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Wolfgang Peters, Reimund Schwarze, and Anna-Katharina Topp

Contact

Anna-Katharina Topp
European University Viadrina
Große Scharrnstraße 59, 15230 Frankfurt (Oder), Germany
annaktopp@gmail.com

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Wolfgang Peters, Reimund Schwarze

and Anna-Katharina Topp

European University Viadrina

Große Scharrnstr. 59, 15230 Frankfurt (Oder), Germany

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Abstract

We address the international regime of climate finance, which is emerging in the post-Kyoto architecture, and investigate which type of earmarked funding may lead to Pareto improvements for donor and recipient countries. As funding within the post-Kyoto framework is voluntary, sustained finance in the long term can only be guaranteed if all participating countries benefit. In order to rule out for the Bergstrom paradox, which states that recipient countries may end up in a worse-off situation as a consequence of conditional transfers, we presume a framework in which donor countries commit themselves not to reduce their own mitigation efforts. Regarding three types of earmarked climate funding, which compensate either mitigation, adaptation or damage costs, we find that only funds that are directed at mitigation activities boost the global level of mitigation and may induce Pareto improvements. Transferring our results into the political context of the Green Climate Fund, we recommend to prioritize finance of “energy generation and access”, which aims at enhancing mitigation through low-emission power generation and access.

JEL classification: Q54, H41, H87, C72

Keywords: adaptation, climate change, funding, mitigation, Nash bargaining

1 Motivation

Over the past years, global negotiations on climate change under the roof of the United Nations Framework Convention on Climate Change (UNFCCC) have stagnated. Only a few countries are willing to commit to meaningful binding greenhouse-gas mitigation targets: 16 countries which account for approximately 35 per cent of the global emissions submitted INDCs, most of them targeted at 2030 and several (3) conditional upon measures taken by all developed countries (status June 16th, 2015). However, progress evolved with respect to the system of climate funding. This new post-Kyoto architecture differs in many respects from the previous Kyoto regime. It links efforts in mitigation to efforts in adaptation and connects them to a comprehensive, worldwide system of monitoring, reporting and verification of greenhouse gas emissions. Moreover, it introduces a new international funding regime of voluntary financial pledges for these efforts, which is the focus of our paper.

The new architecture for international public climate finance emerging from the COP17 negotiations was preceded by a rudimentary finance architecture of the otherwise largely failed round of negotiations in Copenhagen in 2009 (COP15). The Copenhagen Accord already provides for a fast-track finance (FTF) and mentions (without detailing it) a track of long-term finance (LTF) the then called Copenhagen Green Fund, which was subsequently re-labelled in Cancun as Green Climate Fund (GCF). FTF comprises immediate funding of USD 30 billion in the period 2010-2012 for adaptation and mitigation, but explicitly excludes funding for poverty alleviation and other development objectives, in order to be new and additional to pre-existing funding from the Global Environmental Facility (GEF) of the World Bank and other Official Development Aid (ODA). The contributions to the FTF are voluntary pledges to be communicated to the UNFCCC's secretariat in Bonn. LTF is only mentioned in the Copenhagen Accord as a program to mobilize USD100 billion per year by 2020 for the immense need for funding adaptation and mitigation measures in developing countries (IPCC, 2007; Barrett, 2008). The Copenhagen Green Fund was seen as the heart of LTF in the Copenhagen Accord, but the associated call for public and private sources, bilateral and multilateral channels, as well as alternative sources of finance (e.g. insurance and derivatives for climate change loss and damages) already indicates the breadth of LTF in the negotiation context. In the following, we will be concerned with LTF in this comprehensive definition, without mere focus on the Green Climate Fund.

Glemarec (2011) has delivered a useful graphical representation, which depicts the possible new architecture for international public climate finance emerging from the COP17 negotiations (Figure 1). Climate finance will be implemented under the

political roof of the UNFCCC's negotiation process (COPs). As such, it will be part of the overall negotiation process. In practice, it will define the total amount of funding, set the rules for contributions and receipt of funding, and select a standing committee on finance to bundle the diverse efforts of LTF. The Green Climate Fund is at the heart of this funding scheme, but politically connected in transparent ways to other existing UNFCCC funding streams, such as the so-called Adaptation Fund (AF), and parallel non-UNFCCC streams of funding, such as the GEF of the World Bank. These diverse lines of climate finance will be considered in the COP negotiations holistically, despite the fact that different UNFCCC and non-UNFCCC agencies are in charge for the programming, planning and budgeting of the funding schemes, e.g. the World Bank's GEF agencies. Mitigation and adaptation shall be considered in the GCF in a balanced manner. A new program, decided in Durban, addresses loss and damage.

Figure 1: Architecture for international public climate finance after the COP17 negotiations in Durban (cf. Glemarec, 2011, adjusted)

The present paper analyzes the effects of three different types of climate funding on total costs of climate change in a non-cooperative mitigation-adaptation framework. We regard transfer payments between industrialized countries, which are the donors

of the payments, and emerging economies¹, which are the recipients. In specific, we examine the following three funding instruments, each tied to a different purpose: Funding compensates either a share of the adaptation costs, of the mitigation costs, or of the residual damage costs of the emerging countries. These types of funding instruments reflect the purposes of existing funds presented above; however, we strongly simplify the sophisticated design. Considering these instruments, we investigate how to design the system of climate finance in order to achieve Pareto improvements. Since funding is voluntary, neither donor nor recipient can be forced to participate in funding. Thus, apart from altruistic motives² only a funding system which generates Pareto improvements can endure on a long-term basis. As countries negotiate the actual system of climate finance, we model the decision on the levels of the funding instruments as a cooperative decision using the concept of Nash bargaining. The decisions on mitigation and adaptation, on the other hand, are modeled non-cooperatively, since most countries recently do not agree to binding commitments in climate politics. We find that only funding that compensates a share of mitigation costs in the emerging country yields Pareto improvements since it induces the emerging economy to raise its level of mitigation. As a consequence, the positive externality of mitigation on the industrialized country can be internalized by means of funding. The efficient solution, however, cannot be achieved by unilateral funding as the donor does not internalize the positive externality of its mitigation on the recipient country. Funding that compensates a share of adaptation costs as well as finance that is tied to residual damages do not (necessarily) improve the non-cooperative equilibrium. As a consequence, the result of Nash bargaining rules out funding with regard to adaptation and damages and proposes to only engage in compensating mitigation costs in the emerging country.

Our work is related to the literature on the strategic relationship between adaptation and mitigation as well as to the literature on matching mechanisms, and, more specifically, climate finance. The strategic relationship between adaptation and mitigation has been analyzed within various approaches (see, e.g. Zehaie, 2009; Ebert and Welsch, 2012; Eisenack and Kähler, 2012; Auerswald et al., 2011; Heuson et al., 2015b). While mitigation has the characteristics of a global public good, the benefits of adaptation occur on a private or national level, and is thus modeled as a private good. One central question is whether the strategies of adaptation and mitigation are complements or substitutes with respect to reducing the damage costs of climate change. Studies from Ingham et al. (2005); Buob and Stephan

¹Although many recipient countries are developing or even least developed countries, here we explicitly regard emerging countries because the latter have a large emission mitigation potential, and thus might contribute to climate protection.

²We disregarded altruistic motives in this framework assuming that self-serving motives dominate in governmental decisions.

(2011) state that in special cases adaptation and mitigation are complements, for example in case of maladaptation, which is a kind of adaptation that causes emissions and, thus, makes further mitigation necessary. Most literature, however, assumes a substitutive relationship since mitigation lowers the damage costs, and thus reduces the effectiveness of adaptation and vice versa (see, e.g. Pittel and Rübbelke, 2013; Ebert and Welsch, 2012). In this paper we follow the latter, more general reasoning and focus on mitigation and adaptation as substitutes.

Climate finance can be seen as a unilateral conditional transfer (matching) as it is earmarked for a specific purpose. This type of climate finance alters the recipient's relative costs of mitigation and adaptation and, in turn, influences the non-cooperative decisions. Thus, a well-designed system of climate funding might induce Pareto improvements for donor as well as recipient countries. However, as shown by Bergstrom (1989); Buchholz et al. (2015b,a), a unilateral matching of public good contributions might lead to the paradoxical effect that the recipient of transfers gets worse off due to offsetting behavior of the donor.³ We rule out for this so-called Bergstrom paradox regarding a framework in which the donor commits to a certain level of mitigation and, accordingly, commits not to offset its contribution to the public good mitigation.

The most closely related works are those from Buob and Stephan (2013), Pittel and Rübbelke (2013) and Heuson et al. (2015b) who investigate the role of adaptation finance. Buob and Stephan (2013) consider a non-cooperative framework in which the industrialized North commits itself to a certain level of mitigation and, in a second stage, decides on domestic adaptation as well as adaptation transfers to the developing South. They find that only if adaptation and mitigation of the South are complements, adaptation finance can be beneficial to the donor country. Moreover, a tighter mitigation commitment of the donor country crowds out adaptation funding. Pittel and Rübbelke (2013) compare the performance of in-kind transfers in form of adaptation that are conditional on the mitigation level of the recipient region with mitigation subsidies. According to Bergstrom (1989), they find that both types of conditional transfers may make the recipient worse and the donor region better off. Moreover, conditional adaptation transfers can be more effective than mitigation subsidies and, thus, might explain the existence of adaptation funds. However, this result holds only under specific conditions and the authors conclude that the occurrence of adaptation funds generally remains a puzzle. Heuson et al. (2015b) investigate the effects of various modes of the existing system of climate finance setting up minimum requirements for conditional climate transfers to achieve Pareto improvements. They take up a damage function of Kane and Shogren (2000) that

³For a more detailed description of the effect, see section 3.1.

distinguishes between the probability of climate change, which can be reduced by mitigation, and the potential damages, which can be lowered by means of adaptation. Heuson et al. (2015b) find that subsidizing mitigation as well as transfers which are conditional on the vulnerability of a country fulfill the minimum requirements for a Pareto improvement. The present paper differs from Heuson et al. (2015b) with respect to the following points: First, it takes up a more general damage function, which does not distinguish between the effects of mitigation reducing the probability of climate change and adaptation lowering the potential damage costs. Second, it models the decision on the funding instruments by Nash bargaining, which reflects that funds like the GCF are decided under the political roof of the UNFCCC regime. Third, the present approach identifies actual Pareto improvements instead of minimum requirements. Moreover, this paper rules out for the Bergstrom paradox establishing a political framework in which the donor country credibly commits to a certain level of mitigation.

The remaining paper is organized as follows: Section 2 presents the basic adaptation-mitigation model of climate change. Moreover, the non-cooperative benchmark as well as the efficient solution are established. Section 3 introduces the funding instruments and determines the funding equilibrium, which is compared to the benchmark allocations. Section 4 discusses the main results and its possible application.

2 Economic Framework

In this section, we introduce a basic economic model of climate change regarding the decisions on mitigation and adaptation. Moreover, we determine two benchmark allocations, the non-cooperative Nash equilibrium and the efficient allocation, which will serve as points of reference for the assessment of different funding instruments in section 3.

2.1 Basic Model

We set up a two-country framework⁴ with an industrialized country (uppercase letters) and an emerging country (lowercase letters) following Ebert and Welsch (2012). Countries decide on their efforts in mitigation of greenhouse gas emissions (M, m) as well as on their levels of adaptation to climate change (A, a) . Mitigation and adaptation, in each case, reduce the damage costs of climate change $D(M+m, A)$

⁴The two countries may represent in each case a group of industrialized and emerging countries, respectively. We do not regard free-riding incentives within these groups. Instead we focus on the modification of the incentive structure between the two groups due to climate finance.

with decreasing marginal returns, i.e. $D_1 < 0, D_{11} > 0$ and $D_2 < 0, D_{22} > 0$.⁵ While mitigation is a public good and, accordingly, reduces damage costs in both countries, adaptation is modeled as a private good, which is only effective on the national level. Furthermore, we assume that adaptation and mitigation are substitutes in the sense that adaptation increases marginal damage of mitigation and vice versa, $D_{12} > 0$. Costs of efforts in mitigation $C(M)$ and adaptation $G(A)$ are modeled as increasing and convex functions in the respective variables

$$\begin{aligned} TC &= D(M + m, A) + C(M) + G(A) \\ tc &= d(M + m, a) + c(m) + g(a). \end{aligned} \tag{1}$$

We regard the case in which countries engage simultaneously in mitigation and adaptation. This case is analogous to the sequencing of fixing mitigation before adaptation since in each case strategic incentives do not arise (see, e.g. Zehaie, 2009; Heuson et al., 2015a). The latter sequencing is usually seen as the natural order since mitigation combats the cause of climate change and adaptation alleviates the consequences of climate change that had not been avoided by mitigation.⁶ Thus, we only rule out for the sequencing of advancing adaptation before mitigation.

2.2 Benchmarks

In order to assess the effects of funding, we need to establish two benchmark allocations. The “business-as-usual” scenario is represented by the non-cooperative Nash equilibrium of the basic model. In a second step, we determine the efficient solution and compare the non-cooperative equilibrium to the efficiency benchmark in order to determine the scope for Pareto improvements.

⁵Moreover, the damage function D is strictly convex, i.e. $D_{11}D_{22} - D_{12}^2 > 0$.

⁶For a detailed discussion of possible sequencing see, e.g., Ebert and Welsch (2012) who argue that emissions are inseparably tied to economic activity and, therefore, mitigation cannot be chosen after adaptation.

2.2.1 Non-cooperative equilibrium without funding

In the Nash-equilibrium without funding, each country minimizes its respective total costs (1) with respect to domestic mitigation and adaptation. The first-order conditions for the emerging country read

$$\frac{\partial tc}{\partial a} = d_2(M + m, a) + g_1(a) = 0 \quad (2)$$

$$\frac{\partial tc}{\partial m} = d_1(M + m, a^N) + c_1(m) = 0. \quad (3)$$

The first-order conditions for the industrialized country are analogous. This system of four equations yields the allocation in the Nash equilibrium without funding (M^N, m^N, A^N, a^N) .

2.2.2 Efficiency benchmark

By minimizing aggregate total costs with respect to all four decision variables, $\min_{A,a,M,m}\{TC + tc\}$, the efficient allocation arises. The first-order conditions with respect to adaptation are analogous to the non-cooperative ones (2). Regarding mitigation of the emerging country, the first-order condition in case of efficiency reads

$$\frac{\partial TC + tc}{\partial m} = d_1(M + m, a) + c_1(m) + D_1(M + m, A) = 0. \quad (4)$$

The first-order condition with respect to mitigation of the industrialized country is analogous. Comparing (3) with (4), we notice that the positive externality of mitigation in the emerging country on damage costs of the industrialized country, D_1 , is internalized in efficiency but not in the Nash equilibrium. Conversely, within the non-cooperative framework, the problem of underprovision arises. Adaptation, in turn, increases since it serves as a substitute to mitigation.⁷

Accordingly, there is scope for Pareto improvements: The efficient allocation can be approached by an increase in the level of global mitigation (independently of its origin), and a consequential decrease in adaptation in both countries.

⁷For a more detailed analysis of the comparison of the Nash equilibrium with the efficient solution see Heuson et al. (2015a)

3 Funding

In this section we investigate the effect of climate funding on the global allocation of mitigation and adaptation. In particular, we ask which modes of conditional transfer payments from industrialized towards emerging countries may yield Pareto improvements. First, we discuss the impact of the so-called Bergstrom paradox and frame a strategy to avoid its occurrence. Next, we identify the equilibrium in the last stage, in which countries decide on mitigation and adaptation, and we determine the impacts of funding on the equilibrium. Finally, we model a preceding stage in which the levels of funding instruments are chosen and we assess each instrument separately whether it may induce a Pareto improvement.

3.1 Bergstrom paradox

As shown by Bergstrom (1989) and Buchholz et al. (2015b,a), unilateral matching of the public good supply induces a paradoxical effect placing the recipient of the transfer payments into a worse-off situation. The reason is that the donor country incentivizes the recipient to enlarge its contribution to the public good mitigation. However, since the mitigation levels are strategic substitutes, the donor country partially offsets this increase in mitigation by a lower own contribution. As a result, the donor country shifts the burden of mitigation costs towards the recipient country. Purely conditional transfers that are earmarked for additional mitigation (beyond the non-cooperative level) in the emerging economy would evoke this paradox, which hampers a Pareto improvement, in the same way.

In order to rule out this so-called ‘Bergstrom paradox’, we regard a political framework in which the industrialized country credibly commits itself to a certain level of mitigation which is exogenously determined (cf. Buchholz et al., 2015b,a). A plausible commitment would be not to deviate from the amount of mitigation in Nash equilibrium $\bar{M} = M^N$, which would also be the “outside option”, i.e. the level of mitigation the donor chooses if negotiations on climate funding fail. By fixing mitigation in the industrialized country, damage D does, in turn, only depend on the emerging country’s mitigation m , i.e. $D(m, A)$ and $d(m, a)$. This commitment of the donor country could become credible by engaging in up-front investments in mitigative technology. Due to the undertaken expenses, crowding out would not be beneficial to the industrialized country.

3.2 Set of funding instruments

Now, we integrate into the basic model a stylized system of climate transfers between the industrialized country, which is the donor of the transfers, and the emerging country, which receives the funding. We distinguish between three different instruments of funding which in each case have a different purpose:

- f^a compensates a share of the adaptation costs of the emerging economy,
- f^d compensates a share of the residual damage costs of the emerging country,
- f^m compensates a share of the mitigation costs of the emerging country.

Accordingly, f^d can be interpreted as vulnerability-related funding, whereas f^a and f^m serve as matching instruments for adaptation and mitigation efforts in the emerging country. We do not include the possibility of taxing instead of funding, i.e. $(f^a, f^m, f^d) \in \mathbb{R}_+^3$.⁸

The total costs of climate change of the industrialized and the emerging country, respectively, including climate funding are given by

$$\begin{aligned}
 TC^f &= D(m, A) + C(\overline{M}) + G(A) + f^m c(m) + f^a g(a) + f^d d(m, a) \\
 tc^f &= [1 - f^d] d(m, a) + [1 - f^m] c(m) + [1 - f^a] g(a).
 \end{aligned}
 \tag{5}$$

3.3 Impact of funding on mitigation and adaptation

In this subsection we determine the equilibrium regarding adaptation and mitigation in the last stage of the game and we investigate the impact of the different funding instruments on the equilibrium allocation. In order to keep the analysis compact, we determine the first-order conditions for a Nash equilibrium including all three instruments. However, we analyze each instrument separately and identify whether it might induce a Pareto improvement.

The first-order conditions of the emerging and the industrialized country regarding adaptation read

⁸These funding instruments do not correspond exactly to the existing tiers of funding under the roof of the UNFCCC since the guidelines of funding are far more sophisticated. Nevertheless, these stylized instruments do catch the basic types of earmarking which persist in UNFCCC funding as outlined in section 1. Therefore, this analysis might be interpreted as a basic evaluation of different modes of earmarking funds for emerging countries.

$$\frac{\partial tc^f}{\partial a} = [1 - f^d] d_2(m, a) + [1 - f^a] g_1(a) = 0 \quad (6)$$

$$\frac{\partial TC^f}{\partial A} = D_2(m, A) + G_1(A) = 0. \quad (7)$$

Moreover, the emerging country decides on mitigation m while the level of mitigation of the industrialized country is fixed to the level in the non-cooperative Nash equilibrium $\bar{M} = M^N$. The first-order condition with respect to mitigation in the emerging economy reads

$$\frac{\partial tc^f}{\partial m} = [1 - f^d] d_1(m, a) + [1 - f^m] c_1(m) = 0. \quad (8)$$

Equations (6), (7) and (8) determine the equilibrium of the last stage of the sequential game (m^f, A^f, a^f) . The decision on adaptation in the industrialized country (7) does not have any drawbacks on decisions within the emerging economy. Thus, the comparative statics of this equilibrium with respect to the funding instruments can be established by means of (6) and (8) only.

We determine the comparative statics of the equilibrium in the last stage by totally differentiating the system of equations (6) and (8) with respect to the three funding instruments f^a, f^d and f^m . Rearranging terms, comparative statics for the case of funding instrument f^a yield

$$\frac{dm}{df^a} = \frac{-g_1 [1 - f^d] d_{12}}{det} < 0, \quad (9)$$

$$\frac{da}{df^a} = g_1 \frac{[1 - f^d] d_{11} + [1 - f^m] c_{11}}{det} > 0.^9$$

Since adaptation becomes cheaper due to the partial compensation of adaptation costs, the level of adaptation of the emerging economy increases in equilibrium due to instrument f^a . As a consequence, the emerging country substitutes mitigation for adaptation. Thus, the effect of instrument f^a on the emerging country's level of mitigation in equilibrium is negative because.

⁹The determinant det is positive: $det = [[1 - f^d] d_{22} + [1 - f^a] g_{11}] [[1 - f^d] d_{11} + [1 - f^m] c_{11}] - [[1 - f^d] d_{12}]^2 > 0$.

With regard to instrument f^d , comparative statics yield

$$\begin{aligned}\frac{dm}{df^d} &= \frac{1}{det} \left[\underbrace{d_1 [[1 - f^d] d_{22} + [1 - f^a] g_{11}]}_{\text{direct eff.}(-)} - \underbrace{d_2 [1 - f^d] d_{12}}_{\text{indirect eff.}(+)} \right], \\ \frac{da}{df^d} &= \frac{1}{det} \left[\underbrace{d_2 [[1 - f^d] d_{11} + [1 - f^m] c_{11}]}_{\text{direct eff.}(-)} - \underbrace{d_1 [1 - f^d] d_{12}}_{\text{indirect eff.}(+)} \right].\end{aligned}\tag{10}$$

In case of instrument f^d , two opposing effects arise. A partial compensation of the damage costs f^d induces a decrease in mitigation as well as in adaptation of the emerging country, which is the direct effect of instrument f^d . The reason is that the emerging country faces lower costs of climate change and, accordingly, mitigation as well as adaptation become less effective. However, due to the substitutional relationship between mitigation and adaptation, the decrease in mitigation induces an indirect positive effect on adaptation and vice versa. If the substitutional effect between mitigation and adaptation is small, i.e. $d_{12} \rightarrow 0$, the indirect effects disappear. As a consequence, the direct effects outweigh the indirect ones and a partial compensation of damages lowers the levels of mitigation and adaptation, i.e. $\frac{dm}{df^d} < 0$ and $\frac{da}{df^d} < 0$.

Comparative statics of the equilibrium in the last stage with respect to funding instrument f^m yields

$$\begin{aligned}\frac{dm}{df^m} &= \frac{c_1 [[1 - f^d] d_{22} + [1 - f^a] g_{11}]}{det} > 0, \\ \frac{da}{df^m} &= \frac{-c_1 [1 - f^d] d_{12}}{det} < 0.\end{aligned}\tag{11}$$

Instrument f^m , which compensates a fraction of the mitigation costs of the emerging economy, induces an increase in the level of mitigation of the emerging country. This, in turn, negatively affects adaptation in the emerging country. The reason is that due to instrument f^m , mitigation in the emerging country becomes cheaper; as a consequence, the emerging country partially substitutes adaptation for mitigation.

While instruments f^a and f^d fail to raise the global level of mitigation, instrument f^m has a positive effect on mitigation and, thus, may induce a Pareto improvement.

The next section illustrates how the levels of funding are decided within Nash bargaining.

3.4 Nash bargaining with side payments

We assume that countries decide on the levels of the funding instruments in a first stage before fixing mitigation and adaptation. As the members of the Green Climate Fund originate equally from emerging and industrialized countries, it seems appropriate to model the decision on the size of the funding instruments by Nash bargaining. For reasons of simplicity, we assume that countries can split the efficiency gains of Nash bargaining by means of a side payments s .¹⁰

In stage 1, the industrialized and the emerging country negotiate the level of the respective funding instruments f^a, f^m, f^d as well as the transfer payment s . The outside options of the emerging and the industrialized countries are given by its respective total costs that occur in case of non-cooperative Nash behavior (see section 2.2), i.e. $tc^N = tc(M^N, m^N, a^N)$ and $TC^N = TC(M^N, m^N, A^N)$. The objective function of Nash bargaining reads

$$B = [TC^f - s - TC^N] [tc^f + s - tc^N] \rightarrow \max_{f^a, f^d, f^m, s}. \quad (12)$$

Since we allow for side-payments s , the cost savings due to funding are split equally among the two countries. With respect to the funding instruments, the following Kuhn-Tucker conditions arise

$$f^\bullet \geq 0 \text{ and } f^\bullet \left[\frac{\partial TC^f}{\partial f^\bullet} + \frac{\partial tc^f}{\partial f^\bullet} \right] = 0, \quad (13)$$

where $\bullet = a, m, d$, respectively. Thus, the levels of funding are chosen in order to minimize aggregate total costs, i.e. $\min\{TC^f + tc^f\}$, which, in turn, guarantees a second-best efficiency. For institutional reasons, $f^\bullet$ is restricted to be non-negative as we deal with funding emerging countries through financial aids by industrialized countries.

Evaluating each of the three funding instruments separately, i.e. fixing the remaining funding instruments to zero, we receive the following results.

i) Funding adaptation f^a

¹⁰As we allow for side payments, efficiency gains are always split equally among the two bargaining parties. Consequently, the Nash bargaining solution is simplified and it is possible to analyze the bargaining outcome more profoundly.

The first-order condition with respect to instrument f^a with $f^d = f^m = 0$ is given by

$$f^a \left[\frac{\partial TC}{\partial f^a} + \frac{\partial tc}{\partial f^a} \right] \bigg|_{f^m=f^d=0} = f^a \underbrace{\left[\frac{\partial m}{\partial f^a} D_1 + \frac{\partial a}{\partial f^a} g_1 f^a \right]}_{+} = 0. \quad (14)$$

A positive f^a increases aggregate total costs from climate change. This can be intuitively explained by the fact that f^a , which partially compensates adaptation costs, has a negative effect on the level of mitigation in the emerging country (see (9)). Thus, as the term in square brackets is positive, the optimal f^a equals zero.

ii) Funding according to damage costs f^d

For instrument f^d , the first-order condition reads

$$f^d \left[\frac{\partial TC}{\partial f^d} + \frac{\partial tc}{\partial f^d} \right] \bigg|_{f^a=f^m=0} = f^d \underbrace{\left[\frac{\partial m}{\partial f^d} [D_1 + f^d d_1] + \frac{\partial a}{\partial f^d} d_2 f^d \right]}_{+} = 0. \quad (15)$$

Again, we observe that f^d raises aggregate total costs of climate change at least for the case that the direct effect outweighs the indirect one, see (10). The reason is that instrument f^d partially compensates the residual damage costs. This, in turn, lowers the benefits of mitigation. In order to reduce total costs, however, the level of mitigation needs to rise. Thus, countries optimally do not engage in funding according to residual damages, i.e. $f^d = 0$.

iii) Funding mitigation f^m

Considering instrument f^m , the first-order condition reads

$$f^m \left[\frac{\partial TC}{\partial f^m} + \frac{\partial tc}{\partial f^m} \right] \bigg|_{f^a=f^d=0} = f^m \frac{\partial m}{\partial f^m} \left[\underbrace{D_1}_{-} + \underbrace{f^m c_1}_{+} \right] = 0. \quad (16)$$

Solving for the optimal level of f^m yields

$$f^m = \frac{-D_1}{c_1} > 0. \quad (17)$$

The optimal f^m is positive since it induces an increase in the level of mitigation in the emerging country. Due to this type of funding, the positive externality

of mitigation can be (at least partially) internalized and, thus, it serves as an instrument for Pareto improvements.

Inserting the optimal level of funding $f^m = \frac{-D_1}{c_1}$ into the first-order conditions of the emerging country (8) and (6), and refraining from the instruments $f^a = f^d = 0$ yields

$$d_1 + g_1 = 0 \tag{18}$$

$$D_1 + G_1 = 0 \tag{19}$$

$$d_1 + c_1 + D_1 = 0. \tag{20}$$

These three first-order conditions correspond to the efficient solution outlined in section 2.2.2. The positive externality of mitigation of the emerging economy on the industrialized country is internalized. However, as the level of mitigation in the industrialized country is fixed at $\bar{M} = M^N < M^*$, the first-best solution cannot be implemented via funding, and, instead, a second-best arises.

4 Conclusion

Climate change negotiations on binding emission targets have not been successful for several years. The only measure countries agreed upon are various climate funds which support developing and emerging countries in mitigation and adaptation activities as well as in compensating damages. These funds might encourage recipient countries to extend their mitigation activities and, thus, alleviate the problem of underprovision of mitigation. Moreover, the existing funding architecture can only be sustained on a long-term basis if donor as well as recipient countries benefit.

We examined three different climate funding instruments and their impacts on the non-cooperative decisions on mitigation and adaptation. Only if transfer payments increase the level of mitigation in the recipient country, funding may create Pareto improvements. We rule out for the occurrence of the Bergstrom paradox which states that transfers may harm the recipient country due to offsetting behavior of the donor country. Considering funding that either compensates adaptation, damage or mitigation costs, we find that only the latter instrument may induce Pareto improvements. The reason is that due to funding, mitigation in the recipient country becomes cheaper and, thus, the emerging economy increases its level of mitigation. Compensating a share of the adaptation costs has the analogous effect on adaptation in the recipient country. However, since adaptation and mitigation are substitutes in reducing the costs of climate change, an increase in adaptation induces a decline in mitigation. Thus, a Pareto improvement is not possible with adaptation funding.

Transfer payments which compensate a share of the damage costs in the emerging country reduce the losses of climate change, and, consequently, make adaptation and mitigation less beneficial. If this direct effect predominates, mitigation declines and Pareto improvements due to funding are not achievable.

Since funding according to adaptation costs and damage costs, respectively, does not yield Pareto improvements, it is not in line with the interest of both recipient *and* donor country. Therefore, it is questionable how those funds will be financed voluntarily in the future. However, our approach does not take into account motives of fairness or altruism, which also might play a role in international climate funding. Still, it remains doubtful if those incentives are sufficient to guarantee continuous finance.

Funding mitigation is the only type of climate finance which can guarantee funding in the long term, since both donor and recipient benefit. However, although funding of mitigation costs in emerging countries may alleviate the problem of climate change, it is not possible to achieve the first-best allocation via unilateral funding. The reason is that also donor countries need to increase their levels of mitigation apart from rendering the financial means of funding. Thus, unilateral funding might render a second-best solution and alleviate the damages of climate change. However, binding commitments of donor countries are also necessary to combat climate change.

Transferring these results carefully into the political context, it is recommendable to prioritize the funding of mitigation activities. Accordingly, projects associated with the “energy generation and access” within the GCF, which aim at enhancing mitigation regarding low-emission electricity generation and energy use (GCF, 2015, p.12), should be promoted. The current system of “investment priorities” according to the GCF-board (GCF, 2015, p.9), however, does not lean towards a structure of funding that would allow to establish a system of climate finance that induces Pareto improvements and, thus, could be sustained in the long term.

5 Appendix

5.1 General solution of Nash bargaining

$$B = [TC^f - s - TC^N] [tc^f + s - tc^N] \rightarrow \max_{f^a, f^d, f^m} \quad (21)$$

$$\frac{\partial B}{\partial f^\bullet} = \frac{\partial TC^f}{\partial f^\bullet} [tc^f + s - tc^N] + \frac{\partial tc^f}{\partial f^\bullet} [TC^f - s - TC^N] = 0 \quad (22)$$

$$-\frac{\frac{\partial TC^f}{\partial f^\bullet}}{\frac{\partial tc^f}{\partial f^\bullet}} = \frac{[TC^f - s - TC^N]}{[tc^f + s - tc^N]} \quad (23)$$

Optimal $f^\bullet$ when impact on aggregate costs is zero, i.e. marginal global benefits of funding equal marginal costs of funding.

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