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Development Aid and Climate Finance

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Abstract

This paper discusses the implications of climate change for official transfers from rich countries (the North) to poor countries (the South). The concern is no longer just about poverty alleviation (i.e. income in the South), but also about global emissions and resilience to climate risk. Another implication is that traditional development transfers to increase income are complemented by new financial flows to reduce greenhouse gas emissions (mitigation transfers) and become climate-resilient (adaptation transfers). We find that in the absence of institutional barriers to adaptation, mitigation or development, climate change will make isolated transfers less efficient: A large part of their intended effect (to increase income, reduce emissions, or boost climate-resilience) dissipates as the South reallocates its own resources to achieve the mitigation, adaptation and consumption balance it prefers. Only in the case of least-developed countries, which are unable to adapt fully due to income constraints, will adaptation support lead to more climate resilience. In all other cases, if the North wishes to change the balance between mitigation, adaptation and consumption it should structure its transfers as "matching grants", which are tied to the South's own level of funding. However, the North can also provide an integrated transfer package that recognizes the combined climate and development requirements of the South.

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1. Introduction

The twin needs of poverty alleviation and environmental protection have long been recognized as complementary challenges. There is by now an extensive body of work that documents the close links between environment and development, a literature to which Anil Markandya has made wideranging contributions (e.g. Pearce et al. 1990; Markandya and Pearce 1991; Markandya 1998, 2002, 2008; Markandya and Nurty 2004).

Perhaps less appreciated in the academic literature is the fact that environment-development links also extend to questions of finance. Official development assistance has been subject to extensive research in particular about aid effectiveness (e.g., Bourguignon and Sundberg 2007; Collier and Dollar 2002, 2004; Dollar and Easterly 1999). Environmental finance has become a topic of wider academic interest only recently in the context of climate change. See Haites (2013) for an overview and Fankhauser and Pearce (2014) for a more conceptual discussion.

There has been no systematic analysis up to now of how environmental finance and development aid interact, either from a donor perspective (e.g., in terms of overlapping or competing donor objectives) or from a recipients' point of view (e.g., in terms of the incentives that multiple funding streams provide). The aim of this paper is to close this gap, using climate change as a pertinent example.

Under the Copenhagen Accord of 2009, and reaffirmed in subsequent negotiation documents, developed countries have promised to provide additional climate finance of up to $100 billion a year from 2020 to help developing countries to reduce their emissions and adapt to the consequences of climate change. The offer needs to be seen in a broader context of financial assistance to developing countries, which also includes development aid: Climate finance is to be explicitly provided on top of conventional development assistance, which developed countries have pledged to increase to 0.7% of GDP as part of the Millennium Development Goals.

This paper offers a theoretical model to analyze the motivation of donors in providing three kinds of funding to developing countries: funding to alleviate poverty (development aid), funding to reduce greenhouse gas emissions (mitigation finance) and funding to prepare for

unavoidable climate change (adaptation finance). The model also studies how the three funding streams affect the ability and inclination of recipient countries to increase income, reduce emissions and strengthen resilience to climate change.

The basic tenet is that transfers reflect the ethical beliefs of those making them. That is, transfers are not made primarily for strategic reasons, but because people in developed countries care about the welfare of people in developing countries. We also assume that these beliefs can be expressed in an appropriately specified utility function, and study how the level and composition of financial flows depend on the ethical beliefs of developed countries (which, with apologies to the antipodes, we shall call the North). For a more detailed discussion of the ethical dimensions of climate change see Stern (2012) and Kverndokk and Rose (2008).

Most of the existing literature on financial transfers focuses on their strategic value, that is, their merit in securing an international agreement (see e.g., Barrett, 2003, 2007 and Hong and Karp, 2012, on forming international environmental agreements; an exception is Grasso 2010). Already in the 1990s, Carraro and Siniscalco (1993) and Kverndokk (1994) argued that side payments mainly from OECD countries to non-OECD countries would be an effective policy instrument for making a limited treaty significant. Eyckmans and Tulkens (2003) show that a proportional surplus- sharing rule can stabilize a grand coalition and secure the first-best global climate policy, and Carraro et al. (2005) demonstrate the importance of monetary transfers as strategic instruments to foster stability of voluntary climate agreements. Further, Hoel (2001) argues that monetary transfers are also important to reduce carbon leakage, while Chatterjee et al. (2003) study transfers to promote economic growth and contrast the effects of a transfer tied to public infrastructure investments with a traditional pure transfer.

Our paper is also part of a more recent literature on the interplay between adaptation and mitigation (see for instance Buob and Stephan 2011, Ebert and Welsch 2012; Tulkens and van Steenberghe 2009; Ingham et al. 2007; Bréchet et al. 2013). A recurring insight from this body of work is the following. While the benefits of mitigation are non-excludable, the benefits of adaptation are often excludable, meaning that adaptation is primarily a private good and the benefits accrue only to the nation doing the adaptation investment (Kane and Shogren, 2000;

3

Barrett, 2008).[1] Thus, nations should have the incentives to do the appropriate adaptation investment themselves in contrast to mitigation.

Another issue in this literature is that adaptation and mitigation can be substitutes (Ingham et al., 2005). Thus, by reducing the effects of climate change, the incentive to mitigate may be lower and give a negative feedback to the donors. To bypass this issue, Pittel and Rübbelke (2013) develop a two-region model, similar to ours, to explore the merit of financial adaptation transfers that are conditional on mitigation efforts. Also Heuson et al. (2013) consider a stylized two-region model of mitigation and adaptation with different types of transfers from the industrialized region to compensate for mitigation and adaptation costs and expected and potential climate change damages in the developing region. In contrast to these approaches, we allow for development assistance (in the form of productive capital transfers) as an additional transfer channel and, more importantly, we consider a more general preference structure that allows for ethically motivated behavior.

This paper departs from the existing literature in other respects. First, unlike the side payment literature we treat financial transfers as an equity issue rather than a strategic question. Transfers are determined by ethical preferences and not by the need to secure cooperation (although there are, inevitably, some strategic effects). Second, we are not concerned with optimizing global social welfare. Rather than a global perspective, we take the point of view of donor and recipient countries and ask what their social welfare functions imply for the impact of different financial transfers. The type of transfers we consider constitutes the third difference. While the literature focuses predominantly on mitigation finance, our model offers a choice between mitigation finance, development aid and adaptation finance.

The paper is structured as follows. Section 2 sets out our theoretical model. It features a two-period game of transfers from North to South with utility functions that include the welfare in the other region. We then use this framework to study a series of questions relating to the interplay of development aid and official finance for mitigation and adaptation.

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[1] There are examples of adaptation actions with regional public goods features, such as the management of international water systems, but we can treat these as exceptions from the rule.

The first three questions concern decision making in the South: Section 3 studies the effect of official transfers on the mitigation decisions of the South, while section 4 studies the impact on adaptation. Section 5 analyses the special case of a least-developed country, whose ability to spend money on climate change is constrained by the need to maintain a subsistence level of consumption.

The next two sections concern decision making in the North. Section 6 analyses the incentive of the North to offer adaptation, mitigation and development transfers, bearing in mind the strategic reaction of the South observed in sections 3 and 4. Section 7 studies the same question but in a more general set up where the efficiency of transfers varies. That is, a varying fraction of funding is lost in the course of the transfer. Section 8 concludes.

2. A two-period model of transfers

Our model is structured as a simple game between two regions, j, over two periods ($t = 0,1$). The two regions are called *North* (j = N) and *South* (j = S), where North is a rich region and South is poor. Each region produces an exogenous output y_j^t, which results in greenhouse gas emissions e_j^t.[2] The combined emissions from both regions result in climate change damage, which reduces available output in period 1. Damage in period 0 is assumed to be negligible.

In period 0 each region chooses the amount it wishes to invest in mitigation technology m_j and adaptation technology a_j. The benefit of adaptation is reduced impacts from climate change in period 1. We assume that climate change damage in country j, D_j, is a constant share of output, and that a fraction, α_j, of this damage can be avoided through adaptation. Investing in adaptation has decreasing returns: $0 \leq \alpha_j\left(a_j\right) \leq 1$ with $\alpha_j' \geq 0$ and $\alpha_j'' \leq 0$. These are highly simplistic assumptions but they are common in the literature (e.g., Fankhauser, 1994; Kverndokk, 1994; Tol, 2002; Nordhaus and Boyer, 2000; de Bruin, Dellink and Tol 2009; de Bruin, Dellink and Agrawala 2009; for a critique see Pindyck 2013).

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[2] Thus, we implicitly assume that real capital investments are made optimally.

The benefit of investing in mitigation is lower emissions for a given level of production. Mitigation capital is long-lived so that the choice of m_j determines emissions over both periods. Emissions are proportional to output, that is, $e_j^t = \sigma_j(m_j)y_j^t$, where $\sigma_j(m_j)$ can be interpreted as the emission-to-output ratio. We assume that mitigation investment has decreasing returns (equivalently, the abatement costs functions is convex): $\sigma_j' < 0$ and $\sigma_j'' \geq 0$.

We assume that each region has its own emission constraints, which one may think of as being part of an international agreement to constrain emissions over both regions:

(1) $$e_N^0 + e_N^1 \leq \hat{e}_N; \quad e_S^0 + e_S^1 \leq \hat{e}_S; \quad \hat{e}_N + \hat{e}_S \leq \hat{e}$$

For simplicity we assume that there is no interaction (e.g. through carbon trading) between the two emission spaces. The respective emissions constraints apply separately to each region, although emissions are fungible across time periods. We will lift the restriction on carbon trading briefly in section 3 to study the impact of a global carbon market on official financial flows.[3]

The North can make three types of transfer in period 0:
- a productive capital transfer (development assistance), T^i, which will increase the available output (and emissions) of the South in period 1,
- a mitigation transfer, T^m, which helps the South reduce its emissions in both periods
- an adaptation transfer, T^a, which augments the adaptation capital available to the South.

The transfers introduce some intra- and intergenerational tradeoffs. Mitigation (and mitigation support) has an immediate and lasting impact because it lowers the emission intensity in both periods. Adaptation and productive capital support however, are subject to a time delay. Today's investment only pays off in the next period. Hence, we assume that changing the productive

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[3] An alternative formulation would be to associate the benefit of mitigation directly with reduced damage. However, this would introduce climate change as a strategic externality into the model and make it difficult to distinguish the equity case for transfers from the strategic case. Moreover, our representation is not unrealistic. Very few countries are large enough to influence global emissions. For most, the incentive to reduce emissions comes from an exogenously agreed target and/or the prospect of carbon market revenues, rather than the possibility to reduce damage directly.

capital base and adaptation capacity of a country requires more time than curbing its emission intensity.[4]

The output that is left after transfers and investments in mitigation and adaptation in period 0 is consumed. The consumption levels in each region and period, c_j^t, and the corresponding emissions, e_j^t, can now be specified, as shown in Table 1.

Table 1: Consumption and emissions levels in each region and period.

	Period 0 (now)	Period 1 (future)
N (North)	$c_N^0 = y_N^0 - m_N - a_N - T^m - T^a - T^i$ $e_N^0 = \sigma_N(m_N) y_N^0$	$c_N^1 = \left[1 - \left[1 - \alpha_N(a_N)\right] D_N(\hat{e})\right] y_N^1$ $e_N^1 = \sigma_N(m_N) y_N^1$
S (South)	$c_S^0 = y_S^0 - m_S - a_S$ $e_S^0 = \sigma_S(m_S + T^m) y_S^0$	$c_S^1 = \left[1 - \left[1 - \alpha_S(a_S + T^a)\right] D_S(\hat{e})\right]\left[y_S^1 + T^i\right]$ $e_S^1 = \sigma_S(m_S + T^m)\left[y_S^1 + T^i\right]$

 The final, crucial element of the model is each region's utility function. We assume that both regions gain utility from consumption (that also includes feedback from the environment). For simplicity we assume linear utility functions, and we can write the intertemporal utility function of the South as:

(2) $$U_S\left(c_S^0, c_S^1\right) = c_S^0 + \delta_S c_S^1$$

where δ_S is the consumption discount factor of the South, expressing the intergenerational equity preferences of the region.

To be able to study transfers from North to South that are not motivated primarily by strategic reasons, we assume that the North also cares about the intragenerational distribution of consumption, that is, consumption in the South. One way of doing this is to follow Fehr and

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[4] In reality, there will also be quick wins in improving adaptation capacity and productivity. At the same time, some mitigation efforts will only curb emission intensity in the long run. We abstract from these possibilities mainly because it allows us to keep the model tractable.

Schmidt (1999) and assume that the North expresses inequality aversion in consumption;[5] people in the North dislike that the South is poorer than them, but would dislike it even more if the South were richer.[6] Obviously, as North is the richer region initially, and would not make transfers that make the South richer than them, we have $c_N > c_S$. The utility function of the North can then be written as:

$$(3) \qquad U_N\left(c_N, c_S\right) = c_N - \mu(c_N - c_S) = (1-\mu)c_N + \mu c_S, \quad c_j = c_j^0 + \delta_j c_j^1, \quad j = N, S$$

where $\mu > 0$ is a parameter expressing the intragenerational preferences of the North, while δ_N is the discount rate of the North, expressing its intergenerational preferences.

From (3) we see that $\mu < 1$ is required for consumption in the North to add to the North's welfare. In addition, it is reasonable to assume that consumption in the North adds more to the utility of the North than consumption in the South. Thus, we set $\mu < 1/2$.[7]

3. Financial transfers and mitigation in the South

The first issue to which we apply our model is the question of how the need to reduce emissions affects how the South treats official financial flows from the North. The optimal transfers from the North will be discussed in Section 5 below. For the time being we also ignore the need for adaptation and focus on mitigation only.

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[5] We could also introduce the inequality preferences in the welfare function of the South as in Kverndokk et al. (2014). This would give preferences for a higher consumption level in the South. However, as will be obvious from the discussions in Sections 3 and 5 below, equity preferences will not affect the optimal mitigation and adaptation levels, and inequality aversion in the South would not matter for our analysis.

[6] The general case would be $U_N\left(c_N, c_S\right) = c_N - \eta \max\{c_S - c_N, 0\} - \mu \max\{c_N - c_S, 0\}, \quad c_j = c_j^0 + \delta_j c_j^1, \quad j = N, S$, where η is a parameter representing the negative feeling of being worse off than the South, while μ is the parameter representing the negative feeling of being better off. We then have $\eta \geq \mu$. The second part of the welfare function equals zero as $c_N > c_S$.

[7] We could also introduce a consumption transfer from North to South in both periods as a means to reduce consumption inequality. However, as we have assumed that $\mu < 1/2$, no interior solution would be possible from the optimization problem, and there would not be any consumption transfer between the two regions. This is because utility is linear in consumption, and the North will always prefer one extra consumption unit to itself than to the South. Note, however, that with a concave utility function, we would get an interior solution, and the marginal utility of consumption as well as the equity weights will determine the outcome. If $\mu = 0$ so that North does not care about the welfare level of the South, there will not be any consumption transfer even in this case. The reason is that the consumption transfer has no strategic effect. The only reason to transfer consumption is that the North cares about the welfare of the South.

First, note that as long as there is no emissions trading, the emissions constraint in the North given by equation (1) determines the need for mitigation in the North, i.e., the optimal level of m_N follows directly from the emissions constraint and is unaffected by the transfers to the South. We return to the case with emissions trading below.

The optimization problem of the South with respect to mitigation is given by maximizing the following Lagrangian,

(4)
$$max_{m_S} \; \mathrm{L}_S = c_S^0 + \delta_S \, c_S^1 + \lambda_S [\hat{e}_S - e_S^0 - e_S^1]$$
$$= y_S^0 - m_S - a_S + \delta_S \left\{ [1 - [1 - \alpha_S(a_S + T^a)] D_S(\hat{e})][y_S^1 + T^i] \right\} + \lambda_S \left\{ \hat{e}_S - \sigma_S(m_S + T^m)[y_S^0 + y_S^1 + T^i] \right\}$$

where λ_S is the shadow price on carbon. Assuming the emissions constraint is binding, the necessary first-order condition (FOC) for an interior solution is

(5)
$$\frac{\partial \mathrm{L}_S}{\partial m_S} = -1 - \lambda_S \, \sigma_S' \left[y_S^0 + y_S^1 + T^i \right] = 0$$
$$\Rightarrow \quad -1/\sigma_S' \left[y_S^0 + y_S^1 + T^i \right] = \lambda_S$$

That is, the shadow price of carbon, λ_S, is determined by the marginal cost of mitigation, measured over both periods. Equation (5) together with the binding emissions constraint $e_S^0 + e_S^1 = \hat{e}_S$ from equation (1) constitutes a two-equation system with two variables m_S and λ_S, which are functions of income y_S^0, y_S^1, transfers T^i, T^m and the emissions constraint $\hat{e}_S$. Note that adaptation is not present in the FOC for mitigation effort, which allows us to study the mitigation decision separately.

We solve the system by totally differentiating the two equations. Expressed in matrix form this yields:

9

(6)
$$\begin{bmatrix} \sigma_S'' \cdot \breve{y}_S & -1/\lambda_S^2 \\ \sigma_S' \cdot \breve{y}_S & 0 \end{bmatrix} \begin{bmatrix} dm_S \\ d\lambda \end{bmatrix} = \begin{bmatrix} -\sigma_S'' \cdot \breve{y}_S & -\sigma_S' & 0 \\ -\sigma_S' \cdot \breve{y}_S & -\sigma_S & 1 \end{bmatrix} \begin{bmatrix} dT^m \\ dT^i \\ d\hat{e}_S \end{bmatrix}$$

where $\breve{y}_S = \left[y_S^0 + y_S^1 + T^i \right]$ is total undiscounted income over both periods. We find that:

(7)
$$\frac{dm_S}{d\hat{e}_S} = \frac{1}{\sigma_S' \cdot \breve{y}_S} < 0; \quad \frac{dm_S}{dT^m} = -1 ; \quad \frac{dm_S}{dT^i} = \frac{-\sigma_S}{\sigma_S' \cdot \breve{y}_S} > 0.$$

The first expression confirms that a more lenient emissions constraint in the South leads to reduced mitigation effort. The second expression suggests that a dedicated mitigation transfer completely crowds out the South's own mitigation efforts. Since the cap on emissions is fixed the transfer allows the South to free up its own resources for consumption. As a result there is no additional mitigation in the South. A binding emissions constraint in the South renders mitigation transfers ineffective, i.e.

(8)
$$\frac{de_S}{dT^m} = \sigma_S' \left(1 + \frac{dm_S}{dT^m} \right) = 0 .$$

The final expression in equation (7) shows the effect of development assistance on mitigation in the South. It suggests that additional aid will trigger further mitigation. This is because a productive income transfer leads to higher output and therefore more emissions, and additional mitigation is needed to remain within the carbon constraint. Again, the presence of an emissions constraint makes the transfer less effective, in the sense that development assistance now leads to a lower increase in utility in the South, and therefore also the North. To see this we differentiate the utility function of the South with respect to development assistance:

(9)
$$\frac{dU_S}{dT^i} = -\frac{dm_S}{dT^i} + \delta_S \left\{ 1 - \left[1 - \alpha_S(.) \right] D_S(\hat{e}) \right\}$$

10

The second term of the equation represents the increase in period 1 consumption that a productive transfer would normally have. The first term is negative and reflects the reduction in consumption due to the need for more mitigation. Because wellbeing in the South features in the utility function of the North, utility in the North is affected in the same way. Note that the effect on period 1 consumption depends on climate damages. We will return to this issue in the next section.

Equations (7) to (9) give rise to the following proposition:

Proposition 1: Mitigation and development transfers become less effective if the South has a binding emissions constraint, in the sense that the transfers result in less additional mitigation or additional consumption, respectively, than the same transfer in the absence of a constraint. This is because each of the transfers focuses on only one objective (emissions cuts and higher output, respectively), and the South will redeploy its own resources to establish its preferred balance between the two goals.

If the North wishes to preserve the full effect of development transfers[8] it will have to recognize the twin importance of both output growth and emissions cuts. The North may then devise a combined package of transfers $\check{T}$ that includes both development and mitigation assistance. In particular, a package that combines each dollar of development assistance with $-\sigma_S \big/ \sigma_S' \breve{y}_S$ dollars of mitigation transfer (recall that σ_S' is negative, see equation (7)), would be emissions-neutral and not require any further adjustments in the South:

$$(10) \qquad \check{T} = T^i + \frac{-\sigma_S}{\sigma_S' \cdot \breve{y}_S} T^m \quad \rightarrow \quad \frac{de_S}{d\check{T}} = 0; \ \frac{dm_S}{d\check{T}} = 0$$

We can think of such a package as low-carbon development assistance (say, access to renewable energy) rather than traditional, high-carbon development aid (access to fossil fuel-based energy), where the incremental cost of the clean solution constitutes the mitigation transfer. The presence

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[8] Note that this will not necessarily follow from the optimization problem of the North, see Section 5.

of an emissions constraint in the South thus strengthens the case for low-carbon development aid, and raises questions about development support for high-carbon projects like coal.

If the North is intent on increasing mitigation in the South beyond the emissions constraint $\hat{e}_S$, it may wish to structure mitigation transfers as "matching grants", where for each dollar the South spends on mitigation, the North would pay an additional τ^m dollars for further mitigation.[9] This would provide an incentive to reduce emissions in the South beyond what its carbon constraint requires. Defining $\widetilde{m_S} = [1 + \tau^m]$ as the total mitigation level in the South, it is easy to show that there is still crowding out but at a lower rate:

$$(11) \quad d\breve{m}_S = dm_S\left[1+\tau^m\right] + m_S d\tau^m = 0 \quad \Rightarrow \quad dm_S / d\tau^m = -m_S / \left[1+\tau^m\right].$$

Hence, the effect of a slight increase of the matching grant *rate* (from say 10% to 11%) is a decrease in mitigation expenditure in the South of $-m_S / \left[1 + \tau^m\right]$. In order to make this comparable to the effect of the direct grant (which is measured in monetary terms), we have to divide by m_S in equation (11). Therefore, the effect of a slight change in the matching grant is given by $-1/\left[1 + \tau^a\right] \in \left[-1, 0\right]$, showing that there is incomplete crowding out in the matching grant case.

An incomplete crowding out implies that more is spent on mitigation measures and emissions fall. However, unlike in the case of low-carbon development assistance, the matching grant will not result in a welfare maximizing allocation of resources from the perspective of the South as the South would allocate resources differently without the matching grant restriction.

We summarize these findings in the following proposition:

Proposition 2: The North can respond to the impact that an emissions constraint in the South has on the effectiveness of transfers by switching to a low-carbon form of development assistance and / or by offering mitigation assistance in the form of a matching grant. The former would

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[9] Again, this may not necessarily be an optimal policy for the North.

ensure that the twin objectives of output growth and emissions cuts are met simultaneously. The latter would encourage the South to undertake additional mitigation beyond what its emissions constraint requires.

An interesting extension to consider is how the possibility of carbon trading might affect the case for official development and mitigation assistance. To explore this we replace the separate regional emissions constraints of equation 1 with a global emissions target,

$$(12) \qquad\qquad e_N^0 + e_N^1 + e_S^0 + e_S^1 \leq \hat{e},$$

where $\hat{e} = \sum\sum \hat{e}_j^t$. Countries are allowed to trade in deviations between actual and target emissions, which gives rise to an additional financial flow that affects utility in both regions: $p(\hat{e}_j^t - e_j^1)$, where p is the international price of carbon.

The consumption levels in each region and at each time period is now specified in Table 2.

Table 2: Consumption levels in each region and period. Permit trading.

	Period 0 (now)	Period 1 (future)
N (North)	$c_N^0 = y_N^0 - m_N - a_N - T^m - T^a - T^i$ $\qquad\qquad + p\left[\hat{e}_N^0 - e_N^0\right]$ $e_N^0 = \sigma_N(m_N) y_N^0$	$c_N^1 = \left[1 - \left[1 - \alpha_N(a_N)\right]D_N(\hat{e})\right] y_N^1$ $\qquad\qquad + p\left[\hat{e}_N^1 - e_N^1\right]$ $e_N^1 = \sigma_N(m_N) y_N^1$
S (South)	$c_S^0 = y_S^0 - m_S - a_S$ $\qquad + p\left[\hat{e}_S^0 - e_S^0\right]$ $e_S^0 = \sigma_S(m_S + T^m) y_S^0$	$c_S^1 = \left[1 - \left[1 - \alpha_S(a_S + T^a)\right]D_S(\hat{e})\right]\left[y_S^1 + T^i\right]$ $\qquad\qquad + p\left[\hat{e}_S^1 - e_S^1\right]$ $e_S^1 = \sigma_S(m_S + T^m)\left[y_S^1 + T^i\right]$

The presence of carbon trading introduces a strategic element to the North's decision about development and mitigation transfers, since the impact these have on Southern emissions may feed back to the North in the form of different carbon market dynamics:

Proposition 3: When emissions are controlled through a global carbon market, a transfer of mitigation capital completely crowds out mitigation in the South. The transfer has no impact on the optimal mitigation level in the North. Development assistance that increases output and emissions in the South will increase the mitigation effort in the South, while the mitigation effort in the North is also likely to increase.

We demonstrate these results in Annex 1. It shows that most results also carry over to the case with emissions trading. The main difference is that mitigation in the South affects the permit price. When development assistance is given, southern emissions increase and the South needs to mitigate more to meet its target, or to buy permits from the North. In the Annex we show that both are likely to happen, which means that mitigation will increase in both regions and the price for permits goes up.

4. Financial transfers and adaptation in the South

We now turn to the adaptation decision of the South and explore how the adaptation in the South depends on transfers from the North. The maximization problem of the South is given by:

(13)
$$\begin{aligned} max_{a_S}\; \mathrm{L}_S &= c_S^0 + \delta_S\, c_S^1 + \lambda_S[\hat{e}_S - e_S^0 - e_S^1] \\ &= y_S^0 - m_S - a_S + \delta_S\left\{[1-[1-\alpha_S(a_S+T^a)]D_S(\hat{e})][y_S^1+T^i]\right\} + \lambda_S\left\{\hat{e}_S - \sigma_S(m_S+T^m)[y_S^0+y_S^1+T^i]\right\} \end{aligned}$$

The necessary first-order condition for a maximum (interior solution[10]) with respect to adaptation effort, a_S, is given by: $-1+\delta_S\alpha_S' D_S\left[y_j^1+T^i\right]=0$. Thus, we get

(14) $\delta_S\alpha_S'\left(a_S+T^a\right)D_S\left(\hat{e}\right)\left[y_S^1+T^i\right]=1$

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[10] Sufficient conditions for an interior solution are that the first unit of investment in adaptation has a very large effect on the residual damages ($\alpha_i'(0)=+\infty$) and that this effect vanishes for very large investments ($\lim_{a_i\to+\infty}\alpha_i'(a_i)=0$).

The optimal adaptation effort is found by equalizing the marginal benefits of adaption (the left hand side) and its marginal costs (the right hand side). The FOC determines adaptation effort as an implicit function of adaptation and productive investment and the global emission cap: $\tilde{a}_S\left(T^a, T^i, \hat{e}\right)$.

In a similar way, we can find the optimal adaptation level in the North:[11]

(15) $\quad \delta_N y_N^1 D_N(\hat{e}) \alpha_N' = 1$.

Thus, as for the South, the discounted marginal benefits of adaptation should equal the marginal cost of adaptation. The optimal adaptation level follows from economic considerations only, which means that both the mitigation level and adaptation level of the North is unaffected by its equity preferences. In addition, they are also unaffected by transfers to the South.

To see the impact of transfers on the adaptation level in the South, we find from equation (14):

(16) $\quad \alpha_S''\left[da_S + dT^a\right] D_S\left[y_S^1 + T^i\right] + \alpha_S' D_S'\left[y_S^1 + T^i\right] d\hat{e} + \alpha_S' D_S dT^i = 0$

It follows straightforwardly that

(17) $\quad \dfrac{\partial}{\partial \hat{e}} \tilde{a}_S\left(\hat{e}, T^a, T^i\right) = \dfrac{da_S}{d\hat{e}} = \dfrac{-\alpha_S' D_S'}{\alpha_S''} > 0$

A higher global cap on emissions will cause the South to adapt more as the marginal benefit to adaptation is more important.

If follows also that

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[11] See equation (23) for the optimization problem.

(18) $\quad \dfrac{\partial}{\partial T^a} \tilde{a}_S\left(\hat{e}, T^a, T^i\right) = \dfrac{da_S}{dT^a} = -1$.

That is, additional adaptation support completely crowds out the South's own adaptation effort. Direct adaptation support funded by the North does not lead to additional adaptation because the South decreases its own adaptation effort by the same amount. In the same way as for mitigation, additional adaptation support frees up resources that the South prefers to use for consumption. The reason for this is seen from the first order condition given by equation (14). Adaptation transfers do not address any exogenous constraints to adaptation but simply offer additional adaptation resources. But since the benefit from adaption is the same before and after the transfer, it will be optimal for the South to stick to its original adaptation level. Thus, this is in line with the literature discussed in the introduction claiming that the benefits of adaptation are excludable, so the poor region has the right incentives to adapt even before the transfer.

As for mitigation transfers discussed above, the North could increase the adaptation in the South, and thus reduce damage in the South, by again using a "matching grant" form of support. As before this would lead to incomplete crowding out, but as this gives a different allocation of resources than without the matching grant restriction, it would result in a welfare loss for the South.

This gives us the following proposition:

Proposition 4: *Adaptation capital transfer from the North to South will completely crowd out adaptation investments in the South, unless a matching grant support function is used, but this will not give the welfare maximizing allocation of resources for the South.*

To study the effect on adaptation of development assistance, it follows from (16) that

(19) $\quad \dfrac{\partial}{\partial T^i} \tilde{a}_S\left(\hat{e}, T^a, T^i\right) = \dfrac{da_S}{dT^i} = \dfrac{\delta_S \alpha'_S D_S}{\delta_S\left[-\alpha''_S\right] D_S\left[y^1_S + T^i\right]} = \dfrac{\alpha'_S}{\left[-\alpha''_S\right]\left[y^1_S + T^i\right]} > 0$,

16

hence, productive capital support leads to the desired result that the South increases its adaptation effort. Intuitively, by promoting GDP growth in the South, more value is at risk in the region due to climate change.[12] This gives an incentive to increase adaptation efforts. Note that this effect hinges on the assumption that damages are proportional to output, a standard assumption in economic studies as mentioned in Section 2. The result can be stated in a Proposition:

Proposition 5: *An increase in development assistance will increase the adaptation level of the South.*

As seen from equations (7) and (19), increasing development assistance that increases production in developing countries has a positive impact on both mitigation and adaptation effort in the developing countries. This is in contrast to climate finance that gives transfer of adaptation and mitigation capital. These results hinge on the assumption that development assistance has a positive effect on production in the poor countries, and that we do not have a complete crowding out of investments in real capital. We will discuss this in further detail in Section 5 below.[13]

5. Financial transfers when the South is income-constrained

Up to now, we have assumed that the South is sufficiently affluent that it can invest some of its resources in adaptation or mitigation. We now relax this assumption by requiring that consumption in the initial period should be at least equal to some minimal subsistence level $\underline{c}$. We can think of this as the situation of a least-developed country.

The South's optimization problem is now given by:

$$(20) \qquad \max_{m_S, a_S} \quad U_S = c_S^0 + \delta_S c_S^1 \quad \text{s.t.} \quad c_S^0 \geq \underline{c} \quad \text{and} \quad e_S^0 + e_S^1 \leq \hat{e}_S$$

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[12] In addition, higher income may lead to higher demand for climate protection, but we do not model this income effect.

[13] Note that the results for adaptation depend on a given level of accumulated emissions in the second period. That is, it does not matter whether the permits are tradable or not.

Associating a Lagrange multiplier θ to the minimal consumption requirement and λ_S with the emission constraint as before, we can write the FOC for optimal mitigation (assuming an interior solution[14]) as follows:

(21) $$-[1+\theta] - \lambda_S \, \sigma_S' \left[y_S^0 + y_S^1 + T^i \right] = 0$$

The first term denote the marginal cost of a dollar invested in mitigation in the first period: one unit of consumption forgone plus the shadow price of the subsistence requirement. The second term measures the marginal return of that extra mitigation investment which depends on the shadow value of the emissions constraint. The FOC for optimal adaptation efforts is given by:

(22) $$-[1+\theta] + \delta_S \alpha_S' D_S \left[y_S^1 + T^i \right] = 0$$

The first term stands for the marginal adaptation cost and the shadow price of the minimal subsistence consumption level. The second term stands for the marginal benefit, i.e., reduction in remaining climate change damages. Compared to the unconstrained case (equation (5) for mitigation and equation (14) for adaptation), we see that marginal cost of investment will be higher in the constrained case. Hence, the South will mitigate and adapt less if it is constrained in consumption in the initial period which is very intuitive. They would like to mitigate and adapt more but they cannot because otherwise they would starve to death.

The comparative statics and derivations are shown in Annex 2. When both the emissions and consumption constraints are binding, we find exactly the same results for mitigation as in the unconstrained case discussed earlier. In particular, mitigation support is completely crowded out, adaptation support has no impact on mitigation efforts, productive capital support leads to higher mitigation (in order to compensate for higher emissions), a more lenient emission constraint implies less mitigation, and the minimal consumption level (and hence a pure transfer of consumption) has no impact on the mitigation decision.

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[14] We can safely do this because we have assumed that the marginal benefits of the first units of mitigation- and adaptation investments are unbounded.

The comparative statics for adaptation by the South are however different from the unconstrained case. First, extra mitigation support leads to more adaptation in the constrained case (remember it did not affect adaptation in the unconstrained case). The transfer of mitigation capital leads to complete crowding out of mitigation as the South will lower its own effort by exactly the same amount. However, this frees resources that can be invested in adaptation which was previously constrained.

Secondly, extra adaptation support has no impact on the adaptation choice of the South in the sense that they do not change their own adaptation investments. The reason is that they were constrained in adaptation. Hence, the support alleviates the constraint and increases to total adaptation capital of the South.

Thirdly, productive capital support leads to higher second period emissions which have to be compensated by higher mitigation if the emission constraint is binding. This implies that resources should be drained away from adaptation in order to obey the consumption constraint. Thus, traditional development assistance leads to lower adaptation investments in the poorest countries. Recall that this was different in the unconstrained case, in which the South reacted with extra adaptation efforts when receiving development assistance.

Fourthly, a more lenient global carbon constraint results in more adaptation investment in the South because the marginal benefit of adaptation increases. This effect is the same as in the unconstrained case.

A final result is that simply transferring consumption (i.e., relaxing the consumption constraint) would lead to higher adaptation. The additional consumption is used to direct more resources to constrained adaptation investments.[15]

Proposition 6: _If the South is very poor (i.e. constrained to subsistence consumption in the initial period), adaptation can be boosted by providing (1) targeted adaptation support, (2) mitigation_

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[15] Thus, as opposed to the result in the main model in Section 2, a consumption transfer may be optimal in this case.

support, or (3) direct consumption transfers. All three routes are equally efficient at boosting
adaptation. Productive capital support leads however to lower adaptation.

6. The financial transfer decisions of the North

To decide on its adaptation level and the transfers to the South, the North wants to maximize its
intertemporal welfare function, given all restrictions from Section 2 and subject to its adaptation
level (a_N) and transfers (T^a, T^i, T^m). The optimal mitigation level (m_N) is found in Section 3.

The optimization problem for the North can then be written as

(23)
$$\max_{T^a, T^i, T^m} \mathrm{L}_N = (1-\mu)\left(y_N^0 - m_N - a_N - T^a - T^i - T^m\right) + \mu\left(y_S^0 - m_S - a_S\right)$$
$$+ \delta_N \begin{bmatrix} (1-\mu)\left(y_N^1\left(1-(1-\alpha_N(a_N))\right)D_N(\hat{e})\right) \\ +\mu\left((y_S^1 + T^i)\left(1-(1-\alpha_S(a_S + T^a))\right)D_S(\hat{e})\right) \end{bmatrix}$$
$$+ \lambda_N\left\{\hat{e}_N - \sigma_N(m_N)[y_N^0 + y_N^1]\right\},$$

where λ_N is the shadow price of carbon in the North. The Kuhn-Tucker conditions, where the
choices of the South are taken as given, are

(24) $\dfrac{\partial \mathrm{L}_N}{\partial T^a} = -(1-\mu) + \mu\delta_N\left(y_S^1 + T^i\right)D_S(\hat{e})\alpha_S'\left(\dfrac{\partial a_S}{\partial T^a} + 1\right) \leq 0$

(25) $\dfrac{\partial \mathrm{L}_N}{\partial T^m} = -(1-\mu) - \mu\left(\dfrac{\partial m_S}{\partial T^m}\right) \leq 0$

(26) $\dfrac{\partial \mathrm{L}_N}{\partial T^i} = -(1-\mu) - \mu\left[\dfrac{\partial m_S}{\partial T^i} + \dfrac{\partial a_S}{\partial T^i}\right] + \delta_N\mu\left[\left(1-\left(1-\alpha_S(a_s + T^a)\right)\right)D_S(\hat{e}) + \left(y_S^1 + T^i\right)\alpha_S'\dfrac{\partial a_S}{\partial T^i}D_S(\hat{e})\right] \leq 0,$

where equality holds for interior solutions of the respective endogenous variables.

Before discussing the first order conditions, note that by setting $\mu = 0$, the only reasons for
transfers from North to South would be strategic. Thus, ethical reasons such as "to do good"
would not apply. As is obvious from equations (24) to (26), there are no strategic reasons for

20

transfers in this model. However, as we will discuss below, this will change when we introduce tradable permits.

To find the optimal levels of transfers, we need to work with the first-order condition. Let us start with the *adaptation transfers*. For an interior solution, we find from (24):

$$(27) \qquad 1 - \mu = \mu \delta_N \left(y_S^1 + T^i \right) D_S(\hat{e}) \alpha_S' \left(\frac{\partial a_S}{\partial T^a} + 1 \right)$$

This shows that the marginal cost of the transfer in the North, weighted with the equity weight (left hand side), should equal the benefit of increased consumption in the South in the next period, also weighted with the equity weight (right hand side). But from (18) we know that $\frac{\partial a_S}{\partial T^a} = -1$ and the adaptation transfer completely crowds out South's adaptation effort if there are no constraints to the transfer. In this case we see that (27) does not hold, and there is no interior solution. Thus, it will not be optimal for the North to transfer adaptation capital to the South.[16]

However, if there are constraints attached to the adaptation transfers, such that for every dollar used on adaptation in the South, the North transfers τ^a dollars (a matching grant), we know from Section 3 that there is crowding out, but it is not necessarily complete. Using a matching grant may, therefore, give an interior solution of the optimization problem and a positive adaptation transfer from the North to the South will occur. The magnitude of this transfer is increasing with the equity weight put on the utility of the South, and the transfer would be zero if the weight is set to zero.

If the South is constrained in consumption (Section 5), we know that $\frac{da_S}{dT^a} = 0$, see Annex 2. This has implications for the adaptation transfers as equation (27) now becomes:

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[16] Note that an adaptation transfer in this case would be equal to a pure consumption transfer. As discussed in footnote 7, a consumption transfer will not be optimal with a linear utility function. Note, however, that with a concave utility function, we would get an interior solution, and it would be optimal with an adaptation transfer even if the adaptation level in the South did not increase. The reason is that consumption in South would increase and the inequality between the two sectors would be lower. This would increase the utility of the North as they express inequality aversion.

(28) $\qquad 1 - \mu = \mu \delta_N \left(y_S^1 + T^i \right) D_S(\hat{e}) \alpha_S'$

Thus, as we do not have crowding out, it may be optimal for the North to transfer adaptation capital to the South.

To study the optimal *mitigation transfers* we combine (25) and (7) and find

(29) $\qquad \dfrac{\partial \mathrm{L}_N}{\partial T^m} = -(1 - \mu) + \mu < 0$

As for adaptation transfers, there is no interior solution to mitigation transfers and the optimal level is equal to zero. The mitigation transfer would just work as a consumption transfer, which is not optimal with the linear utility function. This also holds if the South is income-constrained.

This gives us the following proposition:

Proposition 7: Due to the complete crowding out of adaptation and mitigation in the South from adaptation and mitigation transfers respectively, these would work as pure income transfers, which will not be optimal with a linear utility function. The transfers could be optimal if they are designed as a matching grant function. Also, if the South is income-constrained, adaptation transfers would be optimal for the North as they will increase the total adaptation capital in the South.

The optimal level of development assistance follows from equation (26). Assuming an interior solution, it can be re-organized as:

(30) $\qquad 1 - \mu = -\dfrac{\partial m_S}{\partial T^i} \mu - \dfrac{\partial a_S}{\partial T^i} \left[\mu \left(1 - \delta_N \cdot \left(y_S^1 + T^i \right) \alpha_S' D_S(\hat{e}) \right) \right] + \delta_N \mu \left[\left(1 - \left(1 - \alpha_S(a_s + T^a) \right) \right) D_S(\hat{e}) \right]$

As seen from (30), the development assistance has impacts on the utility of the North via changes in the mitigation and adaptation efforts in the South, as well as the income increase in the South as the region gets richer. Thus, there may be an interior solution meaning that there may exist an optimal level of development assistance.

For the case where the South is income-constrained, we may still have an interior solution, but note that the sign of $\frac{\partial a_S}{\partial T^i}$ now turns from positive to negative, which has an impact on the size of the transfer. Whether, it increases or decreases is undetermined as adaptation in the South has both a positive (reduces utility in the first period) and negative (increases utility in the second period) impact on the intertemporal utility of the poor region.

If there is a permit market, the development assistance has additional impacts on the utility of the North via changes in the permit price, see Annex 1. This has again impacts for the mitigation effort in both countries. Thus, even if the North does not care about the welfare of the South, the region may still be interested in transferring development assistance for strategic reasons as the transfer has impacts on the financial flows from the permit market and its mitigation effort. Note, however, that the strategic and ethical incentives may go in different directions. For instance, even if the North cares about the South, it may still refrain from transferring development assistance or reduce the ethically optimal level due to the effect of the transfer on its mitigation and the financial flows from the emission permit market.

7. The decisions of the North when financial transfers are inefficient

In addition to the incentive effects studied so far, the effects of international transfers also depend on "leakage", i.e., the extent to which transfers do not reach their intended beneficiary. With weak or corrupt institutions, which are prevalent in many countries, money may disappear along the road.

In our model, the efficiency of transfers can be modeled in different ways. For instance, the α- and σ-functions describe how adaptation measures and mitigation measures are transferred into

reduced damage and emissions respectively. Thus, these functions also describe the efficiency of these transformations. As an example, the α-function may describe the costs of adaptation.

To model what actually reaches the targets, we can introduce *efficiency parameters* $0 \leq b^j \leq 1, j = a,i,m$. This means that the North may pay more than what reaches the South. Thus, while the North's optimization problem is unchanged, these parameters need to be incorporated in *South's* optimization problem.

The introduction of efficiency parameters only has modest impacts for the qualitative conclusions of the model. In the case of permit trading, the permit price will be affected by the effectiveness of development aid. Also, crowding out of adaptation and mitigation capital will be less if less reaches the South, i.e., there is only crowding out of the actual transfer that reaches the target.

Our conclusions on the effect of development aid hinges on the assumption that development assistance has a positive effect on production in the poor countries, and that we do not have a complete crowding out of investments in real capital. In our model, we have assumed that investments in real capital are exogenous, so that the growth potential of development aid is not crowded out. Some studies suggest that aid does not necessary raise capital stocks in developing countries, and that the outcome depends on domestic policies and institutions, see e.g., Dollar and Easterly (1999); Easterly and Pfutze (2008), but there are also more optimistic views on the effects of development aid (e.g. Sachs (2005); Banerjee and Duflo (2011)). Temple (2010) examines the conditions under which foreign aid will be effective in raising growth. Based on the evidence, he finds that aid can be effective, and that the hypothesis that aid may be harmful does not have backing. Thus, while we have modeled the effect of aid in a simple way, we can conclude that as long as aid is given in a way that promotes growth (not complete crowding out), the effect on mitigation and adaptation effort in the developing countries will be positive.

The leakages do not change the qualitative conclusions for mitigation and adaptation transfers. In the main model, it is not optimal for the North to transfer mitigation and adaptation capital as we have full crowding out and the transfers go to consumption. However, this is based on the

assumption of linear utility functions. With concave utility functions, the option for the North would be to increase the Southern consumption by either transferring consumption goods directly, or transferring adaptation or mitigation capital. The choice would depend on transaction costs akin to the "leaky bucket" problem; i.e., efficiency loss in distribution. As a consequence, transferring adaptation or mitigation capital may give different effects on consumption and on who receives the consumption good than a direct transfer of the good itself.

8. Conclusions

This paper discusses the interplay of different types of donor assistance to developing countries: development assistance to boost output and income, mitigation support to reduce greenhouse gas emissions, and adaptation support to increase resilience to climate risks. The motivation for these transfers is derived solely from the North's concern about well-being in the South. Our main model does not include any strategic reasons for mitigation and adaptation transfers, such as the need to secure a global agreement on emissions, or concerns about international trade, where countries specializing in an adaptation or mitigation technology may expand their market if others apply that technology.

The main model does not contain any market distortions that are not internalized. In particular, there are no barriers to either effective adaptation or effective economic management (such as poor institutions), and we assume a binding global emissions constraint to address the climate change externality. We may associate this situation with middle income countries, which tend to have fairly advanced institutions.

We find that under these assumptions isolated transfers aimed solely at development, mitigation or adaptation are relatively inefficient: A large part of their intended effect (to increase income, reduce emissions, or boost climate-resilience) dissipates as the South reacts to the transfers by reallocating its own resources until it has established the mitigation, adaptation and consumption balance that optimizes its welfare. In essence, climate change finance works as a pure consumption transfer and any impacts on mitigation and adaptation are indirect, triggered by the softer budget constraint.

25

If the North wishes to change the balance between mitigation, adaptation and consumption in the South it needs to structure its transfers as "matching grants", which vary according to the South's own level of funding. In our model such conditional funding would not lead to a welfare maximizing allocation of resources. Matching grants could only be justified if the North cares particularly about climate security in the South, rather than welfare more broadly.

Ultimately if the North wants to preserve the full effect of development transfers, it may recognize how climate change complicates welfare maximization and provide an integrated transfer package that addresses the combined climate and development requirements of the South. The development community has started to call this climate-smart development – or, more catchily green growth (Jacobs 2013; World Bank 2012; Bowen and Fankhauser 2011).

The result changes if we introduce a binding income constraint. We can think of this as the situation of least-developed countries, which have to secure a subsistence level of income before money can be allocated for climate change purposes. In this situation financial transfers can have some unexpected consequences. For example, a mitigation transfer may lead to higher levels of adaptation because the South's own mitigation budget is freed up and can be reallocated. But more expectedly, an adaptation transfer will have the desired effect by easing the constraint on adaptation and increasing climate resilience.

This suggests that adaptation support could usefully be targeted at countries that are income (and therefore adaptation) constrained. In addition to the efficiency argument made here, there are also compelling equity reasons in support of prioritizing adaptation support for least-developed countries, which tend to be highly vulnerable to the impacts of climate change. In fact, without effective adaptation the development achievements of past decades will be at risk (e.g. World Bank 2010).

In our main model the transfer decisions of the North are driven purely by their concern about welfare in the South. In the absence of any strategic considerations, the mitigation and adaptation levels of the North itself are unaffected by its equity preferences. This only changes under an international emissions constraint that allows for carbon trading. Carbon trading introduces

strategic element into the transfer decisions of the North. Mitigation in the North is affected indirectly by the impact of development assistance on the international carbon market.

Our conclusions complement those of Kverndokk et al. (2014). They also apply the Fehr/Schmidt inequality aversion in consumption to study an optimal global climate treaty, and find that inequality aversion lifts the consumption path of the poor region, while it lowers the consumption path of the rich region, which must take a greater share of the climate burden. Our findings also relate to the widely held view, expressed most prominently by Schelling (1992, 1997) that economic development is an effective way to reduce vulnerability to climate change, although our argumentation is slightly different. Unlike Schelling, we acknowledge the power of dedicated adaptation spending in reducing vulnerability. Our point is that, whatever the nature of the transfers, developing countries will find their own balance between adaptation and development. See also Bowen et al. (2012) for a more nuanced discussion of the links between climate vulnerability, adaptation and development.

The results depend on an international agreement that constrains global emissions, which we introduced to isolate the climate finance aspects of the problem. This may not be realistic for some years to come. However, the cap on emissions does not need to be strict or environmentally optimal for the model to work. The assumption does not necessarily constrain emissions in the South as their emissions limit may be set equal to their business-as-usual level or even higher. Permit trading in this case could be seen as a Clean Development Mechanism-style transfer, where the North can avoid mitigation at home by paying for mitigation in the South.

The model could be extended in several directions. Output could be modeled as a function of the stock of productive capital and hence introducing an endogenous capital investment process. This would complicate the analyses considerably because both the mitigation and capital accumulation process would have to be modeled as the outcome of a non-cooperative game. We do not believe that the added complications would fundamentally affect the basic results derived in the simpler formulation.

A more interesting extension would be the introduction of market imperfections. So far, we have assumed that the South can chose its adaptation strategy without restriction. In reality however, capital market imperfections and other constraints are likely to restrain the adaptation potential in the South. It would be interesting to investigate how this might affect the results and maybe open up the possibility for other types of assistance (like subsidized loans and technical assistance).

A third set of extensions would involve alternative ways of modeling the equity preferences of the North. One interesting option could be to study the historical responsibility case, where climate damages rather than the consumption level in the South enters North's utility function, or alternatively that the North only cares about the size of the transfers and not on the effect.

Finally, we did not consider explicitly a social optimum of mitigation and adaptation. It would be interesting to study transfers that could secure an international climate treaty, although this is studied in several other papers as mentioned in the introduction. Implicitly, we could say that part of the optimal solution in our model lies in the appropriate choice of the overall emission ceiling $\hat{e}$. Given that we modeled the adaptation process as a private instead of public good, there is no market failure to be expected in adaptation. More sophisticated formulations are conceivable but are beyond the scope of this paper.

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Annex 1: Official financial flows under global carbon trading

In this Annex we extend the original model with separate regional carbon constraints to a situation where regional emissions targets give rise to international emissions trading in a global carbon market. The mitigation functions for North and South remain the same, but the emissions constraint is replaced by:

(31) $\qquad e_N^0 + e_N^1 + e_S^0 + e_S^1 \le \hat{e}$.

Where the aggregate target $\hat{e}$ is the sum of individual targets by regions and time periods, $\hat{e} = \Sigma_j \Sigma_t \hat{e}_j^t$. The difference between the emissions target and actual emissions creates a financial flow, $p(\hat{e}_j^t - e_j^t)$, where p is the inter-temporal market-clearing carbon price.

In this case, the optimization problems for the South and North respectively are:

(32)
$$
\begin{aligned}
\max_{m_S} \quad U_S &= c_S^0 + \delta_S c_S^0 = y_S^0 - m_S - a_S + p\left[\hat{e}_S^0 - e_S^0\right] + \\
&\quad \delta_S\left\{\left[1-\left[1-\alpha_S(a_S + T^a)\right]D_S(\hat{e})\right]\left[y_S^0 + T^i\right] + p\left[\hat{e}_S^1 - e_S^1\right]\right\} \\
&= y_S^0 - m_S - a_S + p\left[\hat{e}_S^0 - \sigma_S\left(m_S + T^m\right)y_S^0\right] + \\
&\quad \delta_S\left\{\left[1-\left[1-\alpha_S(a_S + T^a)\right]D_S(\hat{e})\right]\left[y_S^1 + T^i\right] + p\left[\hat{e}_S^1 - \sigma_S\left(m_S + T^m\right)\left[y_S^1 + T^i\right]\right]\right\}
\end{aligned}
$$

(33)
$$
\begin{aligned}
\max_{m_N} \quad U_N &= (1-\mu)\left(y_N^0 - m_N - a_N - T^a - T^i - T^m + p(\hat{e}_N^0 - \sigma_N(m_N)y_N^0)\right) \\
&\quad + \mu\left(y_S^0 - m_S - a_S + p(\hat{e}_S^0 - \sigma_S(m_S + T^m)y_S^0)\right) \\
&\quad + \delta_N\left[\begin{array}{l}(1-\mu)\left(y_N^1\left(1-(1-\alpha_N(a_N))D_N(\hat{e})\right) + p(\hat{e}_N^1 - \sigma_N(m_N)y_N^1)\right) \\ +\mu\left((y_S^1 + T^i)\left(1-(1-\alpha_S(a_S + T^a))D_N(\hat{e})\right) + p(\hat{e}_S^1 - \sigma_S(m_S + T^m)(y_S^1 + T^i))\right)\end{array}\right]
\end{aligned}
$$

The carbon market equilibrium

To find the optimal mitigation levels, we first consider the optimization problem of each region with respect to mitigation. The necessary first-order condition (FOC) for an interior solution with respect to mitigation efforts m_S and m_N is given by

(34) $-1/\left(\sigma'_S(m_S + T^m)\left[y_S^0 + \delta_S\left(y_S^1 + T^i\right)\right]\right) = p$;

(35) $-1/\left(\sigma'_N(m_N)\left[y_N^0 + \delta_N y_N^1\right]\right) = p$.

This implies that the mitigation function of the North only depends on the permit price p, while optimal mitigation in the South also depends on mitigation and development transfers. Combining (34) and (35) to eliminate the price and denoting $\breve{y}_N = y_N^0 + y_N^1$, $\breve{y}_S = y_S^0 + y_S^1 + T^i$, $y_N = y_N^0 + \delta_N y_N^1$ and $y_S = y_S^0 + \delta_S\left(y_S^1 + T^i\right)$ to save notation, we get

(36) $\sigma'_N\left(m_N\right)\left[y_N^0 + \delta_N y_N^1\right] = \sigma'_S\left(m_S + T^m\right)\left[y_S^0 + \delta_S\left(y_S^1 + T^i\right)\right]$

Differentiating this condition yields:

(37) $\sigma''_N y_N dm_N = \sigma''_S y_S\left[dm_S + dT^m\right] + \sigma'_S\delta_S dT^i$

Differentiated the market clearing condition gives:

(38) $\sigma'_N \breve{y}_N dm_N + \sigma'_S \breve{y}_S\left[dm_S + dT^m\right] + \sigma_S dT^i = d\hat{e}$

Together, (37)and (38) define a system in two endogenous variables dm_N and dm_S and several exogenous parameters T^i, T^m and $\hat{e}$. The relevant comparative statics look as follows:

(39) $\dfrac{dm_N}{dT^m} = \dfrac{1}{\det \mathbf{A}}\det\begin{bmatrix} \sigma''_S y_S & -\sigma''_S y_S \\ -\sigma'_S \breve{y}_S & \sigma'_S \breve{y}_S \end{bmatrix} = 0$

(40) $\dfrac{dm_S}{dT^m} = \dfrac{1}{\det \mathbf{A}}\det\begin{bmatrix} \sigma''_N y_N & \sigma''_S y_S \\ \sigma'_N \breve{y}_N & -\sigma'_S \breve{y}_S \end{bmatrix} = \dfrac{1}{\det \mathbf{A}}\left[-\sigma''_N y_N \sigma'_S \breve{y}_S - \sigma''_S y_S \sigma'_N \breve{y}_N\right] = -\dfrac{\det \mathbf{A}}{\det \mathbf{A}} = -1$

(41) $\quad \dfrac{dm_N}{dT^i} = \det \mathbf{A} \det \begin{bmatrix} \delta_S \sigma_S' & -\sigma_S'' y_S \\ -\sigma_S & \sigma_S' \breve{y}_S \end{bmatrix} = \det \mathbf{A} \left[\delta_S \sigma_S' \sigma_S' \breve{y}_S - \sigma_S'' y_S \sigma_S \right]$

(42) $\quad \dfrac{dm_S}{dT^i} = \det \mathbf{A} \det \begin{bmatrix} \sigma_N'' y_N & \delta_S \sigma_S' \\ \sigma_N' \breve{y}_N & -\sigma_S \end{bmatrix} = \det \mathbf{A} \left[-\sigma_N'' y_N \sigma_S - \delta_S \sigma_S' \sigma_N' \breve{y}_N \right] > 0$

where: $\det \mathbf{A} = \sigma_N'' y_N \sigma_S' \breve{y}_S - \left[-\sigma_S'' y_S \right] \sigma_N' \breve{y}_N = \sigma_N'' \sigma_S' y_N \breve{y}_S + \sigma_S'' \sigma_N' y_S \breve{y}_N < 0$

The impact on the mitigation effort by firms in the North cannot be signed easily. However, a sufficient condition for the effect to be positive, is that

$\dfrac{\left[\sigma_S' \right]^2 \delta_S \breve{y}_S}{\sigma_S' \breve{y}_S} - \dfrac{\sigma_S \sigma_S'' y_S}{\sigma_S' \breve{y}_S} > 0$, or $\left[\sigma_S' \right]^2 \delta_S \breve{y}_S < \sigma_S \sigma_S'' y_S < \sigma_S \sigma_S'' \breve{y}_S$ (since $\delta_S < 1$) and therefore:

$\left[\sigma_S' \right]^2 \delta_S < \sigma_S \sigma_S'' \Rightarrow \dfrac{\left[\sigma_S' \right]^2 \delta_S}{\sigma_S} < \sigma_S''$. This condition requires that the South is on beginning or flat

part of its marginal abatement cost curve (MAC) where σ_S'' is high and therefore $1/\sigma_S''$ (i.e., the slope of MAC) low. This is very likely since most developing countries have only just started to

invest in mitigation effort. We can, therefore, conclude that it is very likely that $\dfrac{dm_N}{dT^i} > 0$, and

because we know from the first order condition of mitigation in the North that $dp = \dfrac{p \sigma_N''}{-\sigma_N'} dm_N$, it

follows directly that this will give a higher equilibrium price of emission permits, i.e., $\dfrac{dp}{dT^i} > 0$.

Optimal transfers from the North

The optimization problem for the North can then be written as

(43)
$$
\begin{aligned}
\max_{T^a, T^i, T^m} U_N = &\; (1-\mu)\left(y_N^0 - m_N - a_N - T^a - T^i - T^m + p(\bar{e}_N^0 - \sigma_N(m_N) y_N^0) \right) \\
&+ \mu\left(y_S^0 - m_S - a_S + p(\bar{e}_S^0 - \sigma_S(m_S + T^m) y_S^0) \right) \\
&+ \delta_N \left[\begin{array}{l} (1-\mu)\left(y_N^1 \left(1 - (1 - \alpha_N(a_N))\right) D_N(\hat{e}) + p(\bar{e}_N^1 - \sigma_N(m_N) y_N^1) \right) \\ +\mu\left((y_S^1 + T^i)\left(1 - (1 - \alpha_S(a_S + T^a))\right) D_S(\hat{e}) + p(\bar{e}_S^1 - \sigma_S(m_S + T^m)(y_S^1 + T^i)) \right) \end{array} \right]
\end{aligned}
$$

The Kuhn-Tucker conditions, where the choices of the South are taken as given, are

$$(44) \quad \frac{\partial U_N}{\partial T^a} = -(1-\mu) + \mu \delta_N \left(y_S^1 + T^i \right) D_S(\hat{e}) \alpha_S' \left(\frac{\partial a_S}{\partial T^a} + 1 \right) \leq 0$$

$$
\begin{aligned}
\frac{\partial U_N}{\partial T^m} =\ & -(1-\mu)\left(\frac{\partial m_N}{\partial T^m} + 1 - \frac{\partial p}{\partial T^m}(\hat{e}_N^0 - \sigma_N(m_N)y_N^0) + p\sigma_N'(m_N)\frac{\partial m_N}{\partial T^m} y_N^0 \right) \\
& -\mu\left(\frac{\partial m_S}{\partial T^m} - \frac{\partial p}{\partial T^m}(\hat{e}_S^0 - \sigma_S(m_S + T^m)y_N^0) + p\sigma_S'(m_N)\left(\frac{\partial m_S}{\partial T^m} + 1 \right) y_N^0 \right) \\
(45)\quad & + \delta_N(1-\mu)\left(\frac{\partial p}{\partial T^m}(\hat{e}_N^1 - \sigma_N(m_N)y_N^1) + p\sigma_N'(m_N)\frac{\partial m_N}{\partial T^m} y_{Ni}^1 \right) \\
& + \delta_N \mu\left(\frac{\partial p}{\partial T^m}(\hat{e}_S^1 - \sigma_S(m_S + T^m)y_N^1) + p\sigma_S'(m_N)\left(\frac{\partial m_S}{\partial T^m} + 1 \right) y_N^1 \right) \leq 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial U_N}{\partial T^i} =\ & -(1-\mu)\left(\frac{\partial m_N}{\partial T^i} + 1 - \frac{\partial p}{\partial T^i}\cdot\left(\hat{e}_N^0 - e_N^0 \right) + p\sigma_N'\frac{\partial m_N}{\partial T^i} y_N^0 \right) \\
& -\mu\left[\frac{\partial m_S}{\partial T^i} + \frac{\partial a_S}{\partial T^i} - \frac{\partial p}{\partial T^i}\cdot\left(\hat{e}_S^0 - e_S^0 \right) + p\sigma_S'\frac{\partial m_S}{\partial T^i} y_S^0 \right] \\
(46)\quad & + \delta_N(1-\mu)\left(\frac{\partial p}{\partial T^i}\cdot\left(\hat{e}_N^1 - e_N^1 \right) - p\sigma_N'\frac{\partial m_N}{\partial T^i} y_N^1 \right) \\
& + \delta_N \mu \left[\begin{array}{l} \left(1 - \left(1 - \alpha_S(a_s + T^a)\right)\right)D_S(\hat{e}) + \left(y_S^1 + T^i \right)\alpha_S' \dfrac{\partial a_S}{\partial T^i} D_S(\hat{e}) \\[2mm] + \dfrac{\partial p}{\partial T^i}\cdot\left(\hat{e}_S^1 - e_S^1 \right) - p\sigma_S'\dfrac{\partial m_S}{\partial T^i}\cdot\left(y_S^1 + T^i \right) - p\sigma_S(m_S + T^m) \end{array} \right] \leq 0,
\end{aligned}
$$

where equality holds for interior solutions of the respective endogenous variables.

The optimal level of development assistance follows from equation (46). Assuming an interior solution, it can be re-organized as:

36

$$-(1-\mu) - \frac{\partial m_N}{\partial T^i}\left[(1-\mu)\cdot\left(1 + p\sigma'_N \cdot \left(y^0_N + \delta_N y^1_N\right)\right)\right]$$

$$+\frac{\partial p}{\partial T^i}\left[(1-\mu)\cdot\left(\hat{e}^0_N - e^0_N + \delta_N \cdot \left(\hat{e}^1_N - e^1_N\right)\right) + \mu\cdot\left(\hat{e}^0_S - e^0_S + \delta_N \cdot \left(\hat{e}^1_S - e^1_S\right)\right)\right]$$

$$(47)\qquad -\frac{\partial m_S}{\partial T^i}\left[\mu\left(1 + p\sigma'_S \cdot \left(y^0_S + \delta_N \cdot \left(y^1_S + T^i\right)\right)\right)\right]$$

$$-\frac{\partial a_S}{\partial T^i}\left[\mu\left(1 - \delta_N \cdot \left(y^1_S + T^i\right)\alpha'_S D_S(\hat{e})\right)\right]$$

$$+\delta_N \mu\left[\left(1 - \left(1 - \alpha_S(a_s + T^a)\right)\right)D_S(\hat{e}) - p\sigma_S \cdot (m_S + T^m)\right]$$

$$= 0$$

As seen from (47), the development assistance has impacts on the utility of the North via changes in the permit price and the mitigation efforts in both countries, the adaptation level in the South as well as the income increase in the South as the region gets richer.

Annex 2: Mitigation and adaptation in an income-constrained South

Consider the case where the South is constrained in the sense that a minimal consumption level $\underline{c}$ is required in every period, see the optimization problem in equation (20) and the first order conditions (FOCs) in equations (21) and (22).

Combining the two FOCs above and totally differentiating yields:

(48)
$$\delta_S \alpha_S'' \left[da_S + dT^a \right] D_S \left[y_S^1 + T^i \right] + \delta_S \alpha_S' D_S' d\hat{e} \left[y_S^1 + T^i \right] + \delta_S \alpha_S' D_S dT^i =$$
$$-d\lambda_S \sigma_S' \left[y_S^0 + y_S^1 + T^i \right] - \lambda_S \sigma_S'' \left[dm_S + dT^m \right] \left[y_S^0 + y_S^1 + T^i \right] - \lambda_S \sigma_S' dT^i$$

Combining this with the differentiated minimal consumption constraint and emission constraint, we can write the following system of three equations in three endogenous variables:

$$\begin{cases} -da_S - dm_S = d\underline{c} \\ \sigma_S' \left[y_S^0 + y_S^1 + T^i \right] \left[dm_S + dT^m \right] + \sigma_S dT^i = d\hat{e}_S \\ \delta_S \alpha_S'' \left[da_S + dT^a \right] D_S \left[y_S^1 + T^i \right] + \delta_S \alpha_S' D_S' d\hat{e} \left[y_S^1 + T^i \right] + \delta_S \alpha_S' D_S dT^i = \\ \qquad\qquad -d\lambda_S \sigma_S' \left[y_S^0 + y_S^1 + T^i \right] - \lambda_S \sigma_S'' \left[dm_S + dT^m \right] \left[y_S^0 + y_S^1 + T^i \right] - \lambda_S \sigma_S' dT^i \end{cases}$$

Reorganizing and defing $\breve{y}_S = y_S^0 + y_S^1 + T^i$ and $\bar{y} = y_S^1 + T^i$, we get:

$$\begin{cases} -dm_S - da_S = d\underline{c} \\ \sigma_S' \breve{y}_S dm_S = -\sigma_S' \breve{y}_S dT^m - \sigma_S dT^i + d\hat{e}_S \\ \lambda_S \sigma_S'' \breve{y}_S dm_S + \delta_S \alpha_S'' D_S \bar{y}_S da_S + \sigma_S' \breve{y}_S d\lambda_S = \\ \qquad\qquad -\lambda_S \sigma_S'' \breve{y}_S dT^m - \delta_S \alpha_S'' D_S \bar{y}_S dT^a - \delta_S \alpha_S' D_S dT^i - \lambda_S \sigma_S' dT^i - \delta_S \alpha_S' D_S' \bar{y}_S d\hat{e} \end{cases}$$

Rewriting in matrix notation:

$$\begin{pmatrix} -1 & -1 & 0 \\ \sigma_S' \breve{y}_S & 0 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} \cdot \begin{pmatrix} dm_S \\ da_S \\ d\lambda_S \end{pmatrix} =$$

(49)

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ -\sigma_S' \breve{y}_S & 0 & -\sigma_S & 1 & 0 \\ -\lambda_S \sigma_S'' \breve{y}_S & -\delta_S \alpha_S'' D_S \bar{y}_S & \left[-\delta_S \alpha_S' D_S + \lambda_S \sigma_S' \right] & -\delta_S \alpha_S' D_S' \bar{y}_S & 0 \end{pmatrix} \begin{pmatrix} dT^m \\ dT^a \\ dT^i \\ d\hat{e}_S \\ d\underline{c} \end{pmatrix}$$

It can easily be checked that the determinant of the coefficient matrix is positive and equal to

$$\det \begin{pmatrix} -1 & -1 & 0 \\ \sigma_S' \breve{y}_S & 0 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \left[\sigma_S' \breve{y}_S \right]^2 \geq 0$$

The full comparative statics for *mitigation* are shown below.

(50)
$$\frac{dm_S}{dT^m} = \frac{1}{\left[\sigma_S' \breve{y}_S\right]^2} \det \begin{pmatrix} 0 & -1 & 0 \\ -\sigma_S' \breve{y}_S & 0 & 0 \\ -\lambda_S \sigma_S'' \breve{y}_S & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{-\left[\sigma_S' \breve{y}_S\right]^2}{\left[\sigma_S' \breve{y}_S\right]^2} = -1 < 0$$

(51)
$$\frac{dm_S}{dT^a} = \frac{1}{\left[\sigma_S' \breve{y}_S\right]^2} \det \begin{pmatrix} -1 & -1 & 0 \\ \sigma_S' \breve{y}_S & 0 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = 0$$

(52)
$$\frac{dm_S}{dT^i} = \frac{1}{\left[\sigma_S' \breve{y}_S\right]^2} \det \begin{pmatrix} 0 & -1 & 0 \\ -\sigma_S & 0 & 0 \\ 2\lambda_S \sigma_S' & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{-\sigma_S}{\sigma_S' \breve{y}_S} \geq 0$$

(53)
$$\frac{dm_S}{d\hat{e}_S} = \frac{1}{\left[\sigma_S' \breve{y}_S\right]^2} \det \begin{pmatrix} 0 & -1 & 0 \\ 1 & 0 & 0 \\ -\delta_S \alpha_S' D_S' \bar{y}_S & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{\sigma_S' \breve{y}_S}{\left[\sigma_S' \breve{y}_S\right]^2} = \frac{1}{\sigma_S' \breve{y}_S} \leq 0$$

$$(54) \qquad \frac{dm_S}{d\underline{c}} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} 1 & -1 & 0 \\ 0 & 0 & 0 \\ 0 & \delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = 0$$

The full comparative statics for *adaptation* are shown below.

$$(55) \qquad \frac{da_S}{dT^m} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} -1 & 0 & 0 \\ \sigma_S' \breve{y}_S & -\sigma_S' \breve{y}_S & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & -\lambda_S \sigma_S'' \breve{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{[\sigma_S' \breve{y}_S]^2}{[\sigma_S' \breve{y}_S]^2} = +1 > 0$$

$$(56) \qquad \frac{da_S}{dT^a} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} -1 & 0 & 0 \\ \sigma_S' \breve{y}_S & 0 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & -\delta_S \alpha_S'' D_S \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = 0$$

$$(57) \qquad \frac{da_S}{dT^i} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} -1 & 0 & 0 \\ \sigma_S' \breve{y}_S & -\sigma_S & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & 2\lambda_S \sigma_S' & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{\sigma_S \sigma_S' \breve{y}_S}{[\sigma_S' \breve{y}_S]^2} = \frac{\sigma_S}{\sigma_S' \breve{y}_S} \leq 0$$

$$(58) \qquad \frac{da_S}{d\hat{e}_S} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} -1 & 0 & 0 \\ \sigma_S' \breve{y}_S & 1 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & -\delta_S \alpha_S' D_S' \bar{y}_S & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{-\sigma_S' \breve{y}_S}{[\sigma_S' \breve{y}_S]^2} = \frac{-1}{\sigma_S' \breve{y}_S} \geq 0$$

$$(59) \qquad \frac{da_S}{d\underline{c}} = \frac{1}{[\sigma_S' \breve{y}_S]^2} \det \begin{pmatrix} -1 & 1 & 0 \\ \sigma_S' \breve{y}_S & 0 & 0 \\ \lambda_S \sigma_S'' \breve{y}_S & 0 & \sigma_S' \breve{y}_S \end{pmatrix} = \frac{-[\sigma_S' \breve{y}_S]^2}{[\sigma_S' \breve{y}_S]^2} = -1 < 0 \ .$$