time, since the environment quality improves, the demand for x decreases in accordance to m_z. This combined effect exerts an upward pressure on the price whenever $m_x > m_z$, which follows from the stability conditions. The second and the third terms correspond to similar effects on the relative price of x, this time from the donor's side. Lower disposable income and a better environmental quality in the donor tend to decrease demand for good x directly and indirectly, as required to compensate for pollution according to m_z^*. This exerts a negative impact on the price. The last term represents another indirect price effect of aid and the general equilibrium impact exerted on the prices of goods by the increased clean-up efforts, via factor prices. The increase in abatement efforts, following foreign aid, partially crowds out the production of good x, which leads to an increase in the equilibrium price of x. Also, the demand for x depends on the clean-up cost c_g and the impact of clean-up on total collected emission tax revenues.

Therefore we can state the following intermediary result:

Lemma 1. *The terms of trade effect of the green transfer is positive* $\left(\frac{dp}{dA} > 0\right)$ *when* m_x^*, *is relatively small and/or* c_A^g *is high in absolute value (the technology is effective enough). When* m_x^* *is relatively large and/or* c_A^g *is low in absolute value, the terms of trade effect of the transfer is negative* $\left(\frac{dp}{dA} < 0\right)$.

The intuition is based on the following demand and supply considerations. While the cost of the transfer tends to depress the donor share of world demand for x without directly increasing the recipient-based share, a relatively low marginal propensity to consume the polluting good in the donor dampens this effect. An effective technology makes public abatement of pollution more effective than x production in using the shared factors, and thus 'crowds-out' the latter. These demand and supply effects combined produce a positive terms of trade outcome. The intuition is the same only reversed for the second part of the lemma.

Chao and Yu (1999) assume identical marginal propensities to consume in the two countries in order to obtain a positive terms of trade effect for the dirty good exporter donor. Naito (2003) shows that even untied environmental aid can generate a Pareto optimal outcome in the more empirically plausible case when the marginal propensity to consume the dirty good is larger in the donor, such that the terms of trade effect again favors the donor. We follow Naito (2003) in allowing for different marginal propensities to consume good x in the two countries. In addition, as mentioned above, we also allow for the recipient to be the equilibrium net exporter of the dirty good. Therefore, depending on the parameters, both an increase or a decrease in the price of good x are possible as a result of the green technology transfer. What is new here is that the donor may gain in welfare terms (and a Pareto-improvement is possible) with or without a terms of trade gain, as we argue further below.

Next we look at the effect of the transfer on public pollution abatement. From equations (2) and (12), we have:

$$\frac{dg}{dA} = \frac{-\left(tR_{tp} + gc_p^g\right)\frac{dp}{dA} - gc_A^g}{\left(c^g + tR_{tg}\right)} \ .$$

If $\frac{dp}{dA} < 0$, then $\frac{dg}{dA} > 0$ unambiguously. When $\frac{dp}{dA} > 0$, $\frac{dg}{dA}$ could be negative at first sight. This could potentially be the case as the increase in the price of x, following the increase in the level of foreign aid, gives rise to a significant increase in the economic cost of environmental clean-up relative to the production of the dirty good. Interestingly however, we find that the public abatement change in the recipient is always positive, even when the terms of trade effect is positive, $\frac{dp}{dA} > 0$. This holds under the stability conditions detailed in Appendix A and whenever good x has a normal output response to price changes.[16]

By substituting (15) in the above equation, we get an explicit expression for the change in abatement

$$\frac{dg}{dA} = \frac{1}{G}\Big\{ -\left(tR_{tp} + gc_p^g\right)\frac{\gamma}{gc_A^g}m_x^* - M\left(m_x^* - m_x\right) - \left(pS_{pp} - tm_xR_{tp}\right) - \\ -\left[\theta_1 E_z\left(m_x - m_z\right) + \theta_2 E_{z^*}^*\left(m_x^* - m_z^*\right)\right]\frac{R_{tp}}{\theta_1 + \alpha\theta_2}\Big\} > 0. \quad (16)$$

Proposition 1. *Green technological transfer always induces more public abatement in the recipient, when the recipient is the exporter of the dirty good ($M < 0$), the marginal propensity to consume x is weakly larger in the donor than in the recipient ($m_x^* \geq m_x$) and the market for x is Walras-stable.*

This result also holds when the donor exports x in equilibrium and the recipient has a larger marginal propensity to consume the polluting good, although for reasons explained above this is not our preferred scenario. It is worth emphasizing here that green technology transfer appears more likely to be effective in increasing pollution abatement in the recipient than conditional monetary transfers.[17]

The above proposition indicates that there will be more public abatement of pollution after the donation. Does this mean there will be a cleaner environment overall? Not necessarily. While more abatement is undertaken, there may also be more production of x as a result of a potentially positive terms of trade effect, and thus more pollution. We now move to analyze the effect of the green technology transfer on pollution levels in the two countries. From (13) and (14), we have:

$$\frac{dz}{dA} = -\frac{\theta_1}{\theta_1 + \alpha\theta_2}\left(R_{tp}\frac{dp}{dA} + R_{tg}\frac{dg}{dA}\right)$$
$$\frac{dz^*}{dA} = -\frac{\theta_2}{\theta_1 + \alpha\theta_2}\left(R_{tp}\frac{dp}{dA} + R_{tg}\frac{dg}{dA}\right).$$

[16] The last sufficient condition is derived from: $R_{tp} = -\frac{dz}{dx}\frac{dx}{dp} < 0$.

[17] Chao and Yu (1999), for instance, require identical marginal propensities to consume good x in the two countries in order to obtain this result.

Using the result in Proposition 1, there will be less pollution overall when the transfer induces a lowering of the international price of x: $\frac{dz}{dA} < 0$ and $\frac{dz^*}{dA} < 0$ if $\frac{dp}{dA} < 0$. In such a case there is both less production of x and more cleanup. However, even when the price effect is positive, there will be less pollution when the clean-up effect is strong enough. But we can also have $\frac{dz}{dA} > 0$ and $\frac{dz^*}{dA} > 0$ when $\frac{dp}{dA} > 0$ and $\frac{dg}{dA} < \left(-\frac{R_{tp}}{R_{tg}}\right)\frac{dp}{dA}$, i.e. when the clean-up effect is relatively small compared to the terms of trade (ToT) effect.

By substituting (15) and (16) in the above equations and after the necessary substitutions we have:

$$\frac{dz}{dA} = \frac{\theta_1 \left\{ \left(pR_{pg} + c^g m_x\right) R_{tp} - \left[\theta_1 E_z \left(m_x - m_z\right) + \theta_2 E^*_{z^*} \left(m^*_x - m^*_{z^*}\right)\right] R_{tp} \right\}}{\left(\theta_1 + \alpha\theta_2\right) G} - $$
$$-\frac{\theta_1 \left\{ \left(c^g R_{tp} - g c^g_p R_{tg}\right) \frac{\gamma}{g c^g_A} m^*_x - \left[M \left(m^*_x - m_x\right) + pS_{pp}\right] R_{tg} \right\}}{\left(\theta_1 + \alpha\theta_2\right) G}. \tag{17}$$

The sign of $\frac{dz}{dA}$ is ambiguous in general. It depends on a positive first component (again assuming $\frac{dp}{dA} > 0$) which represents the pollution increasing effect of higher prices via more production, and a negative second component corresponding to the clean-up effect on pollution. Signing expression (17) relies on the stability conditions and on the assumption that x is a normal good.

Turning now to the pollution level in the donor country, we have:

$$\frac{dz^*}{dA} = -\frac{\theta_2}{\theta_1 + \alpha\theta_2} R_{tp} \frac{dp}{dA} - \frac{\theta_2}{\theta_1 + \alpha\theta_2} R_{tg} \frac{dg}{dA},$$

or

$$\frac{dz^*}{dA} = \frac{\theta_2 \left\{ \left(pR_{pg} + m_x c^g\right) R_{tp} - \left[\theta_1 E_z \left(m_x - m_z\right) + \theta_2 E^*_{z^*} \left(m^*_x - m^*_{z^*}\right)\right] R_{tp} \right\}}{\left(\theta_1 + \alpha\theta_2\right) G} - $$
$$-\frac{\theta_2 \left\{ \left(c^g R_{tp} - g c^g_p R_{tg}\right) \frac{\gamma}{g c^g_A} m^*_x - \left[M \left(m^*_x - m_x\right) + pS_{pp}\right] R_{tg} \right\}}{\left(\theta_1 + \alpha\theta_2\right) G}. \tag{18}$$

The sign of $\frac{dz^*}{dA}$ is also ambiguous when $\frac{dp}{dA} > 0$, depending again on a positive price effect of pollution component and a negative component corresponding to the clean-up effect on pollution.

Proposition 2. *The green technology transfer reduces the equilibrium level of pollution in both the recipient and the donor countries when the clean-up effect dominates any positive price effect. If the transfer has a negative terms of trade effect, the effect of the transfer on pollution is unambiguously negative.*

Let us now turn to the global welfare effects of the green technology transfer. Adding equations (4) and (6) yields the following:

$$\frac{du + du^*}{dA} = (t - E_z)\frac{dz}{dA} + (\theta_1 E_z + \theta_2 E^*_{z^*} - c^g)\frac{dg}{dA} + (\alpha t - E^*_{z^*})\frac{dz^*}{dA} - \gamma \tag{19}$$

If total environmental gains (in both countries) exceed total economic cost of clean-up activities in the recipient country and the direct economic cost of the transfer to the donor, then tied foreign aid tends to improve global welfare. More specifically, the coefficients of the pollution change terms in (19) are negative, since the environmental policy regime in the recipient is less than efficient by assumption (recall that $t < E_z$ and $\alpha t < E^*_{z^*}$), while the coefficient of the clean-up spending change is positive whenever abatement is socially desirable, or an appropriately weighted average of the marginal willingness to pay for pollution reduction in the two countries exceeds the marginal cost of abatement: $\theta_1 E_z + \theta_2 E^*_{z^*} > c^g$. We then substitute (16), (17), (18) in the above equation and after some further manipulation, we obtain the explicit expression for the change in global welfare after the green transfer, which can be found in Appendix C. This explicit expression is too complicated to yield any further economic intuition. Still, we can conclude from (19) that as long as the conditions in Proposition 2 hold, or parameters are such that the clean-up effect is larger than the price effect, the green technology transfer leads to an improvement in the combined welfare of the two countries.

From equation (4), we can express the welfare effect in the recipient as:

$$\frac{du}{dA} = -M\frac{dp}{dA} + \alpha t \frac{dz^*}{dA} + (t - E_z)\frac{dz}{dA} + (\theta_1 E_z - c^g)\frac{dg}{dA}. \tag{20}$$

When there is an increase in the price of the polluting good ($\frac{dp}{dA} > 0$), the recipient's welfare increases if the environmental effect and the ToT effect of foreign aid are strong enough to compensate for the net economic cost of environmental clean-up. Even when $\frac{dp}{dA} < 0$, the recipient's welfare may still increase if the environmental effect of foreign aid is strong enough to compensate for the economic cost of environmental clean-up and the recipient's terms of trade loss. On one hand, as one would expect, when there is a relatively efficient pollution taxation regime such that the tax rate is close to the marginal damage of pollution ($t \approx E_z$), the welfare effect of pollution changes in the recipient is negligible. Likewise, the pollution changes in the donor do not affect recipient's welfare when the tax rate is small and/or the coefficient of internalization of cross-boundary pollution (α) is small. This second effect provides justification for the following section of the paper, in which green technology transfer is complemented with a border tax adjustment that aims to target the transboundary externality more directly. On the other hand, when the recipient country does not significantly internalize the domestic pollution externality (such that $t \ll E_z$), any changes in pollution following such targeted foreign aid have substantial welfare effects in the recipient.

Similarly, the change in welfare in the donor is:

$$\frac{du^*}{dA} = -\gamma + M\frac{dp}{dA} - E^*_{z^*}\frac{dz^*}{dA} + \theta_2 E^*_{z^*}\frac{dg}{dA}. \tag{21}$$

When $\frac{dp}{dA} > 0$, the donor's welfare increases if the environmental effect of foreign aid is strong enough to compensate for the donor's monetary and terms of trade losses. When $\frac{dp}{dA} < 0$, the donor's welfare increases if its environmental and terms of trade gains are strong enough to compensate for the monetary loss associated with the transfer. The analytical solutions for the individual welfare effects are provided in Appendix C. The welfare effects can be summarized as follows:

Proposition 3. *When the recipient of the green technology transfer is the net exporter of the polluting good: i. The recipient always gains in welfare terms when the environmental benefit is large enough to compensate for a potentially negative ToT effect; ii. The donor country can gain when the net environmental benefit of the transfer exceeds the direct cost of the transfer and the potential terms of trade loss.*

Comparing these results to the literature,[18] we can obtain a Pareto-improvement effect of the green transfer both when the donor experiences a positive and an adverse terms of trade effect, in the latter case provided that the environmental benefits are strong enough. Depending on the parameters, the 'normal result' of recipient enrichment and donor immiserization and the 'transfer paradox' when the opposites hold, may also occur in our setting. The former is possible, for instance when the increase in the price of x is relatively large compared to the environmental benefits experienced by the donor as a result of the transfer, while the latter may obtain when the signs of these effects are reversed.

In the setting described at the beginning, there are two levels of inefficiency that characterize environmental policy in the recipient country. One is the failure to undertake an efficient level of public abatement of pollution affecting domestic consumers, and the other is the incomplete taxation of transboundary pollution. While the technology transfer lowers the marginal cost of public abatement in the recipient country and thus is likely to induce lower levels of unabated pollution that spills over borders to affect the donor, there is still an incomplete degree of internalization of the cross-border externality, measured by $\alpha < 1$. We now move to examine the effects of the green transfer when combined with an appropriate border tax adjustment that aims to tackle the transboundary externality more directly.

5. The Effects of Green Technology Transfers Combined with a Border Tax Adjustment

Border tax adjustments (BTAs) are increasingly being put forth as a tool to address differences in the stringency of environmental regulation. In the context of foreign assistance, the case for BTAs is perhaps made even more convincing by the following observations. First, BTAs can help to ensure that the recipient does not misuse the donation. Second, in the presence of an effective green technology transfer, the affordability argument used by developing countries to legitimize environmental protection inaction is less credible. Moreover,

[18] E.g. Chao and Yu (1999) and Hatzipanayotou, Lahiri and Michael (2002).

as argued above in discussing parameter α, the recipient of aid may chose to internalize little or no part of the transboundary pollution affecting the donor. In this section we assess the merits of such BTAs in our context. Will a border tax targeting the incomplete internalization of cross-border pollution, combined with the green technology transfer work?

In what follows, we introduce a border tax adjustment and repeat the exercises in the previous section. The budget constraint in the recipient country can be written as follows:

$$E\left(p-\tau, z-\theta_1 g, u\right)=R\left(p-\tau, t, g\right)+t z' \tag{22}$$

where τ is the border tax adjustment.

Totally differentiating the above equation yields

$$E_p d\left(p-\tau\right)+E_u du+E_z d\left(z-\theta_1 g\right)=R_p d\left(p-\tau\right)+R_g dg+t dz' \ . \tag{23}$$

This is equivalent to

$$E_u du=-M dp-E_z dz+t dz'+\left(\theta_1 E_z-c^g\right) dg+M d\tau, \tag{24}$$

where $M=E_p-R_p=d_x-x<0$.

The budget constraint in the donor country is:

$$E^*\left(p, z^*-\theta_2 g, u^*\right)=R^*\left(p\right)-\gamma A-\tau M \ . \tag{25}$$

where $M=d_x-x=x^*-d_x^*<0$. Totally differentiating the above equation yields:

$$E_p^* dp+E_{u^*}^* du^*+E_{z^*}^* d\left(z^*-\theta_2 g\right)=R_p^* dp-\gamma dA-\tau dM-M d\tau \ , \tag{26}$$

which is also equivalent to:

$$E_{u^*}^* du^*=-\gamma dA+M dp-E_{z^*}^* dz^*+\theta_2 E_{z^*}^* dg-\tau dM-M d\tau. \tag{27}$$

The world market clearing condition is now:

$$E_p\left(p-\tau, z-\theta_1 g, u\right)+E_p^*\left(p, z^*-\theta_2 g, u^*\right)=R_p\left(p-\tau, t, g\right)+R_p^*\left(p\right) \ . \tag{28}$$

Totally differentiating (28) yields:

$$S_{pp}dp = R_{pg}dg - E_{pu}du - E^*_{pu^*}du^* - E_{pz}d\left(z - \theta_1 g\right) - E^*_{pz^*}d\left(z^* - \theta_2 g\right) + M_p d\tau, \tag{29}$$

where $M_p = E_{pp} - R_{pp} < 0$.

Substituting (2), (12), (13), (14), (24), and (27) in (29) yields:

$$\Big\{ (pS_{pp} - tm_x R_{tp}) + M\left(m^*_x - m_x\right) + (tR_{tp} + gc^g_p)(\tfrac{pR_{pg}}{c^g + tR_{tg}} + m_x) +$$
$$+\theta_2 E^*_{z^*}\left(m^*_z - m^*_x\right)\left[\left(\tfrac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right)\tfrac{tR_{tp}+gc^g_p}{c^g+tR_{tg}} - \tfrac{R_{tp}}{\theta_1+\alpha\theta_2}\right] +$$
$$+\theta_1 E_z\left(m_z - m_x\right)\left[\left(\tfrac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right)\tfrac{tR_{tp}+gc^g_p}{c^g+tR_{tg}} - \tfrac{R_{tp}}{\theta_1+\alpha\theta_2}\right] - m^*_x \tau M_p\Big\} dp =$$
$$= \Big\{\theta_1 E_z\left(\tfrac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right)\left(m_x - m_z\right) + \left[\theta_2 E^*_{z^*}\left(\tfrac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right) + \left(c^g + tR_{tg}\right)\tfrac{\gamma}{gc^g_A}\right] m^*_x -$$
$$-\theta_2 E^*_{z^*}\left(\tfrac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right) m^*_{z^*} - \left[pR_{pg} + m_x\left(tR_{tg} + c^g\right)\right]\Big\}\tfrac{gc^g_A}{c^g+tR_{tg}} dA + \left(pM_p - m_x M + m^*_x M\right) d\tau$$

By using the comparative static approach, we can examine the terms of trade effects of the technology transfer and the border tax adjustment (BTA):

$$\frac{dp}{dA}|_{BTA} = \frac{1}{H}\{\theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right)\left(m_x - m_z\right) + [\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right) + \left(c^g + tR_{tg}\right)\frac{\gamma}{gc^g_A}] m^*_x -$$
$$-\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right) m^*_{z^*} - \left[pR_{pg} + m_x\left(tR_{tg} + c^g\right)\right]\} \tag{30}$$

and

$$\frac{dp}{d\tau} = \frac{\left[pM_p + M\left(m^*_x - m_x\right)\right]\left(c^g + tR_{tg}\right)}{gc^g_A H} > 0 \tag{31}$$

where

$$H = \frac{c^g + tR_{tg}}{gc^g_A}\{(pS_{pp} - tm_x R_{tp}) + M\left(m^*_x - m_x\right) + tR_{tp} + gc^g_p)\left(\frac{pR_{pg}}{c^g + tR_{tg}} + m_x\right) +$$
$$+\left[\theta_1 E_z\left(m_z - m_x\right) + \theta_2 E^*_{z^*}\left(m^*_z - m^*_x\right)\right]\left[\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2} + 1\right)\frac{tR_{tp}+gc^g_p}{c^g+tR_{tg}} - \frac{R_{tp}}{\theta_1+\alpha\theta_2}\right] - m^*_x \tau M_p\}$$

with $H > 0$ according to the stability conditions provided in Appendix B.

Compared to the case without a BTA, the numerator of $\frac{dp}{dA}$ does not change, while its denominator has a new negative component in terms of τ. The above results can be summarized in the following intermediary result:

Lemma 2. *The border tax adjustment has a positive ToT effect (i.e. $\frac{dp}{d\tau} > 0$). Moreover, it increases the absolute value of the ToT effect of the technology transfer ($\left|\frac{dp}{dA}|_{BTA}\right| > \left|\frac{dp}{dA}\right|$).*

Intuitively, the revenue shifting induced by the border tax adjustment in conjunction with the assumed larger marginal propensity to consume the polluting good in the donor leads to a higher equilibrium relative price. Looking now at the change in the public abatement of pollution in the recipient:

$$\frac{dg}{dA}\Big|_{BTA} = \frac{-\left(tR_{tp} + gc_p^g\right)\frac{dp}{dA} - gc_A^g}{(c^g + tR_{tg})}.$$

It is straightforward to notice that a negative terms of trade effect would lead to more public abatement of pollution. Not only is technology transfer making g cheaper at the margin, but the lower price decreases production of x and freeing more of the shared factors of production for public abatement. Upon substituting the terms of trade effect expression, this becomes

$$\frac{dg}{dA}|_{BTA} = \frac{1}{H}\Big\{-\left(tR_{tp} + gc_p^g\right)\frac{\gamma}{gc_A^g}m_x^* - M\left(m_x^* - m_x\right) - \left(pS_{pp} - tm_xR_{tp}\right) + [\theta_1 E_z(m_z - m_x) + \\ +\theta_2 E_{z^*}^*(m_{z^*} - m_x^*)]\frac{R_{tp}}{\theta_1 + \alpha\theta_2} + m_x^*\tau M_p\Big\}. \tag{32}$$

By comparing (32) with (16), we can show that the denominator of (32) is lower than that of (16) and (32) has a new negative component on the numerator. Thus, technological transfer can give rise to both more or less clean-up efforts when used alone than when combined with a BTA. Expressing this difference as:

$$\frac{dg}{dA}|_{BTA} - \frac{dg}{dA} = \frac{m_x^*\tau M_p\left(tR_{tp} + gc_p^g\right)}{gc_A^g HG}\Big\{\left(pR_{pg} + m_x\left(c^g + tR_{tg}\right)\right) + [\theta_1 E_z\left(m_z - m_x\right) + \\ +\theta_2 E_{z^*}^*\left(m_{z^*} - m_x^*\right)]\left(\frac{R_{tg}}{\theta_1 + \alpha\theta_2} + 1\right) - \left(c^g + tR_{tg}\right)\frac{\gamma}{gc_A^g}m_x^*\Big\}.$$

leads to the following result.

Proposition 4. *The presence of the BTA reduces the effectiveness of the green technology transfer at increasing public pollution abatement if m_x^* is relatively small and/or c_A^g is high in* *absolute value.*[19] *The amount of public pollution abatement in the recipient country can even decrease below its pre-transfer level if τ is sufficiently high.*

Turning to the changes in pollution, we substitute (30) and (32) into (13) and obtain:

$$\frac{dz}{dA}|_{BTA}=\frac{\theta_1}{(\theta_1+\alpha\theta_2)\,H}\{(pR_{pg}+c^g m_x)\,R_{tp}-[\theta_1 E_z\,(m_x-m_z)+\theta_2 E^*_{z^*}\,(m^*_x-m^*_{z^*})]\,R_{tp}-$$
$$-\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x+[M\,(m^*_x-m_x)+pS_{pp}]\,R_{tg}-m^*_x\tau M_p R_{tg}\}. \tag{33}$$

Comparing (17) and (33), we can see that the latter has a new positive component on the numerator. The denominator still has one new negative component. Then, when the transfer used alone increases pollution in the recipient ($\frac{dz}{dA}>0$, i.e. the green technology transfer is ineffective at reducing pollution), the introduction of the BTA makes the situation even worse as it generates more pollution. When the transfer used alone decreases pollution in the recipient ($\frac{dz}{dA}<0$), the introduction of the BTA may increase or decrease the effectiveness of the technology transfer.

$$\frac{dz}{dA}|_{BTA}-\frac{dz}{dA}=\frac{\theta_1 m^*_x\tau M_p\,(c^g+tR_{tg})}{(\theta_1+\alpha\theta_2)\,gc^g_A HG}\Bigg\{[pR_{pg}+(c^g+tR_{tg})\,m_x]\,R_{tp}+$$
$$+\theta_1 E_z\,(m_x-m_z)\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(R_{tg}\frac{tR_{tp}+gc^g_p}{c^g+tR_{tg}}-R_{tp}\right)+$$
$$+\theta_2 E^*_{z^*}\,(m^*_x-m^*_{z^*})\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(R_{tg}\frac{tR_{tp}+gc^g_p}{c^g+tR_{tg}}-R_{tp}\right)-$$
$$-\left(tR_{tp}+gc^g_p\right)\left(\frac{pR_{pg}}{c^g+tR_{tg}}+m_x\right)R_{tg}-\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x\Bigg\}.$$

The introduction of the BTA decreases the effectiveness of the green technology transfer at reducing pollution in the recipient (i.e. $\frac{dz}{dA}|_{BTA}-\frac{dz}{dA}>0$) if $(c^g R_{tp}-gc^g_p R_{tg})\frac{\gamma}{gc^g_A}m^*_x\simeq 0$, i.e. m^*_x is relatively small and/or c^g_A is high in absolute value (i.e, when the technology transfer is

[19] i.e, when the technology transfer is effective enough at reducing abatement costs. Note that these conditions match exactly those for $\frac{dp}{dA}>0$.

effective enough).[20] Thus, whenever there is a positive terms of trade effect of the transfer, the border tax adjustment instrument leads to a worsening of the equilibrium level of pollution in the recipient.

Substituting (30) and (32) into (14), we obtain the following expression for the change in donor pollution:

$$\frac{dz^*}{dA}|_{BTA} = \frac{\theta_2}{(\theta_1+\alpha\theta_2)\,H}\big\{ (pR_{pg}+m_x c^g)\,R_{tp} - [\theta_1 E_z\,(m_x-m_z)+\theta_2 E^*_{z^*}\,(m^*_x-m^*_{z^*})]\,R_{tp} -$$

$$-\left(c^g R_{tp} - gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x + [M\,(m^*_x-m_x)+pS_{pp}]\,R_{tg} - m^*_x\tau M_p R_{tg}\big\}. \tag{34}$$

Similar to the previous case where the technology transfer is the only instrument used to mitigate transboundary pollution, the above expression has an ambiguous sign. It has a lower denominator than (18), and its numerator has one new component which is always positive. Just like for the recipient country, we can show that when the use of the transfer alone increases pollution in the donor ($\frac{dz^*}{dA}>0$), the introduction of the BTA makes the situation even worse (it gives rise to more pollution). In turn, when the use of the technology transfer alone decreases pollution in the donor ($\frac{dz^*}{dA}<0$), the introduction of the BTA can either increase or decrease the effectiveness of the technology transfer. The introduction of the BTA decreases the effectiveness of the green technology transfer at reducing pollution levels in the donor ($\frac{dz^*}{dA}|_{BTA}-\frac{dz^*}{dA}>0$), if $\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x \simeq 0$, i.e. m^*_x is relatively small and/or c^g_A is high in absolute value (i.e, when the technology transfer is effective enough).

$$\frac{dz^*}{dA}|_{BTA} - \frac{dz^*}{dA} = \frac{\theta_2 m^*_x \tau M_p\,(c^g+tR_{tg})}{(\theta_1+\alpha\theta_2)\,gc^g_A HG}\Bigg\{ [pR_{pg}+(c^g+tR_{tg})\,m_x]\,R_{tp}+$$

$$+\theta_1 E_z\,(m_x-m_z)\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(R_{tg}\frac{tR_{tp}+gc^g_p}{c^g+tR_{tg}}-R_{tp}\right)+$$

$$+\theta_2 E^*_{z^*}\,(m^*_x-m^*_{z^*})\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(R_{tg}\frac{tR_{tp}+gc^g_p}{c^g+tR_{tg}}-R_{tp}\right)-$$

[20] Note again that these conditions match exactly those for $\frac{dp}{dA}>0$ and $\frac{dg}{dA}|_{BTA}-\frac{dg}{dA}<0$.

$$- \left(tR_{tp} + gc_p^g\right) \left(\frac{pR_{pg}}{c^g + tR_{tg}} + m_x\right) R_{tg} - \left(c^g R_{tp} - gc_p^g R_{tg}\right) \frac{\gamma}{gc_A^g} m_x^* \Bigg\}.$$

Proposition 5. *The border tax adjustment typically worsens the environmental outcome in the two countries and can only serve an environmental purpose when the technology transfer is itself ineffective at reducing the cost of public pollution abatement (i.e. $c_A^g \simeq 0$) or when the marginal willingness to consume the polluting good in the donor m_x^* is significantly high.*

We consider the welfare effects of the green transfer next. Adding equations (24) and (27), we obtain:[21]

$$\frac{du + du^*}{dA}|_{BTA} = (t - E_z) \frac{dz}{dA} + (\alpha t - E_{z^*}^*) \frac{dz^*}{dA} + (\theta_1 E_z + \theta_2 E_{z^*}^* - c^g) \frac{dg}{dA} - \gamma. \tag{35}$$

From the analysis above, we know that when the technology transfer is effective at reducing the cost of public pollution abatement and/or when the marginal willingness to consume the polluting good in the donor is significantly low, the transfer-induced change in abatement $\frac{dg}{dA}$ is always lower in (35) (with the BTA) than in (19) (without the BTA), while $\frac{dz}{dA}$ and $\frac{dz^*}{dA}$ are smaller in absolute value in (35) than in (19). Therefore, maintaining our assumptions that the existing tax in the recipient is inefficient ($t < E_z$ and $\alpha t < E_{z^*}^*$), abatement is socially desirable ($\theta_1 E_z + \theta_2 E_{z^*}^* > c^g$), and when the transfer is effective in curbing pollution ($\frac{dz}{dA} < 0$ and $\frac{dz^*}{dA} < 0$), the global welfare is larger when technological transfer is used alone than when it is combined with a border adjustment tariff.[22] This adds support to the often made claim that BTAs induce significant costs, related mostly to increase in protectionism.

The welfare change in the recipient country is:

$$\frac{du}{dA}|_{BTA} = -M \frac{dp}{dA} + (t - E_z) \frac{dz}{dA} + \alpha t \frac{dz^*}{dA} + (\theta_1 E_z - c^g) \frac{dg}{dA} \ . \tag{36}$$

[21] Recall that $E_u = E_{u^*}^* = 1$ by choice of units.

[22] Note that the reverse is true when the technology transfer is ineffective at reducing the cost of public pollution abatement and/or when the marginal willingness to consume the polluting good in the donor is significantly large.

As discussed above, for technology transfers effective at reducing the cost of public pollution abatement and/or significantly low marginal willingness to consume the polluting good in the donor, $\frac{dg}{dA}$ is always higher when the only instrument used is technological transfer than when the latter is combined with a border tax adjustment. This is also the case for the absolute values of $\frac{dz}{dA}$ and $\frac{dz^*}{dA}$. Therefore, when technical transfer is effective in reducing the level of pollution ($\frac{dz}{dA} < 0$ and $\frac{dz^*}{dA} < 0$), the terms in $\frac{dz}{dA}$ and $\frac{dg}{dA}$ are always smaller in (36) than in (20), yielding a lower level of welfare in the recipient.[23] The term in $\frac{dz^*}{dA}$ is always smaller than its counterpart without the BTA.[24]As far as $\frac{dp}{dA}$ is concerned, when $\frac{dp}{dA} > 0$, the term in $\frac{dp}{dA}$ is larger in (36) than in (20). Therefore, the border tax adjustment is likely to induce lower welfare gains in the recipient country than the transfer alone when the former induces a small increase in the ToT effect.

Turning to the welfare change in the donor country, we obtain:

$$\frac{du^*}{dA}|_{BTA} = -\gamma + (M - \tau M_p) \frac{dp}{dA} - E^*_{z^*} \frac{dz^*}{dA} + \theta_2 E^*_{z^*} \frac{dg}{dA} \ . \tag{37}$$

Comparing again this result with its counterpart for the case without the border tax adjustment, the $\frac{dz^*}{dA}$ and $\frac{dg}{dA}$ terms are always smaller in (37) than in (21) when the technology transfer is effective at reducing the cost of public pollution abatement and/or when the marginal willingness to consume the polluting good in the donor is significantly low. When $\frac{dp}{dA} > 0$, the $\frac{dp}{dA}$ term can be smaller or larger in (37) than in (21). As shown above, the absolute value of the change in p is larger but the coefficient of $\frac{dp}{dA}$ is smaller in absolute value ($M < M - \tau M_p$). This suggests that a border tax can help the donor offset partially the negative impact of the ToT effect on its welfare. However, this occurs at the price of a decrease in the environmental benefits of the transfer. Moreover, recall that in this case we

[23]This holds under our assumptions that the tax rate is lower than the marginal willingness to pay for pollution reduction ($t < E_z$) and abatement is socially desirable in the recipient country ($\theta_1 E_z > c^g$).

[24] As shown above, the absolute magnitude of the change in donor pollution is lower as well, when the technology transfer is effective at reducing the cost of public pollution abatement and/or when the marginal willingness to consume the polluting good in the donor is significantly low.

can have less public abatement ($\frac{dg}{dA} < 0$), a result obtainable when there is a positive terms of trade effect ($\frac{dp}{dA} > 0$). Under such circumstances, the donor is more likely to experience a welfare deterioration as a result of the green transfer coupled with the border tax adjustment. This may lead to the so-called 'normal' effect of the transfer in which the recipient gains and the donor loses, thus rendering the incentive-compatibility of the voluntary transfer program problematic.

These results can be summarized as follows:

Proposition 6. *From a global welfare perspective, green technology transfers and border tax adjustments do not appear to be complements. The 'carrot and stick' approach - which uses both a green transfer targeted at reducing the costs of public abatement and a border tax adjustment- is dominated by the 'carrot only' approach -which uses the green transfer alone- when the latter is effective at dealing with the transboundary pollution problem. This holds for both recipient and donor countries when the change in the ToT effect following the introduction of the border tax is minimal.*

Hatzipanayotou, Lahiri and Michael (2002) also argue - without expanding too much on the reasons - that rewarding ('carrot-type') rather than punitive ('stick-type') measures are preferable. Here we show why this may be the case. Many argue that any green assistance project should be accompanied by a mechanism designed to ensure that the recipient country does not 'misbehave', for instance by treating cross-border pollution differently than domestic pollution. This paper shows that - contrary to this intuition - while the 'carrots' are likely to work and may even bring a Pareto-improvement, the use of sticks may backfire.

6. Conclusion

This paper contributes to the literature on the effects of foreign assistance directed at environmental goals. Pollution is generated as a byproduct in the manufacturing of a good. There is both private and public abatement of pollution in the recipient country. However, the system of environmental taxes is inefficient there on two grounds. Firstly, the tax rate is lower than the marginal willingness to pay for pollution abatement. Secondly, only a fraction of cross-boundary pollution affecting the neighbouring country/donor is taxed at even this lower-than-optimal rate. To focus on the effect of the transfer, we assume the donor perfectly internalizes its own emissions. The model specifies the tied aid as a green technological transfer that lowers the marginal abatement cost in the recipient country, which is the actual form taken by many foreign assistance programs focused on the environment.

Compared to the existing literature, the model allows for the more likely scenario that the donor is the importer of the polluting good in equilibrium. Even in such conditions, the green technology transfer can bring about a Pareto improvement, in which both the recipient and the donor gain in welfare terms. The results depend on the relative strength of three effects: the terms of trade effect, the environmental benefit and the direct cost of the transfer. When an additional instrument is used in the form of a border tax adjustment intended to correct for the transboundary externality, the environmental and welfare effects in both the recipient and the donor are shown to deteriorate whenever the transfer is effective.

The main results of this paper have interesting public policy ramifications. One of the key messages to policymakers is that green technology transfers, even as they increase abatement efforts in the recipient, may ultimately lead to a rise in pollution levels in both the donor and recipient countries when they boost the production of dirty goods. Whether or not BTAs can be used as a complement to green technology transfers to reduce transboundary pollution is another important policy question. This paper suggests that implementing BTAs - 'the stick' - carry significant costs, even when combined with green technology transfers - which function as a 'carrot'. As a consequence, the 'carrot-and-stick' combination is less efficient than the 'carrot' alone.

There exist several possible extensions of this paper, some of which we intend to explore in future work. Firstly, an important feature the paper did not consider in its modelling framework is that most of the recipients of green aid import from donor countries most of the goods and services that are used for pollution abatement and the conservation of the environment. This brings in the possibility that tied green aid, and green technology transfer in particular, may be desirable from the point of view of the donor country because it generates more revenues for its environmental goods and services industry. Secondly, this paper considers exogenous policy instruments (the emission tax in the recipient and the levels of technology transfer and BTA in the donor) for simplifying the analysis. However, by endogenizing these policy instruments, the political economy of the interaction between green technology transfers and BTAs could give rise to different welfare and environmental effects than those identified in this paper. Moreover, further research is needed concerning the more detailed differences between the various types of tied green aid. In particular, environmental assistance is often classified as either 'green' if destined for global or regional environmental issues such as climate change or biodiversity preservation, or 'brown' if earmarked for local environmental issues such as water and sanitation (Hicks et al., 2008). Since these two types of aid are characterized by different incentives from the donor point of view, it seems plausible that the welfare and environmental impacts could differ from one type to the other.

Appendix

A. Stability conditions - Green Technology Transfer

Walrasian stability implies that the slope of the global excess demand is negative, or:

$$\frac{d\left[E_p\left(p,z-\theta_1 g,u\right)+E_p^*\left(p,z^*-\theta_2 g,u^*\right)-R_p\left(p,t,g\right)-R_p^*\left(p\right)\right]}{dp}<0, \tag{A-1}$$

which is equivalent to

$$S_{pp}+E_{pz}\frac{dz}{dp}+E_{pz^*}^*\frac{dz^*}{dp}+E_{pu}\frac{du}{dp}+E_{pu^*}^*\frac{du^*}{dp}-\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz^*}^*\right)\frac{dg}{dp}<0 \tag{A-2}$$

Substituting (2), (4), (6), (12), (13), and (14) in the above equation gives

$$\begin{aligned}S_{pp}+E_{pz}\frac{\left[-\frac{\theta_1}{\theta_1+\alpha\theta_2}\left(R_{tp}dp+R_{tg}dg\right)\right]}{dp}+E_{pz^*}^*\frac{\left[-\frac{\theta_2}{\theta_1+\alpha\theta_2}\left(R_{tp}dp+R_{tg}dg\right)\right]}{dp}\\+E_{pu}\frac{\left[-Mdp-E_z dz+tdz'+\left(\theta_1 E_z-c^g\right)dg\right]}{dp}\\+E_{pu^*}^*\frac{\left[-\gamma dA+Mdp-E_{z^*}^*dz^*+\theta_2 E_{z^*}^*dg\right]}{dp}\\-\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz^*}^*\right)\frac{dg}{dp}<0\end{aligned}$$

or

$$S_{pp}-\frac{\theta_1}{\theta_1+\alpha\theta_2}E_{pz}R_{tp}-\frac{\theta_2}{\theta_1+\alpha\theta_2}E_{pz^*}^*R_{tp}-E_{pu}M+E_{pu^*}^*M+\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}E_{pu}R_{tp}-E_{pu}tR_{tp}+\frac{\theta_2 E_{z^*}^*}{\theta_1+\alpha\theta_2}E_{pu^*}^*R_{tp}$$

$$+\left[\begin{array}{c}-\frac{\theta_1}{\theta_1+\alpha\theta_2}E_{pz}R_{tg}-\frac{\theta_2}{\theta_1+\alpha\theta_2}E_{pz^*}^*R_{tg}-R_{pg}-\theta_1 E_{pz}-\theta_2 E_{pz^*}^*+\left(\theta_1 E_z-c^g\right)E_{pu}\\+\theta_2 E_{z^*}^*E_{pu^*}^*+\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}E_{pu}R_{tg}-E_{pu}tR_{tg}+\frac{\theta_2 E_{z^*}^*}{\theta_1+\alpha\theta_2}E_{pu^*}^*R_{tg}\end{array}\right]\frac{dg}{dp}-\gamma E_{pu^*}^*\frac{dA}{dp}<0 \tag{A-3}$$

$$
\begin{aligned}
&S_{pp} - \frac{\theta_1}{\theta_1 + \alpha\theta_2} E_{pz} R_{tp} - \frac{\theta_2}{\theta_1 + \alpha\theta_2} E^*_{pz^*} R_{tp} \\
&-E_{pu} M + E^*_{pu^*} M + \frac{\theta_1 E_z}{\theta_1 + \alpha\theta_2} E_{pu} R_{tp} - E_{pu} t R_{tp} + \frac{\theta_2 E^*_{z^*}}{\theta_1 + \alpha\theta_2} E^*_{pu^*} R_{tp} \\
&+ \left[\begin{array}{c} -\frac{\theta_1}{\theta_1+\alpha\theta_2} E_{pz} R_{tg} - \frac{\theta_2}{\theta_1+\alpha\theta_2} E^*_{pz^*} R_{tg} - R_{pg} - \theta_1 E_{pz} - \theta_2 E^*_{pz^*} \\ + \left(\theta_1 E_z - c^g\right) E_{pu} + \theta_2 E^*_{z^*} E^*_{pu^*} + \frac{\theta_1 E_z}{\theta_1+\alpha\theta_2} E_{pu} R_{tg} \\ -E_{pu} t R_{tg} + \frac{\theta_2 E^*_{z^*}}{\theta_1+\alpha\theta_2} E^*_{pu^*} R_{tg} \end{array} \right] \frac{\left[-\frac{\left(tR_{tp} + gc^g_p\right) dp + gc^g_A dA}{\left(c^g + tR_{tg}\right)} \right]}{dp} \\
&-\gamma E^*_{pu^*} \frac{dA}{dp} < 0
\end{aligned}
$$

or

$$
\begin{aligned}
&S_{pp} - \frac{\theta_1}{\theta_1 + \alpha\theta_2} E_{pz} R_{tp} - \frac{\theta_2}{\theta_1 + \alpha\theta_2} E^*_{pz^*} R_{tp} + \frac{\theta_1}{\theta_1 + \alpha\theta_2} E_{pz} R_{tg} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} + \frac{\theta_2}{\theta_1 + \alpha\theta_2} E^*_{pz^*} R_{tg} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} \\
&+ R_{pg} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} + \theta_1 E_{pz} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} + \theta_2 E^*_{pz^*} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} \\
&+ \left[\begin{array}{c} \frac{\theta_1 E_z}{\theta_1+\alpha\theta_2} R_{tp} - M - tR_{tp} - \left(\theta_1 E_z - c^g\right) \frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \\ -\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2} R_{tg} \frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} + tR_{tg} \frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \end{array} \right] E_{pu} \\
&+ \left[M + \frac{\theta_2 E^*_{z^*}}{\theta_1 + \alpha\theta_2} R_{tp} - \theta_2 E^*_{z^*} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} - \frac{\theta_2 E^*_{z^*}}{\theta_1 + \alpha\theta_2} R_{tg} \frac{\left(tR_{tp} + gc^g_p\right)}{\left(c^g + tR_{tg}\right)} \right] E^*_{pu^*} \\
&- \left[\left(\begin{array}{c} -\frac{\theta_1}{\theta_1+\alpha\theta_2} E_{pz} R_{tg} - \frac{\theta_2}{\theta_1+\alpha\theta_2} E^*_{pz^*} R_{tg} - R_{pg} - \theta_1 E_{pz} - \theta_2 E^*_{pz^*} \\ + \left(\theta_1 E_z - c^g\right) E_{pu} + \theta_2 E^*_{z^*} E^*_{pu^*} + \frac{\theta_1 E_z}{\theta_1+\alpha\theta_2} E_{pu} R_{tg} \\ -E_{pu} t R_{tg} + \frac{\theta_2 E^*_{z^*}}{\theta_1+\alpha\theta_2} E^*_{pu^*} R_{tg} \end{array} \right) \frac{gc^g_A}{\left(c^g + tR_{tg}\right)} + \gamma E^*_{pu^*} \right] \frac{dA}{dp} < 0
\end{aligned}
\tag{A-4}
$$

The market for the polluting good x is stable when:

$$
\begin{aligned}
S_{pp} - \frac{\theta_1}{\theta_1+\alpha\theta_2}E_{pz}R_{tp} - \frac{\theta_2}{\theta_1+\alpha\theta_2}E^*_{pz^*}R_{tp} \\
+\frac{\theta_1}{\theta_1+\alpha\theta_2}E_{pz}R_{tg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} + \frac{\theta_2}{\theta_1+\alpha\theta_2}E^*_{pz^*}R_{tg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \\
+R_{pg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} + \theta_1 E_{pz}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} + \theta_2 E^*_{pz^*}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \\
+\left[\begin{array}{c} \frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}R_{tp} - M - tR_{tp} - \left(\theta_1 E_z - c^g\right)\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \\ -\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}R_{tg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} + tR_{tg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} \end{array}\right]E_{pu} \\
+\left[M + \frac{\theta_2 E^*_{z^*}}{\theta_1+\alpha\theta_2}R_{tp} - \theta_2 E^*_{z^*}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)} - \frac{\theta_2 E^*_{z^*}}{\theta_1+\alpha\theta_2}R_{tg}\frac{\left(tR_{tp}+gc^g_p\right)}{\left(c^g+tR_{tg}\right)}\right]E^*_{pu^*} \\
< 0
\end{aligned}
$$

or

$$
\begin{aligned}
\left(c^g+tR_{tg}\right)\left(pS_{pp}-tm_xR_{tp}\right)+\theta_1 E_z\left(m_z-m_x\right)\left[\left(tR_{tp}+gc^g_p\right)\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right)-\frac{R_{tp}}{\theta_1+\alpha\theta_2}\left(c^g+tR_{tg}\right)\right] \\
+\theta_2 E^*_{z^*}\left(m^*_z-m^*_x\right)\left[\left(tR_{tp}+gc^g_p\right)\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right)-\frac{R_{tp}}{\theta_1+\alpha\theta_2}\left(c^g+tR_{tg}\right)\right] \\
+\left(c^g+tR_{tg}\right)M\left(m^*_x-m_x\right)+\left(tR_{tp}+gc^g_p\right)\left[pR_{pg}+m_x\left(c^g+tR_{tg}\right)\right]<0 \qquad \text{(A-5)}
\end{aligned}
$$

We can show that

$$
\frac{d\left[E_p\left(p,z-\theta_1 g,u\right)+E^*_p\left(p,z^*-\theta_2 g,u^*\right)-R_p\left(p,t,g\right)-R^*_p\left(p\right)\right]}{dp} = G\cdot gc^g_A < 0,
$$

which implies that $G>0$. Therefore, sufficient conditions for stability require: (i) $m_z < m_x\left(m^*_z < m^*_x\right)$; (ii) $m_x < m^*_x$; (iii) $R_{pg}<0$; (iv) $tR_{tp}+gc^g_p>0$; (v) $pR_{pg}+m_x\left(c^g+tR_{tg}\right)<0$; (vi) $pS_{pp}-tm_xR_{tp}<0$ or m_x is relatively small.

B. Stability conditions - Green Technology Transfer combined with a Border-Tariff Adjustment

Walrasian stability requires that the following inequality is verified

$$
\frac{d\left[E_p\left(p-\tau,z-\theta_1 g,u\right)+E^*_p\left(p,z^*-\theta_2 g,u^*\right)-R_p\left(p-\tau,t,g\right)-R^*_p\left(p\right)\right]}{dp}<0, \qquad \text{(B-1)}
$$

which is equivalent to

$$\begin{gathered}
\frac{E_{pp}d\left(p-\tau\right)+E_{pz}d\left(z-\theta_1 g\right)+E_{pu}du+E_{pp}^{*}dp+E_{pz}^{*}d\left(z^{*}-\theta_2 g\right)}{dp} \\
+\frac{E_{pu}^{*}du^{*}-R_{pp}d\left(p-\tau\right)-R_{pg}dg-R_{pp}^{*}dp}{dp}<0
\end{gathered}$$

or

$$S_{pp}-M_p\frac{d\tau}{dp}+E_{pz}\frac{dz}{dp}+E_{pz}^{*}\frac{dz^{*}}{dp}+E_{pu}\frac{du}{dp}+E_{pu}^{*}\frac{du^{*}}{dp}-\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz}^{*}\right)\frac{dg}{dp}<0 \quad \text{(B-2)}$$

where $M_p=E_{pp}-R_{pp}<0$.

Substituting (2), (24), (27), (12), (13), and (14) in equation B-2 gives

$$\begin{gathered}
S_{pp}-E_{pz}\frac{\theta_1}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}} \\
-E_{pz}^{*}\frac{\theta_2}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}} \\
+E_{pu}\left(-M+\left(\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}-t\right)\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}}-\frac{\left(\theta_1 E_z-c^g\right)\left(tR_{tp}+gc_p^g\right)}{c^g+tR_{tg}}\right) \\
+E_{pu}^{*}\left(M+\frac{\theta_2 E_{z^*}^{*}}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}}-\theta_2 E_{z^*}^{*}\frac{\left(tR_{tp}+gc_p^g\right)}{c^g+tR_{tg}}\right) \\
+\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz}^{*}\right)\frac{tR_{tp}+gc_p^g}{c^g+tR_{tg}}-E_{pu}^{*}\tau M_p \\
+\left[\begin{array}{c}
E_{pz}\frac{\theta_1}{\theta_1+\alpha\theta_2}\frac{R_{tg}gc_A^g}{c^g+tR_{tg}}\frac{dA}{dp}+E_{pz}^{*}\frac{\theta_2}{\theta_1+\alpha\theta_2}\frac{R_{tg}gc_A^g}{c^g+tR_{tg}}-E_{pu}\left(\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}R_{tg}-tR_{tg}+\theta_1 E_z-c^g\right)\frac{gc_A^g}{c^g+tR_{tg}} \\
-E_{pu}^{*}\left(\theta_2 E_{z^*}^{*}+\frac{\theta_2 E_{z^*}^{*}R_{tg}}{\theta_1+\alpha\theta_2}+\frac{\gamma(c^g+tR_{tg})}{gc_A^g}\right)\frac{gc_A^g}{c^g+tR_{tg}}+\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz}^{*}\right)\frac{gc_A^g}{c^g+tR_{tg}}
\end{array}\right]\frac{dA}{dp} \\
-\left[M\left(E_{pu}^{*}-E_{pu}\right)+M_p\right]\frac{d\tau}{dp}<0
\end{gathered}$$

The market for x is stable when:

$$
\begin{aligned}
S_{pp} - E_{pz}\frac{\theta_1}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}} \\
-E_{pz}^*\frac{\theta_2}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}} \\
+E_{pu}\left(-M+\left(\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}-t\right)\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}}-\frac{\left(\theta_1 E_z-c^g\right)\left(tR_{tp}+gc_p^g\right)}{c^g+tR_{tg}}\right) \\
+E_{pu}^*\left(M+\frac{\theta_2 E_{z^*}^*}{\theta_1+\alpha\theta_2}\frac{R_{tp}\left(c^g+tR_{tg}\right)-\left(tR_{tp}+gc_p^g\right)R_{tg}}{c^g+tR_{tg}}-\theta_2 E_{z^*}^*\frac{\left(tR_{tp}+gc_p^g\right)}{c^g+tR_{tg}}\right) \\
+\left(R_{pg}+\theta_1 E_{pz}+\theta_2 E_{pz}^*\right)\frac{tR_{tp}+gc_p^g}{c^g+tR_{tg}}-E_{pu}^*\tau M_p<0
\end{aligned}
$$

or

$$
\begin{aligned}
\left(c^g+tR_{tg}\right)\left(pS_{pp}-tm_xR_{tp}\right)+\left(c^g+tR_{tg}\right)M\left(m_x^*-m_x\right) \\
+\left[\theta_1 E_z\left(m_z-m_x\right)+\theta_2 E_{z^*}^*\left(m_{z^*}^*-m_x^*\right)\right]\left[\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right)\left(tR_{tp}+gc_p^g\right)-\frac{R_{tp}}{\theta_1+\alpha\theta_2}\left(c^g+tR_{tg}\right)\right] \\
+\left[pR_{pg}+m_x\left(c^g+tR_{tg}\right)\right]\left(tR_{tp}+gc_p^g\right)-\left(c^g+tR_{tg}\right)m_x^*\tau M_p<0
\end{aligned}
\tag{B-3}
$$

We can show that

$$
\frac{d\left[E_p\left(p,z-\theta_1 g,u\right)+E_p^*\left(p,z^*-\theta_2 g,u^*\right)-R_p\left(p,t,g\right)-R_p^*\left(p\right)\right]}{dp}=H\cdot gc_A^g<0,
$$

which implies that $H>0$. Therefore, sufficient conditions for stability require: (i) $m_z<m_x\left(m_z^*<m_x^*\right)$; *(ii)* $m_x\leqslant m_x^*$; *(iii)* $R_{pg}<0$; *(iv)* $tR_{tp}+gc_p^g>0$; *(v)* $pR_{pg}+m_x\left(c^g+tR_{tg}\right)<0$; *(vi)* $pS_{pp}-\left(tR_{tp}+M\right)m_x<0$ or a relatively small m_x; (vii) $M<\tau M_p$ or $\frac{\tau M_p}{M}>1$.[25]

[25]Note that $\xi_{M,\tau}=\frac{dM}{d\tau}\frac{\tau}{M}=-M_p\frac{\tau}{M}<0$. Therefore, the last condition requires that the elasticity of export supply with respect to the BTA is higher than 1 in absolute value.

C. Further derivations - pollution and welfare effects

The change in pollution in the recipient is:

$$\begin{aligned}\frac{dz}{dA} \quad = \quad & -\frac{\theta_1 R_{tp}}{(\theta_1+\alpha\theta_2)G}\left[\begin{array}{c}(c^g+tR_{tg})\left(\frac{\gamma}{gc_A^g}m_x^*-m_x\right)+\theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m_x-m_z)\\ +\theta_2 E^*_{z^*}(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1)(m_x^*-m_z^*)-R_{pg}\end{array}\right]\\ & -\frac{\theta_1 R_{tg}}{(\theta_1+\alpha\theta_2)G}\left[\begin{array}{c}-\left(tR_{tp}+gc_p^g\right)\frac{\gamma}{gc_A^g}m_x^*-M\left(m_x^*-m_x\right)-(pS_{pp}-tm_xR_{tp})\\ -\left[\theta_1 E_z\left(m_x-m_z\right)+\theta_2 E^*_{z^*}\left(m_x^*-m_z^*\right)\right]\frac{R_{tp}}{\theta_1+\alpha\theta_2}\end{array}\right],\end{aligned}$$

which can be further simplified to yield equation (17) in the text. The expression for the change in pollution in the donor is similar.

The same expression with the BTA for the recipient is equal to:

$$\begin{aligned}\frac{dz}{dA}|_{BTA} \quad = \quad & -\frac{\theta_1 R_{tp}}{(\theta_1+\alpha\theta_2)\,H}\left[\begin{array}{c}(c^g+tR_{tg})\left(\frac{\gamma}{gc_A^g}m_x^*-m_x\right)\\ +\left[\theta_1 E_z\left(m_x-m_z\right)+\theta_2 E^*_{z^*}\left(m_x^*-m_{z^*}^*\right)\right]\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\\ -pR_{pg}\end{array}\right]\\ & -\frac{\theta_1 R_{tg}}{(\theta_1+\alpha\theta_2)\,H}\left[\begin{array}{c}-\left(tR_{tp}+gc_p^g\right)\frac{\gamma}{gc_A^g}m_x^*-(pS_{pp}-tm_xR_{tp})\\ +\left[\theta_1 E_z\left(m_z-m_x\right)+\theta_2 E^*_{z^*}\left(m_{z^*}-m_x^*\right)\right]\frac{R_{tp}}{\theta_1+\alpha\theta_2}\\ -M\left(m_x^*-m_x\right)+m_x^*\tau M_p\end{array}\right]\end{aligned}$$

which can be written as in equation (33) in the text.

For the donor, we have:

$$\begin{aligned}\frac{dz^*}{dA}|_{BTA} \quad = \quad & -\frac{\theta_2 R_{tp}}{(\theta_1+\alpha\theta_2)\,H}\left[\begin{array}{c}(c^g+tR_{tg})\left(\frac{\gamma}{gc_A^g}m_x^*-m_x\right)\\ +\left[\theta_1 E_z\left(m_x-m_z\right)+\theta_2 E^*_{z^*}\left(m_x^*-m_{z^*}^*\right)\right]\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\\ -pR_{pg}\end{array}\right]\\ & -\frac{\theta_2 R_{tg}}{(\theta_1+\alpha\theta_2)\,H}\left[\begin{array}{c}-\left(tR_{tp}+gc_p^g\right)\frac{\gamma}{gc_A^g}m_x^*-(pS_{pp}-tm_xR_{tp})\\ +\left[\theta_1 E_z\left(m_z-m_x\right)+\theta_2 E^*_{z^*}\left(m_{z^*}-m_x^*\right)\right]\frac{R_{tp}}{\theta_1+\alpha\theta_2}\\ -M\left(m_x^*-m_x\right)+m_x^*\tau M_p\end{array}\right]\end{aligned}$$

This can be re-written as in equation (34) in the text.

Substituting equations (16), (17) and (18) into (19) yields:

$$\begin{aligned}
\frac{du+du^*}{dA} &= \frac{(pR_{pg}+c^g m_x)\,tR_{tp}-[\theta_1 E_z(m_x-m_z)+\theta_2 E^*_{z^*}(m^*_x-m^*_{z^*})]\,tR_{tp}}{G}\\
&+\frac{\theta_1 E_z+\theta_2 E^*_{z^*}-c^g}{G}\left[-M(m^*_x-m_x)-\left(tR_{tp}+gc^g_p\right)\frac{\gamma}{gc^g_A}m^*_x-(pS_{pp}-tm_xR_{tp})\right]\\
&-\frac{\theta_1 E_z c^g m_z R_{tp}}{(\theta_1+\alpha\theta_2)\,G}+\frac{\theta_2 E^*_{z^*}c^g R_{tp}}{(\theta_1+\alpha\theta_2)\,G}(m^*_x-m^*_z-m_x)\\
&-\frac{\left(c^g tR_{tp}-gc^g_p tR_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x-[M(m^*_x-m_x)+pS_{pp}]\,tR_{tg}}{G}-\gamma\\
&-\frac{\theta_1 E_z+\theta_2 E^*_{z^*}}{(\theta_1+\alpha\theta_2)\,G}\left[\begin{array}{c} pR_{pg}R_{tp}-\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x\\ +[M(m^*_x-m_x)+pS_{pp}]\,R_{tg}\end{array}\right]
\end{aligned}$$

By substituting equations (16), (17) and (18) into (20), we obtain:

$$\begin{aligned}
\frac{du}{dA} &= -\frac{M}{G}\left[\begin{array}{c}(c^g+tR_{tg})\left(\frac{\gamma}{gc^g_A}m^*_x-m_x\right)+\theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m_x-m_z)\\ +\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m^*_x-m^*_{z^*})-pR_{pg}\end{array}\right]\\
&+\left(t-\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}\right)\left[\begin{array}{c}(pR_{pg}+m_xc^g)\,R_{tp}-[\theta_1 E_z(m_x-m_z)+\theta_2 E^*_{z^*}(m^*_x-m^*_{z^*})]\,R_{tp}\\ -\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x-[M(m^*_x-m_x)+pS_{pp}]\,R_{tg}\end{array}\right]\\
&+(\theta_1 E_z-c^g)\left[\begin{array}{c}-\left(tR_{tp}+gc^g_p\right)\frac{\gamma}{gc^g_A}m^*_x-M(m^*_x-m_x)-(pS_{pp}-tm_xR_{tp})\\ -[\theta_1 E_z(m_x-m_z)+\theta_2 E^*_{z^*}(m^*_x-m^*_z)]\frac{R_{tp}}{\theta_1+\alpha\theta_2}\end{array}\right]
\end{aligned}$$

$$\begin{aligned}
\frac{du^*}{dA} &= -\gamma\\
&+\frac{M}{G}\left[\begin{array}{c}\theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m_x-m_z)+\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right)(m^*_x-m^*_{z^*})\\ -pR_{pg}+m_x(c^g+tR_{tg})+(c^g+tR_{tg})\frac{\gamma}{gc^g_A}m^*_x\end{array}\right]\\
&+\frac{\theta_2 E^*_{z^*}}{G}\left[\begin{array}{c}-\frac{pR_{pg}R_{tp}}{(\theta_1+\alpha\theta_2)}-\left(gc^g_p\frac{\gamma}{gc^g_A}m^*_x+pS_{pp}\right)\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\\ -\frac{M(m^*_x-m_x)R_{tg}}{(\theta_1+\alpha\theta_2)}+\left(\frac{c^g}{(\theta_1+\alpha\theta_2)}-t\right)\left(\frac{\gamma}{gc^g_A}m^*_x-m_x\right)R_{tp}\end{array}\right]
\end{aligned}$$

The expressions for welfare changes with the BTA are:

$$
\begin{aligned}
\frac{du+du^*}{dA}|_{BTA} &= \frac{\left(pR_{pg}+c^g m_x\right)tR_{tp}-\left[\theta_1 E_z\left(m_x-m_z\right)+\theta_2 E^*_{z^*}\left(m^*_x-m^*_{z^*}\right)\right]tR_{tp}}{H} \\
&+\frac{\theta_1 E_z+\theta_2 E^*_{z^*}-c^g}{H}\left[\begin{array}{c} -M\left(m^*_x-m_x\right)-\left(tR_{tp}+gc^g_p\right)\frac{\gamma}{gc^g_A}m^*_x-\left(pS_{pp}-tm_xR_{tp}\right) \\ +m^*_x\tau M_p \end{array}\right] \\
&-\frac{\theta_1 E_z m_z c^g R_{tp}}{\left(\theta_1+\alpha\theta_2\right)H}+\frac{\theta_2 E^*_{z^*}c^g R_{tp}}{\left(\theta_1+\alpha\theta_2\right)H}\left(m^*_x-m_{z^*}-m_x\right) \\
&-\frac{\left(c^g tR_{tp}-gc^g_p tR_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x-\left[M\left(m^*_x-m_x\right)+pS_{pp}\right]tR_{tg}+m^*_x\tau M_p tR_{tg}}{H}-\gamma \\
&-\frac{\theta_1 E_z+\theta_2 E^*_{z^*}}{\left(\theta_1+\alpha\theta_2\right)H}\left(\begin{array}{c} pR_{pg}R_{tp}-\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x \\ +\left[M\left(m^*_x-m_x\right)+pS_{pp}\right]R_{tg} \\ -m^*_x\tau M_p R_{tg} \end{array}\right).
\end{aligned}
$$

$$
\begin{aligned}
\frac{du}{dA}|_{BTA} &= -\frac{M}{H}\left[\begin{array}{c} \left(c^g+tR_{tg}\right)\left(\frac{\gamma}{gc^g_A}m^*_x-m_x\right)+\theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(m_x-m_z\right) \\ +\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)\left(m^*_x-m^*_{z^*}\right)-pR_{pg} \end{array}\right] \\
&+\frac{1}{H}\left(t-\frac{\theta_1 E_z}{\theta_1+\alpha\theta_2}\right)\left(\begin{array}{c} \left(pR_{pg}+c^g m_x\right)R_{tp}-\left(c^g R_{tp}-gc^g_p R_{tg}\right)\frac{\gamma}{gc^g_A}m^*_x \\ +\left[M\left(m^*_x-m_x\right)+pS_{pp}\right]R_{tg}-m^*_x\tau M_p R_{tg} \end{array}\right) \\
&+\frac{\theta_1 E_z-c^g}{H}\left[\begin{array}{c} -\left(tR_{tp}+gc^g_p\right)\frac{\gamma}{gc^g_A}m^*_x-\left(pS_{pp}-tm_xR_{tp}\right) \\ -M\left(m^*_x-m_x\right)+m^*_x\tau M_p \end{array}\right] \\
&+\frac{\left[\theta_1 E_z\left(m_x-m_z\right)+\theta_2 E^*_{z^*}\left(m^*_x-m_{z^*}\right)\right]R_{tp}}{H}\left(\frac{c^g}{\theta_1+\alpha\theta_2}-t\right).
\end{aligned}
$$

$$
\begin{aligned}
\frac{du^*}{dA}|_{BTA} &= -\gamma \\
&+\frac{M-\tau M_p}{H}\left[\begin{array}{c} \theta_1 E_z\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m_x-m_z)+\theta_2 E^*_{z^*}\left(\frac{R_{tg}}{\theta_1+\alpha\theta_2}+1\right)(m^*_x-m^*_{z^*}) \\ -pR_{pg}+(c^g+tR_{tg})\left(\frac{\gamma}{gc^g_A}m^*_x-m_x\right) \end{array}\right] \\
&+\frac{\theta_2 E^*_{z^*}}{H}\left(\begin{array}{c} -\frac{pR_{pg}R_{tp}}{\theta_1+\alpha\theta_2} \\ +R_{tp}\left(\frac{c^g}{\theta_1+\alpha\theta_2}-t\right)\left(\frac{\gamma}{gc^g_A}m^*_x-m_x\right) \\ -gc^g_p\frac{\gamma}{gc^g_A}m^*_x\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right) \\ -\left[M\left(m^*_x-m_x\right)+pS_{pp}\right]\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right) \\ +m^*_x\tau M_p\left(1+\frac{R_{tg}}{\theta_1+\alpha\theta_2}\right) \end{array}\right)
\end{aligned}
$$

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