Climate Finance and Emission Reductions: What Do the Last Twenty Years Tell Us?

Niklas Schoch[a,*] *and Claire Gavard*[a,b,*]

[a] Department of Environmental and Resource Economics, Leibniz Centre for European Economic Research, L7 1, 68161 Mannheim, Germany

[b] Corresponding author: Claire.Gavard@zew.de

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Abstract: In the framework of the Paris Agreement implementation, financial transfers remain a major point of negotiation for addressing equity concerns raised by the ambitious objectives of global emission reductions.

While a lot of theoretical studies as well as experimental or numerical simulations have been conducted on the issue, very little empirical analysis has been drawn so far. Using data of the last 20 years, we assess the role financial transfers have played in enabling CO_2 emission reductions to draw conclusions for the current negotiations. To do so, we develop the current theoretical literature by incorporating financial transfers either as (i) direct bilateral incentives provided by utility-maximizing donor countries to receiving countries or as (ii) surplus sharing schemes redistributing the welfare gains from emission reductions. We derive an equation of the impact of mitigation and adaptation finance on national emissions, taking into account national vulnerabilities. We estimate this model on historical CO_2 emissions of non-OECD countries. Our results support financial transfers as a way of incentivizing emission reductions, but distinctions have to be made between private and public financial flows as well as between mitigation and adaptation finance.

JEL-Classification: C23, C70, D02, K33, Q54, Q58

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1 Introduction

Within the Paris Agreement, countries have agreed to set the objective to limit global warming to a maximum of 2 degrees above preindustrial levels. Reaching this goal requires significant global emission reduction efforts involving the majority of international carbon emitting nations. Addressing equity concerns related to the distribution of these abatement efforts is a major requirement for successful international climate cooperation. The United Nations Framework Convention on Climate Change (UNFCCC) acknowledges the necessity of fair burden sharing accounting for "common but differentiated responsibilities and respective capabilities" (UNFCCC, 1992). With international climate action moving forward, financial transfers remain a key point of negotiation for moderating these equity concerns and, in particular, assisting developing countries in facilitating mitigation and adaptation, as stated in Article 9 of the Paris Agreement (United Nations, 2015). It urges developed countries "to provide financial resources to assist developing country Parties" for both climate change mitigation and adaptation, and recognizes relevant capacity constraints of developing countries for national climate policies. It also rules that financial transfers are to be incorporated in the global stockdate process specified in Article 14 of the agreement. During the 24^{th} Conference of the Parties (COP24) of the UNFCCC held in Katowice in 2018, the decision was taken to initiate new goals in climate finance mobilisation from a floor of $100billion at the COP26 planned in Glasgow for November 2020.[1] Such negotiations call for a factual basis of the role of financial transfers in emission reductions on which to set appropriate financing targets. An improved understanding of the historical impact of climate finance transfers will help inform the future steps in the Paris Agreement implementation, and in particular the global stocktake exercise planned in 2023.

While many theoretical and experimental studies have focused on the topic, little empirical analysis has been conducted so far. Our aim is to take advantage of the historical experience since the RIO Earth Summit 1992 in order to draw lessons for the current negotiations about how financial transfers can adequately support reaching long term climate objectives.

The current academic literature has recognized the importance of equity and fairness in the international climate negotiations and is mainly focused on international coalitions in public good games. It applies these game-theoretic approaches to the formation and stability of international environmental agreements (IAEs). Acknowledging the Westphalian System of international treaties, the literature emphasizes the necessity of self-enforcing agreements, since a country's decision to enter any international contract must be voluntary (Treaty of Vienna, 1969; Nordhaus, 2015). An issue of international cooperation in climate policy is to address the inherently strong free-rider incentives (Nordhaus, 2015). Traditional game theory produces rather pessimistic results about the formation of international environmental cooperation with a large number of participating agents (Barrett, 1994). Many studies have subsequently incorporated a range of measures into the game theoretic literature on coalition formation and investigated their effectiveness in managing these free-rider incentives to ensure the stability of international cooperation on climate change. Proposed instruments to negotiate self-enforcing IEAs other then transfers vary from punishments for de-

[1] Decision 14 of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA1) in Katowice 2018.

viations (Mason et al., 2017), the formation of climate clubs where the participation in a trade-agreement is conditional on emission reduction efforts (Nordhaus, 2015) to the transfer of and investment into climate change adaptation technologies (Yang and Nordhaus, 2006; Li and Rus, 2019; Rubio, 2018). Other studies incorporate heterogeneity amongst players (Pavlova and de Zeeuw, 2013) or inequality averse preferences (Vogt, 2016) and find only small stable international coalitions amongst heterogenous players in the global climate game.

The most widely discussed way to reduce free-rider incentives and facilitate internally stable coalition formation amongst the global players seems to be by balancing the cost of emission reductions via financial transfers. It appears that there are two common means to model financial transfers in international coalition formation, either as a surplus sharing amongst coalition members or as direct incentive payments. Studies of surplus sharing in global climate coalitions find that an appropriate design of transfer schemes can stabilize IAEs in global climate policy (Weikard et al., 2006; Nagashima et al., 2009; Finus et al., 2006; Carraro et al., 2006; Lessmann et al., 2015; Tulkens and Chander, 1998). Direct transfer payments bribing other agents into coalition participation can also be optimal behavior and help reduce global emissions below non-cooperative levels (Ansink et al., 2018; Barrett, 2001; Carraro et al., 2006; Fuentes-Albero and Rubio, 2010). Across these publications, the theoretical results are supported with numerical simulations using data from recognized integrated assessment models, and countries usually face a dichotomous choice of entering a coalition or unilaterally choosing its optimal emissions.

Our paper contributes to the literature on global climate policy and financial transfers in two ways. We first relax the focus on coalition formation and adapt the current literature to model a continous emission choice of a country in the presence of transfers in order to better reflect the negotiations amongst Parties to the Paris Agreement, where nationally determined contributions (NDCs) are negotiated amongst membership parties. Second, we aim to use historical data to estimate our theoretical equations and allow an empirical testing of the role of financial transfers for emission reductions as opposed to employing numerical simulations. Relying on historical data rather than a simulation study enables us to complement the current literature and provide evidence-based insights for the Paris Agreement implementation.

In the following section, we develop the theoretical model for the global emissions game and consider two approaches to integrate financial transfers into it. In section 3, we explain our empirical strategy to test the theoretically derived hypotheses. We present the data employed as well as discuss the estimation results. In section 4, we conclude and discuss the policy implications of our analysis.

2 The model

We start by modelling the global emissions game before introducing two common approaches (supported by the current literature) for incorporating financial transfers. For each of the two approaches, we deduct the optimality condition describing the emissions of each country. We use damage- and benefit functions to deduct analytical equations for the optimal emissions.

We assume that there is no international coalition and countries behave as individual utility maximizers. The reader may raise the concern that there are existing international environmental agreements in place. However, following Nordhaus (2007) or Murdoch and Sandler (1997), one can consider that these agreements simply codify the emission levels observed in a non-cooperative Nash-equilibrium, i.e. under the assumption of individual utility maximization.

2.1 The global emissions game

2.1.1 No financial transfers

We start with the optimal emission choice of country i in the absence of financial transfers. Following Li and Rus (2019), the welfare of country i can be expressed as the benefits received from emissions minus climate-induced damages:

$$W_i = B_i(e_i) - D_i\left(\sum_{j=1}^{N} e_j\right) \tag{1}$$

With:

- $B_i(e_i)$ denoting the benefits country i receives from emitting e_i,
- $D_j\left(\sum_{j=1}^{N} e_j\right)$ the damages caused by the global emission $\sum_{j=1}^{N} e_j$ to country i.

Country i chooses its optimal emission level maximising its welfare with respect to emissions. It's maximisation reads as:

$$\underset{e_i}{max}\; W_i(e_i) = B_i(e_i) - D_i\left(\sum_{j=1}^{N} e_j\right) \tag{2}$$

The first-order condition (FOC) of this maximisation problem is given by:

$$\frac{\partial W_i(e_i)}{\partial e_i} = \frac{\partial B_i(e_i)}{\partial e_i} - \frac{\partial D_i\left(\sum_{j=1}^{N} e_j\right)}{\partial e_i} \overset{!}{=} 0 \tag{3}$$

And the subsequent optimality condition has the form:

$$\frac{\partial B_i(e_i)}{\partial e_i} = \frac{\partial D_i\left(\sum_{j=1}^{N} e_j\right)}{\partial e_i} \qquad \forall i \in N \tag{4}$$

As a country does not incorporate the damages its emissions impose on other countries, the resulting emission level from individual maximization is too high and a reduction of emissions can achieve a global welfare surplus (Samuelson, 1954).

2.1.2 Transfers as surplus sharing

A largy body of the literature on optimal global emission decisions focuses on the implementation of international cooperation as a means to fix this problem. International coalition formation in emission reduction can result in the internalization of external damages from emissions. Countries engaging in international cooperation take into account the damage of their emissions on other coalition members and reduce their emissions (Vogt, 2016). This yields a global welfare surplus compared to the situation of individual maximization. One can distribute this surplus amongst coalition members such that the new allocation achieves a pareto-improvement as compared to the non-cooperative emission behavior.

In the existing coalition formation literature, countries usually face a dichotomous choice between joining an international coalition, or remaining non-signatory (Weikard et al., 2006; Carraro et al., 2006; Finus et al., 2006; Vogt, 2016; Tulkens and Chander, 1998). Transfers are then modelled as a redistribution of arising coalition surpluses in the global emissions game. In contrast, we want to establish a surplus sharing scheme for a continous emission choice. Our model describes a global emissions game where there exists a pre-agreed transfer scheme redistributing the welfare surpluses obtained from unilateral continous emission reductions. Bridging the gap between theoretical model and real negotiations, one can think of this transfer scheme as negotiating parties making further emission reductions conditional on extended financial commitments from the international community. The amount of transfer being a function of emission reductions is therefore a result of negotiations.

We propose the following structure of the game to model this negotiation behavior:

1. There exists an exogenously given transfer scheme, granting each country a share of the welfare surplus resulting from its emission reduction.
2. Countries choose their optimal emission level knowing the transfer scheme will be enforced.

From the Samuelson rule (Samuelson, 1954), we know that a reduction of emission below the non-cooperative level will yield a global welfare increase. The increase arises since, for any emissions above the globally optimal emission level[2], the foregone benefits for country i when reducing its emissions are outweighed by the relieved damages to the other countries. The surplus of emission reduction is defined as the increase in global welfare arising from this emission reduction.

Mathematically, the global surplus for a reduction of the emissions of country i from the non-cooperative level $e_i^{'}$ to e_i can be expressed as:

$$SU = B_i(e_i) - B_i(e_i^{'}) - \sum_{j=1}^{N} \left(D_j \left(e_i, \sum_{k \neq i}^{N} e_k \right) - D_j \left(e_i^{'}, \sum_{k \neq i}^{N} e_k \right) \right) \tag{5}$$

It holds that:

$$SU > 0 \quad \forall \; e_i^{'} > e_i > e_i^{*} \tag{6}$$

with e_i^{*} denoting the global optimum.

It follows that the surplus arises due to the prevented damages to all other countries. We define these

[2]The global optimum are the emissions resulting for all countries incorporating all damages of their emissions on all other countries.

global prevented damages (GPD) as:

$$GPD = \sum_{j=1}^{N} \left(D_j \left(e_i^{'}, \sum_{k \neq i}^{N} e_k \right) - D_j \left(e_i, \sum_{k \neq i}^{N} e_k \right) \right) \tag{7}$$

When choosing their optimal emission level, countries now take into account the transfer payment they receive for reducing their emissions. The magnitude of this transfer depends on the share of surplus λ each country receives. The simplest choice for λ is a Nash-bargaining solution, as described by Carraro et al. (2006). It implies equal shares for all. Other mechanisms are also possible, see Sheriff (2019). Our analysis below is valid for any arbitrary choice of the sharing vector $\lambda = (\lambda_1, ..., \lambda_N)$, assigning each country i an individual λ_i.

Knowing about its individual share λ_i, which it will receive when reducing its emission below the non-cooperative level, the maximisation problem of country i reads as:

$$\underset{e_i}{max}\; W_i = B_i(e_i) - D_i \left(\sum_{j=1}^{N} e_j \right) + \lambda_i GPD \tag{8}$$

The resulting FOC

$$\frac{\partial W_i(e_i)}{\partial e_i} = \frac{\partial B_i(e_i)}{\partial e_i} - \frac{\partial D_i \left(\sum_{j=1}^{N} e_j \right)}{\partial e_i} + \lambda_i \left(\frac{\partial GPD}{\partial e_i} \right) \overset{!}{=} 0 \;\forall i \in N \tag{9}$$

yields the optimality condition:

$$\frac{\partial B_i(e_i)}{\partial e_i} = \frac{\partial D_i \left(\sum_{j=1}^{N} e_j \right)}{\partial e_i} + \lambda_i \sum_{j=1}^{N} \left(\frac{\partial D_j \left(\sum_{k=1}^{N} e_k \right)}{\partial e_i} \right) \;\; \forall i \in N \tag{10}$$

In (4), the benefits for country i to emit an additional unit must only compensate the resulting damage to itself. In contrast, in(10), the additional benefits must compensate for the damages to all other countries, represented by the received transfer.

The second term on the right-hand side shows by how much the transfer increases with an additional unit of emission reduction. This is how we want to define the marginal transfer:

$$MarginalTransfer = -\frac{\partial transfer}{\partial e_i} \tag{11}$$

In this context, the marginal transfer can be expressed as:

$$MarginalTransfer = -\frac{\partial \lambda_i GPD}{\partial e_i} = \lambda_i \sum_{j=1}^{N} \left(\frac{\partial D_j \left(\sum_{k=1}^{N} e_k \right)}{\partial e_i} \right) \tag{12}$$

In (10), as compared to (4), the marginal benefit in optimum is now higher due to the transfer. It has to compensate for the reduced transfer when emitting an additional unit.

Assuming concave benefit and convex damage functions, which is a standard assumption in the literature

(Li and Rus, 2019), a transfer decreases the amount of emissions. Intuitively, when receiving a larger share of the surplus (meaning a larger transfer), a country incorporates a larger share of the avoided damages caused by its emissions to other countries into its maximization. This results in a reduction of the optimal emission level. We will examine the optimality condition (9) further when deriving analytic expressions for a country's optimal emission choice.

2.1.3 Transfers as direct incentive payments

We will now present direct incentive payments as an alternative way to consider financial transfers. To do so, we develop an emissions game with donor and recipient countries. The donor countries choose to pay recipient countries transfers, where the transfer amount depends on the recipient's emission choice. This approach is inspired by Ansink et al. (2018) a.o., where donor countries incentivize recipient countries to join a coalition. They show that there exists a Nash-equilibrium with a positive number of supporters who find it optimal to directly incentivize the behavior of recipient countries with financial transfers. We adapt their approach in order to model a continous emission choice of the recipient countries.

The structure of the game is as follows:

- There are N donor countries and M recipient countries,
- Each donor chooses to pay transfers to the recipients to incentivize emission reductions,
- Each donor sets a transfer scheme, where the transfer paid depends on the recipients final, emissions,
- Given the structure of the transfer scheme, each recipient chooses its optimal emission level.

The maximisatzion of a donor country i now looks as follows:

$$\max_{e_i, \sum_{j=N+1}^{N+M} tr_{i,j}} W_i^D = B_i^D(e_i) - D_i^D\left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j)\right) - \sum_{j=N+1}^{N+M} tr_{i,j}(e_j) \tag{13}$$

With:

- W_i^D denoting the welfare of donor i,
- consisting of the benefits of emissions $B_i^D(e_i)$ depending on its own emissions e_i,
- the damages from global emissions $D_i^D\left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j)\right)$,
- the transfers $tr_{i,j}$ paid to recipient j by donor i,
- and the total amount of transfer recipients j receives from the N donors $tr_j = \sum_{i=1}^{N} tr_{i,j}$.

We first model how a donor will set an incentive-compatible transfer scheme. To derive this optimal transfer scheme, we adapt the approach developed by Habla and Winkler (2013). The transfer scheme has to satisfy the following conditions:

- The donor cannot be worse-off when paying the transfer as opposed to not offering it. The reduced damage due to e_j has to compensate the transfer.

- The recipient has to find it optimal to reduce the emissions and receive a transfer, as opposed to unilaterally choosing its emissions.
- The donor will pay the minimal necessary transfer to convince the recipient to reduce its emissions and receive the transfer.

We propose the following transfer scheme:

$$tr_{i,j}(e_j) = max[0, W_i^{D*} - \overline{W}_i^D] \tag{14}$$

With W_i^{D*} being the realised welfare of donor i depeding on the emissions of recipient j, net of all transfers

$$W_i^{D*} = B_i^D(e_i) - D_i^D \left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j) \right) \tag{15}$$

and $\overline{W}_i^D$ some fixed reference welfare with

$$\overline{W}_i^D \geq W_i^{D'} \tag{16}$$

where $W_i^{D'}$ denotes the donors welfare under unilateral maximisation of all countries. Condition (16) states that $\overline{W}_i^D$ is at least as high as the donor's welfare in case of non-cooperative emissions and ensures the donor is not worse-off through the transfers.

From (14), we get the marginal transfer as defined in (11):

$$-\frac{\partial tr_{i,j}(e_j)}{\partial e_j} = -\frac{\partial W_i^{D*}(e_i)}{\partial e_j} = \frac{\partial D_i^D(e_i)}{\partial e_j} \tag{17}$$

The resulting mechanics of the transfer scheme are as follows:
By conditioning the amount on some reference welfare $\overline{W}_i^D$ satisfying $\overline{W}_i^D \geq W_i^{D'}$, the donor ensures he can never be worse-off through the transfer scheme. But since $\overline{W}_i^D$ is fixed, the marginal transfer is unaffected by $\overline{W}_i^D$ and equals the marginal effect of the recipients emission on the donor. Thus, he sets the marginal transfer to exactly equal to the relieved damages if a recipient decreases emissions. This property ensures full internalization of the external damages on the donor by the recipient.
Knowing this transfer scheme, the recipient maximises:

$$\underset{e_j}{max}\ W_j^R = B_j^R(e_j) - D_j^R \left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j) \right) + \theta_j \sum_{i=1}^{N} tr_{i,j}(e_j) \tag{18}$$

With

- W_j^R denoting the welfare of recipient country j,
- consisting of the benefits of emissions $B_j^R(e_j)$ depending on its own emissions e_j,
- the damages from global emissions $D_j^R \left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j) \right)$,
- the transfers $tr_{i,j}$ paid to recipient j by donor i,

- and a recipient-specific scaling factor θ_j, indicating how much the transfer is valued.

The resulting FOC

$$\frac{\partial W_j^R}{\partial e_j} = \frac{\partial B_j^R(e_j)}{\partial e_j} - \frac{\partial D_j^R\left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j)\right)}{\partial e_j} + \theta_j \sum_{i=1}^{N} \frac{\partial tr_{i,j}(e_j)}{\partial e_j} \stackrel{!}{=} 0 \tag{19}$$

yields the optimality condition:

$$\frac{\partial B_j^R(e_j)}{\partial e_j} = \frac{\partial D_j^R\left(\sum_{i=1}^{N} e_i, \sum_{j=N+1}^{N+M} e_j(tr_j)\right)}{\partial e_j} + \theta_j \sum_{i=1}^{N} \frac{\partial D_i^D(e_i)}{\partial e_j} \tag{20}$$

The marginal benefits of emissions are now equated to the own marginal damages plus the sum of the marginal damages to all donor countries. In optimality condition (20), the marginal benefits are equated to a higher number as compared to (4). Again, the fact that marginal benefits increase in optimum requires a reduction of emissions as compared to the case without transfers, which is described in equation (4). Note that this framework does not yield a global optimum since donor countries do not internalize the damages they impose on recipient countries and damages imposed on each other.

When being offered a transfer scheme, a recipient country faces a dichotomous choice: either choose its unilateral emission level and not receive any transfer, or choose an optimal emission level that accounts for the potential transfers received from donor countries for reducing emissions below non-cooperative levels. Thus, a donor will pay each recipient a transfer that is exactly such that the recipient is indifferent between receiving the transfer and reducing emissions, or choosing its unilateral emissions (Habla and Winkler, 2013).

If we only consider donor i, the recipient decides to reduce its emissions as a response to the offered transfer scheme from donor i if and only if the welfare, when additionally accepting donor i's transfer, is higher or equal to the welfare when accepting all other transfers.

The welfare of recipient j when only receiving transfers from $N-1$ donors, choosing the then optimal $e_j^{'}$, can be expressed as:

$$W_J^{R'} = B_j(e_j^{'}) - D_j(E^{'}) + \theta_j \sum_{i=1}^{N-1} tr_{i,j}(e_j^{'}) \tag{21}$$

The welfare of recipient j when additionally receiving the transfer from donor i, choosing the new optimal emissions e_j, can be expressed as:

$$W_J^R = B_j(e_j) - D_j(E) + \theta_j \sum_{i=1}^{N} tr_{i,j}(e_j) \tag{22}$$

With:

- $E^{'}$ the global realized emissions if j does not accept the transfer scheme from i,
- E the realized global emissions if recipient j chooses to reduce its emissions as a response to the offered transfer scheme.

Set both payoffs equal:

$$B_j(e_j^{'}) - D_j(E^{'}) + \theta_j \sum_{i=1}^{N-1} tr_{i,j}(e_j^{'}) = B_j(e_j) - D_j(E) + \theta_j \sum_{i=1}^{N} tr_{i,j}(e_j) \tag{23}$$

$$tr_{i,j}(e_j) = \frac{\Big(B_j(e_j^{'}) - B_j(e_j)\Big) - \Big(D_j(E^{'}) - D_j(E)\Big) - \theta_j \left(\sum_{i=1}^{N-1} tr_{i,j}(e_j) - \sum_{i=1}^{N-1} tr_{i,j}(e_j^{'})\right)}{\theta_j} \tag{24}$$

The magnitude of the transfer needs to compensate the recipient for the foregone benefits, net of the relieved damages and the increase in transfers received from all other donors. The term is scaled by the magnitude the recipient values a received transfer, θ_j. This overall magnitude determines whether the recipient chooses to reduce its emissions as response to the offered transfers, or whether it chooses not to receive transfers and sets his non-cooperative emissions. The donor sets the amount such that the recipient is exactly indifferent as explained above.

2.2 Introducing structural benefit and damage functions

To deduct an equation for the empirical estimations, we impose structural forms on the benefit and damage functions. In a first-step, we wish to abstract from strategic interactions in the optimal emission setting and impose a linear marginal damage function. This assumption is supported by scientific evidence. Following Golosov et al. (2014), the accumulation of carbon stock in the atmosphere can be described as a logarithmic function of emissions. This carbon stock in the atmosphere induces climate change damages in an exponential manner. Thus, mapping emissions to damages via a linear specification is consistent with the current literature (Habla and Winkler, 2018; Holtsmark and Weitzman, 2020).

Using the definition employed by Habla and Winkler (2018), we propose structural forms for the benefit and damage functions.
We define the benefit function as:

$$B_i(e_i) = \frac{1}{\phi_i} e_i \left(\epsilon_i - \frac{1}{2} e_i\right) \quad \text{with} \quad e_i \in (0, \epsilon_i) \tag{25}$$

With:

- ϵ_i denoting the maximal emissions, which are the emissions a country would choose in the absence of any damages,
- e_i the emissions of country i,
- and ϕ_i a country-specific scaling of the marginal benefits.

This specification exhibits dimishing marginal benefits:

$$B_i^{'}(e_i) = \frac{\epsilon_i - e_i}{\phi_i} \geq 0 \;\; \forall \;\; e_i \leq \epsilon_i \tag{26}$$

$$B_i^{''}(e_i) = -\frac{1}{\phi_i} < 0 \tag{27}$$

We define the damage function as:

$$D_i(E) = \delta_i E \tag{28}$$

With:

- E denoting the global emissions,
- and δ_i country-specific marginal damages.

This specification exhibits constant marginal damages:

$$D_i^{'}(E) = \delta_i \tag{29}$$

$$D_i^{''}(E) = 0 \tag{30}$$

We use the definitions (25) and (28) to obtain the equation describing the optimal emission choice under the two transfer schemes from (10) and (20).

Transfers as a surplus sharing

In the approach considering transfers as surplus sharing, we obtain:

$$\frac{\epsilon_i - e_i}{\phi_i} = \delta_i + \lambda_i \sum_{j=1}^{N} (\delta_j) \tag{31}$$

Transfers as direct incentive payments

In the approach considering transfers as direct incentives, we obtain:

$$\frac{\epsilon_i - e_i}{\phi_i} = \delta_i + \theta_i \sum_{j=1}^{N} (\delta_j) \tag{32}$$

In both cases, we see that the deviation from the maximal emissions positively depends on ϕ_i, the invese of $B_i^{''}$, and the sum of marginal damages and marginal received transfers per emission reduction $\left(\delta_i + \theta_i \sum_{j=1}^{N} (\delta_j)\right)$.

3 Empirical analysis

We now empirically test our hypothesis using Equations (31) and (32). We proceed in two-steps. We first estimate a simplified additive specification in section (3.2) to gain first insights of the historical effects of transfer payments on CO_2 emissions. We then identify our deducted equation by regressing transfer payments on changes in CO_2 intensity in section (3.3). In the following section (3.1), we present the data employed in the estimations.

3.1 Data

For the econometric analysis, we build a panel containing data on 204 countries and territories from 2000 to 2017.[3] We also identified 34 donor countries, which we exclude from the estimations. Due to data-

[3]The dataset includes a number of offshore territories of OECD countries, such as Puerto Rico and French Martinique, which have separate data-points. These offshore territories from OECD countries are excluded from the estimation.

limitations, we keep 140 non-OECD recipient countries[4] in our estimation sample. They receive transfers from 34 richer countries. The estimates consider only the transfers from donor to recipient countries. We report the summary statistics, including a correlation matrix, in Appendix 5.1.

We use the CO_2-emission data from the interdisciplinary research project "Global Carbon Project" (Le Quere et al., 2018). This data-set synthesizes estimates from varying sources into one comprehensive panel. It combines estimates from the Carbon Dioxide Information Analysis Center (CDIAC) - which estimates historical emissions based on coal, oil, and gas consumption (Marland et al., 2008) - with the official UNFCCC inventory reports (UNFCCC, 2018) published for 42 Annex-I countries whenever available.[5]

To measure transfer payments, we use financial inflow data from private and public sources to potentially identify different effects on emissions. For public transfer flows, we follow Halimanjaya (2015) and employ data from the OECD RIO marker database. In the latter, public finance flows from OECD to non-OECD countries are marked as a function of their relevance for various environmental considerations. Climate change mitigation and adaptation are the markers of interest for our analysis. The reported flows include both grants as well as debt instruments, all of which are reported at commitment value in constant US$.[6,7] A database reporting realized disbursement as opposed to commitment amount is only available with very limited coverage, both across time and countries, which is why we opt for the use of commitment values. In the RIO marker reporting system, markers can be attributed to projects as a principal or significant objective. We utilize the RIO marker database as published: 100% of the funds for projects with a principal objective are counted as flows towards this objective, in comparison with 40% of the funds for projects for which the objective is marked as significant. We use the data from the Clean Development Mechanism (CDM) database as a proxy for private investment inflows, as it is the most comprehensive database with consistent definitions available. The flows here are reported in full realized investment amounts. All flows used for the estimations are converted into $billion.

Our controls include data on GDP (World Bank, constant 2010 $), population (World Bank) and the percentage of the national value added that is produced in the industry sector (World Bank). These are natural drivers of CO_2 emissions. We also include the Notre Dame Climate Vulnerability Index published by the Global Adaptation Initiative of Notre Dame University (Chen et al., 2015).[8] We utilize the dataset indicating a country's vulnerability to climate change and extreme weather events in order to obtain a measure for the damages a country faces due to global emissions. We add a range of potential control variables identified in the literature (Halimanjaya, 2015), such as the "Political Stability and No Violence" indicator from the World Governance Indicators (Kaufmann et al., 2010) and forest area as percentage of land-mass published by the World Bank.

[4] A detailed list can be found in Apppendix 5.1

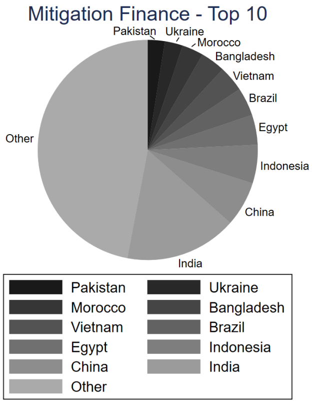
[5] In this dataset, emissions caused by cement production are included using the estimates by Andrew (2018).

[6] Debt instruments include both standard loans, debt relief, and debt swaps.

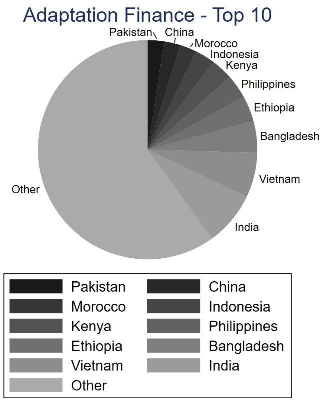
[7] We are aware that it would be good to convert all those values into grant equivalent. This is, however, not possible with the information provided in the dataset, even though the latter is still the best one available.

[8] We have conducted robustness checks using other vulnerability indices such as the Climate Vulnerability Index (CRI) score from GermanWatch e.V. and found similar results. However, due to data limitations, we have chosen to utilize the Notre Dame Climate Vulnerability Index for our analysis.

Regarding public financial flows, Figure 1 presents a descriptive analysis of their distribution across recipients, depicting both RIO mitigation and adaptation finance. Part (a) shows the distribution of mitigation finance flows across recipient countries. We see that the Top 10 recipients of public mitigation inflow account for ≈51% of total public mitigation flows in our sample, with India receiving the largest share (16, 5%). Part (b) depicts the distribution of public adaptation finance flows. The Top 10 recipients here account for only ≈35%. Comparing the recipients of public mitigation and adaptation finance, we can see that a large share of public mitigation finance flows into emerging countries such as Brazil, Indonesia, India, and China. These emerging markets account for ≈31% of total public mitigation flows. The recipients of public adaptation finance however include more developing countries such as Ethiopia, Bangladesh, and the Phillipines. India is the highest recipient of both adaptation and mitigation inflows.



(a) Distribution of mitigation finance



(b) Distribution of adaptation finance

Figure 1: Public Finance Flows

Looking at the development of public flows over time in Figure 2, one observes a strong increase in aggregate global RIO mitigation flows since the start of systematic reporting in 2000. Whilst this increase is partially fueled by improvement in the coverage of reporting (Halimanjaya, 2015),[9] it still shows a growing importance of public mitigation finance. There is also an increasing trend in adaptation finance flows since the marker's introduction in 2010.

[9]We conduct robustness checks with restricted samples and only utilize later time-periods to check the potential impact on our results. Results are discussed in section (3.2) and can be obtained upon request.

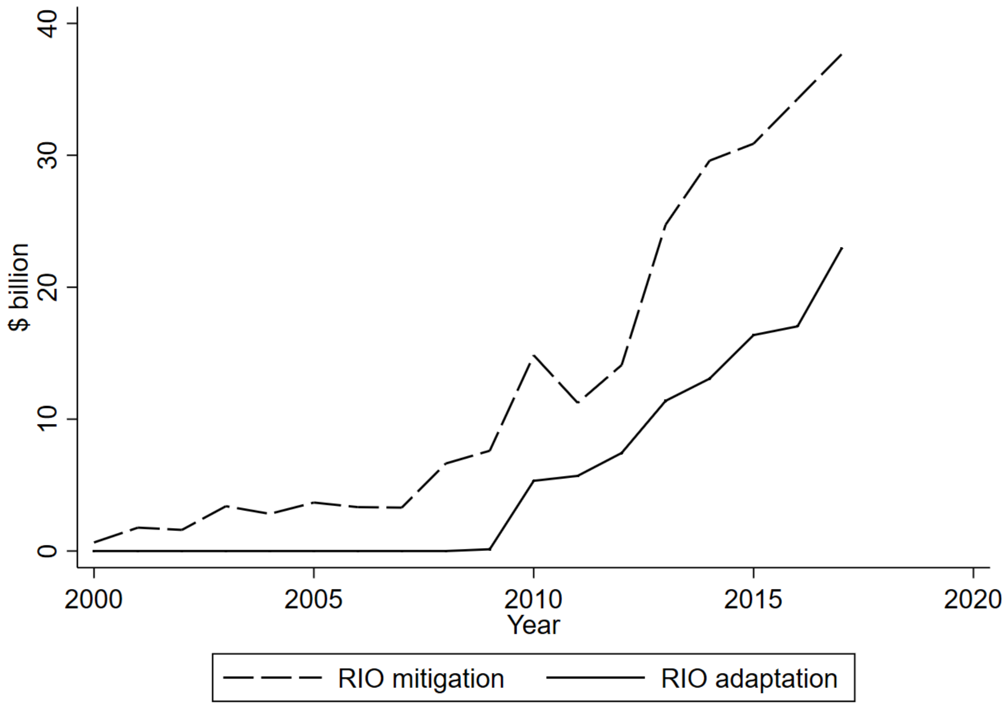


Figure 2: Development of public climate finance over time

Regarding private flows, Figure 3 presents transfers associated with CDM projects. We observe that the distribution of flows across countries is not as even as for public finance flows: 5 countries receive 83% of the total inflow. China alone accounts for more then 57% of all registered CDM flows in our sample. Part of the explanation is that private investments are conducted in countries with favourable economic prospects, explaining the large share of investment flowing into emerging markets. This strong concentration of CDM projects has already been observed at earlier stages of the CDM in studies such as Lecocq and Ambrosi (2007). When interpreting the results for CDM investment, this needs to be kept in mind. We have run estimations excluding China from the data and discuss the impact on our results in the following section.

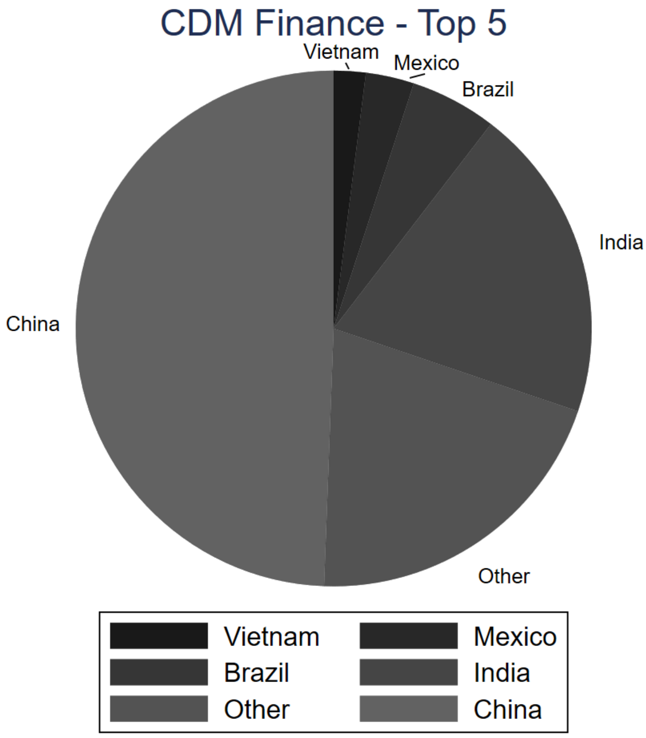


Figure 3: Private Mitigation Finance

Looking at the development of private CDM flows over time, the picture is different as opposed to what we observe for the public flows. Having peaked in 2011, CDM flows decline afterwards due to institutional restrictions and decreased private demand: this is likely due to the fact that in January 2011, the European Commission announced the list of the restrictions for acceptance of CDM credits in the EU Emission Trading Scheme, the largest market accepting them for compliance until then (EC, 2011).[10]

[10]For further development on how these restrictions were introduced, as well as their potential impact on the price of CDM credits and on the development of CDM projects, see (Gavard and Kirat, 2018).

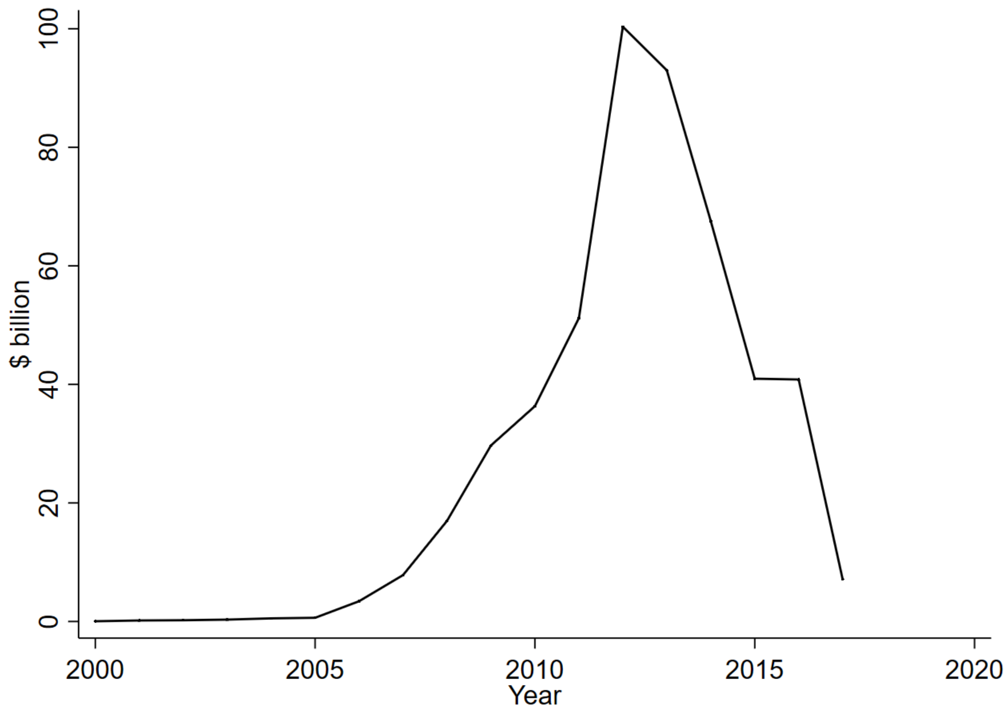


Figure 4: Development of private climate finance over time

3.2 Estimation of the impact of financial transfers on emissions

We investigate the impact of transfers on CO_2 emissions by exploiting the panel structure of our data by using a country fixed-effect specification.[11] Standard errors are robust to heteroskedasticity and autocorrelation. We estimate Equation (33) and report the results for six specifications, including various sets of controls in Table 1.[12]

$$\begin{aligned} ln(Emissions_{i,t}) = & \beta_1 AdaptationFinance_{i,t} + \beta_2 Vulnerability_{i,t} + \beta_3 MitigationFinance_{i,t} \\ & + \lambda X_{i,t} + \theta_i + \epsilon_{i,t} \end{aligned} \tag{33}$$

Results

Regarding public transfers, we observe that mitigation finance ("Rio mitigation finance") contributes to reducing emissions, while adaptation finance ("Rio adaptation finance") tends to increase them. The negative effect of mitigation finance on emissions confirms that transfers considered to support mitigation indeed contribute to emission reductions. Keeping in mind that our dependent variable is in logarithm, the coefficients need to be interpreted as percentage changes. As our transfer flow variables are in $billion, our analysis suggests that a public mitigation transfer inflow of $1billion involves a reduction of a country's emission by $0,04 - 0,046\%$ on average.

[11] The decision to include a country-fixed effect is based on a Hausmann-test indicating the existence of a country fixed-effect.

[12] Theoretical studies have identified a potential substitutability in reducing damages between adaptation and mitigation finance (Heuson et al., 2013; Peters et al., 2015). We abstract from this issue here and estimate the effects for given transfer levels.

Table 1: Regression Results - Emissions

	(1)	(2)	(3)	(4)	(5)
Transfers					
RIO mitigation finance	-0.0447**	-0.0463**	-0.0433**	-0.0419**	-0.0403**
	(0.023)	(0.018)	(0.031)	(0.034)	(0.047)
RIO adaptation finance	0.217***	0.195***	0.187**	0.187**	0.173**
	(0.004)	(0.007)	(0.011)	(0.015)	(0.016)
CDM Inflow	0.00356***	0.00369***	0.00403***	0.00423***	0.00368***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Controls					
ln(Population)	0.854***	0.850***	0.927***	0.881***	0.879***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(GDP)	0.592***	0.519***	0.484***	0.495***	0.504***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Vulnerability		-2.334*	-2.336*	-2.388*	-2.673*
		(0.068)	(0.082)	(0.072)	(0.054)
Industry Share			0.00215	0.00198	0.00192
			(0.198)	(0.246)	(0.243)
Forest area				-0.0105	-0.0101
				(0.131)	(0.152)
Political Stability					-0.00838
					(0.778)
Constant	-11.36***	-8.578***	-9.035**	-8.212**	-8.277**
	(0.000)	(0.005)	(0.015)	(0.022)	(0.024)
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	2456	2334	2244	2244	2116
R^2	0.637	0.659	0.665	0.667	0.661

p-values in parentheses
* Significant at the 10 percent level
** Significant at the 5 percent level
*** Significant at the 1 percent level

Regarding adaptation investment, we find a positive impact on emissions. An addition billion in adaptation inflow increases emissions by $0,21 - 0,17\%$ on average. To explain this positive impact of adaptation investment, we suggest two possible mechanisms. First, adaptation measures (e.g. building irrigation networks on dikes) are likely to involve significant construction efforts, which are themselves carbon intensive. The resulting infrastructure improvement may then additionally enhance economic activity and induce an increase in emissions.

Assessing private transfers, the CDM flows used as a proxy seem to have had a positive impact on emissions. An additional billion in CDM inflow has on average increased emissions by $0,0035 - 0,0042\%$. As 46% of CDM projects between 2000-2017 were conducted in China, we test the robustness of this result when we exclude China from the estimation. We then find that this leaves the CDM coefficient insignificant without substantially altering the other estimates of interest.[13] The CDM coefficient is to a substantial degree driven by Chinese data. These results are consistent with the existing literature on CDM effectiveness and in particular the criticism of a lack of additionality. Thus, given that the CDM is a project-based mechanism, it is not clear that CDM investments have directly led to emission reductions. On the contrary, they might have contributed to economic development and emission increases, which seems to be the case in China. Several studies have found limited effectiveness of the CDM mechanism in enabling sustainable economic development without substantial emission increases (Sutter and Parreno, 2007; Boyd et al., 2009).

To summarize, our estimations suggest that public mitigation inflow tend to reduce emissions, while public adaptation investment seems to increase them. Private finance inflow associated with the CDM appears to have no significant impact on emissions reductions, except in China where it contributed to an increase in emissions. These results remain consistent across specifications.

To check the robustness of these results, we vary the vector of included controls. We keep both population and GDP through all estimations. They control for the size of the country and its economic activity. Both always have a positive and significant effect on emissions.

In regression (2), we add the vulnerability of a country measured by the Notre Dame Vulnerability Index.[14,15] A higher vulnerability is associated with lower emission levels, at the 10% significance level. The inclusion of this control only induces minor changes in our estimation results. It tends to reduce the coefficient for adaptation investment. The effects of both RIO mitigation finance

[13] Detailed results are available upon request.
[14] A higher score indicates a higher vulnerability.
[15] An alternative index, the Climate Risk Index (CRI) published by GermanWatch e.V. has also been considered. The estimation results for our variables of interest are consistent across the use of both indices as a measure for vulnerability.

and CDM inflow are stronger, once vulnerability is included. Highly vulnerable countries are likely to receive less inflow for mitigation efforts, both from private and public sources.[16] These highly vulnerable countries also have lower emissions, likely through decreased industrialization rates. This correlation between low inflows and low emissions lead to an underestimation of the effect of CDM inflow and RIO mitigation inflow in specification (1) in comparison to (2).

In regression (3), we introduce the share of industrial production in % of the total national value added as a control to capture the effects of a structural change in economic activity, e.g. from an agricultural-based economy to an industrial economy. Industry share of value added shows a positive effect on emissions, which is not significant. However, we do observe a drop in the negative impact of mitigation finance and a lower impact of adaptation finance on emissions, whilst the positive impact of CDM inflow increases. The increase in the CDM coefficient is largely driven by the situation in China. In China, we have a negative relationship between industry share and emissions,[17] which is opposite to what is observed through the whole sample. We suggest the influence of industry share on emissions depends on the current state of the economy. A transition from agricultural to industrial output is likely to increase emissions, whilst the emergence of a service sector has probably a limited emission increasing effect. We can see that because CDM inflow is associated with a higher industry share, which is most likely explanable by increased investment opportunities for private agents in already developed industrial structures. This higher industry share is associated with a negative effect on emissions for the special case of China. Hence, Specification (2) likely underestimates the impact of CDM investment. Regarding the drop in the coefficient of adaptation finance, we suggest that, in line with the positive influence of adaptation finance, the construction efforts associated with adaptation measures may contribute to an increase in industrial output and therefore also the industry share as well as emissions. This effect of adaptation investment is partialled out as soon as industry share is included in the estimation. To explain the decreased effect of RIO mitigation finance, we suggest that mitigation investment is likely to be invested into industrial activities, such as replacing coal plants with renewable energies, thereby reducing the influence of the industry share on emissions. If industry share is now included in the estimation, this mechanism is not included in the mitigation coefficient anymore, which explains the reduction in the mitigation coefficient going from (2) to (3).

As an additional robustness check, we include the forest area variable in regression (4). Forest area, as a measure for carbon sink, has been identified as a determinant of climate finance inflow by Halimanjaya (2015). Halimanjaya (2015) found that countries with larger carbon sinks are likely to receive more public mitigation finance. The inclusion of this proxy for carbon sink leaves

[16] This is supported by a negative correlation between mitigation finance and CDm inflow with vulnerability in the data.

[17] The correlation between CDM inflow and industry share is 0.06 across the whole sample, but 0.16 in China, and the correlation between industry share and emissions is 0.14 across the sample and -0.44 in China.

the coefficient for adaptation finance unchanged, whilst we can observe a slight drop in the negative effect of mitigation investment and a notable increase in the positive impact of CDM inflow. Countries with a higher percentage of forest area in their land mass are likely to receive less CDM investment given lower industrial development.[18] This correlation explains the change in the coefficient associated with CDM flows. Regarding public mitigation finance, the forest area variable captures some of the effect of mitigation finance. Additionally, we suggest that this effect could be enhanced by the fact that some mitigation projects include afforestation efforts (Reyer et al., 2009).

In regression (5), we add a control for the political stability as this is identified as an important determinant of climate finance inflow by Halimanjaya (2015): the latter identifies good governance as a determinant for increased public mitigation inflow. All coefficients drop as a result of the inclusion of political stability as a control, with the most notable decrease in the effect of CDM investment. We suggest that higher political stability likely increases the effect of all investments. Including this control partially absorbs the effects of all three inflow variables and the corresponding coefficients decrease. However, the political stability variable itself is not significant. The reason could be that it absorbs partially both, the positive effects of CDM inflow and adaptation investment, and the negative effect of mitigation investment.

To conclude on the results reported in Table 1, the coefficients for all transfer variables remain fairly stable across the specifications, showing the robustness of our results to the inclusion of various control measures.

Appendix (5.2) reports additional robustness checks for our results, in particular by including lags of the transfer variables. One might argue that investment into mitigation takes time for its full effect to unfold. We therefore conduct the estimations using varying lags of our transfer variables. For the public finance flows, we find decreasing significance with higher lags.[19] For public mitigation inflow, we find that the effect decays over time, with the third lag onwards being insignificant. We note that the first lag is still significant with a coefficient of similar magnitude as the contemporaneous term. We consider this addresses potential concerns of endogeneity. Our interpretation of these results is that public mitigation inflow first lowers emissions, but enables economic development in a longer term and thus potentially drives emissions up, which could explain the insignificance of the coefficients associated with the third and sixth lag. We suggest that this effect could be alleviated by accompanying public mitigation inflows with requirements for domestic institutional measures to control emissions. Regarding RIO adaptation inflows, we

[18] These statements are confirmed by correlation statistics in our sample. The correlation between CDM and forest area is -0.2605 and the correlation between forest area and industry share is -0.0219.

[19] Introducing lags restricts the sample size. We have conducted robustness checks with these resulting limited samples and have found that the discussed findings stem from the inclusion of lags itself, and not from the sample restrictions.

had provided two mechanisms to explain the positive effect of adaptation finance earlier in this section. The direct construction efforts would increase emissions in the short term, whilst improved infrastructure tends to contribute to economic development later on. We observe a significant coefficient for adaptation finance up to the fifth lag, suggesting that both channels play a role in explaining the observed effects. Considering CDM flows, we observe that the coefficient lowers and becomes insignificant for lags 1 to 3, with the sign even reversed from the fourth lag onwards. We suggest the following explanation: while CDM inflows have limited effectiveness in the short term, they may contribute to building institutional capacities to control emissions in the longer term. To apply for CDM credits, emission reductions had to be closely monitored and procedural standards met. To do so, monitoring and reporting expertise was developed in governing bodies of recipient countries, possibly enabling effective emission reduction efforts in a longer term.[20]

3.3 Estimation of the impact of financial transfers on CO_2 intensity

We now estimate the equation deducted from our theoretical model. The dependent variable is now the emission deviation from a business-as-usual scenario in which there would have been no climate policy in developing countries.

To eliminate the subjectivity and uncertainty of calculating business-as-usual emissions for all developing countries of the dataset, we purposely opt for the following alternative. Taking the RIO Earth Summit in 1992 as the starting point for significant efforts in global climate policy, we regress climate finance transfers on the difference between the contemporaneous CO_2 intensity of GDP and the intensity in 1992.

We thus estimate equation (35) and report the results in Table 2. The six employed specification include the same sets of controls as in section 3.2. Standard errors are again robust to heteroskedasticity and autocorrelation.
The variable to explain is defined as:

$$\text{Difference in CO}_2\text{ intensity} = \frac{Emissions_{i,1992}}{GDP_{i,1992}} - \frac{Emissions_{i,t}}{GDP_{i,t}} \tag{34}$$

We utilize the following specification to estimate the model:

$$\begin{aligned}\text{Difference in CO}_2\text{ intensity} = {} & \beta_1 AdaptationFinance_{i,t} + \beta_2 Vulnerability_{i,t} \\ & + \beta_3 MitigationFinance_{i,t} + \lambda X_{i,t} + \theta_i + \epsilon_{i,t}\end{aligned} \tag{35}$$

Table 2: Regression Results - CO_2 intensity

	(1)	(2)	(3)	(4)	(5)
Transfers					
RIO mitigation finance	-0.0000587*	-0.0000594*	-0.0000605*	-0.0000596*	-0.0000564*
	(0.065)	(0.061)	(0.057)	(0.061)	(0.070)
RIO adaptation finance	0.000240**	0.000217**	0.000212*	0.000212*	0.000193*
	(0.026)	(0.050)	(0.065)	(0.068)	(0.070)
CDM Inflow	0.00000334*	0.00000343**	0.00000352**	0.00000365**	0.00000300*
	(0.056)	(0.044)	(0.045)	(0.040)	(0.058)
Controls					
ln(Population)	0.000667***	0.000677***	0.000703***	0.000675***	0.000639***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(GDP)	-0.000439**	-0.000508***	-0.000510***	-0.000504***	-0.000488***
	(0.017)	(0.006)	(0.007)	(0.008)	(0.006)
Vulnerability		-0.00280*	-0.00290*	-0.00293*	-0.00326*
		(0.100)	(0.094)	(0.090)	(0.061)
Industry Share			-0.00000161	-0.00000172	-0.00000159
			(0.481)	(0.450)	(0.496)
Forest area				-0.00000642	-0.00000624
				(0.186)	(0.192)
Political Stability					-0.0000230
					(0.601)
Constant	-0.000166	0.00258	0.00231	0.00280	0.00314
	(0.963)	(0.483)	(0.570)	(0.490)	(0.456)
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Observations	2423	2301	2222	2222	2097
R^2	0.160	0.175	0.174	0.176	0.174

p-values in parentheses
* Significant at the 10 percent level
** Significant at the 5 percent level
*** Significant at the 1 percent level

Results

Regarding public transfers, we find that mitigation finance ("RIO mitigation finance") tends to reduce the carbon intensity of GDP at the 10% significance level, whilst adaptation finance ("RIO adaptation finance") tends to increase it. These results are consistent with our findings from section (3.2): transfers supporting mitigation targets can indeed play a role in reducing the carbon intensity of an economy, ultimately resulting in emission reductions. The results on adaptation finance ("RIO adaptation finance") again imply a positive influence of adaptation investment on CO_2 intensity and thus emissions, via the potential mechanisms discussed in section (3.2).

Regarding private transfers, we also verify a positive effect of CDM inflows on carbon intensity. This seems to confirm the questions raised about the effectiveness of the CDM mechanism and the additionality of financed projects. This finding is robust across the specifications reported in Table 2.

We now discuss the robustness of our results to the inclusion of varying sets of controls. As in Table 1, GDP and population are included as controls for all specifications. We observe that the inclusion of the various controls induces comparable changes in the estimates as observed in section (3.2). This suggests that the mechanisms discussed in section (3.2) also hold here.

In regression (2), we add the Notre Dame Vulnerability Index as a measure for the country-specific vulnerability to climate change and extreme weather events. Whilst a higher vulnerability seems to be associated with reduced CO_2 intensity, the results for the transfer variables remain stable and the changes in magnitude are consistet with what we observed in Table 1. We observe a slight increase in the effects of CDM inflow and RIO mitigation inflow, whilst the effect of adaptation investment is again lowered. This confirms the findings from section (3.2).

The inclusion of the the industry share in regression (3) yields changes in the coefficients parallel to those observed in Table 1. The effect of CDM inflows is increased, whilst the effect of adaptation investment is reduced. As opposed to Table 1, the effect of RIO mitigation inflow is slightly increasing when accounting for industry share. But we can still confirm that the qualitative interpretation of our results for transfer inflows are robust to the inclusion of industry structure as an additional control. Similarly, our results are robust the inclusion of forest area as a measure of carbon sink in regression (4). All changes in magnitude for the coefficients associated with transfer variables are consistent with our observations in Table 1. The inclusion of political stability as a control in regression (5) only induces very minor changes to the other coefficients, which is in line

[20] To test for the impact of improved coverage of reporting over time, we also check the robustness of our results by restricting the sample to later years, following Halimanjaya (2015), and exclude the first two and four years respectively. The results show that the coefficients remain stable and are available upon request.

with what we found in the previous section.

As for section (3.2), since the investment financed through financial transfer inflow may take time to develop into full effect, we conduct robustness checks when including lags of the finance flow variables. We report the results in Appendix 5.2. We obtain comparable results as for section (3.2). The positive effect of CDM reverses over time, whilst adaptation and mitigation become insignificant with higher lags, with the adaptation effect remaining up to the 5^{th} lag.[21]

4 Discussion and conclusion

Our analysis aims at assessing the potential of international climate finance transfers in enabling emission reductions, shedding light on this issue for the next steps of the Paris Agreement implementation via the global stocktake and the associated review process. Our study comprises a theoretical model development and consequent econometric estimations on the basis of historical data on climate finance transfers and emissions over the past 20 years.

Our theoretical development contributes to the literature on international climate agreements by relaxing the focus on coalition formation and modelling continous national emission choices. We incoporate financial transfers in two ways: (i) as direct bilateral incentives provided by utility-maximizing donor countries to receiving countries or (ii) as surplus sharing schemes redistributing the global welfare gains from emission reductions. To our knowledge, the econometric analysis is the first empirical contribution to the literature on climate agreements, as we employ historical data as opposed to relying on simulation studies. Our empirical analysis distinguishes between private and public financial flows as well as between mitigation and adaptation investment. After preliminary estimations testing reduced-form relationships between emission levels and transfer payments, we then estimate our model by utilizing the contemporaneous CO_2 intensity of GDP as compared to 1992 as the dependent variable.

Our findings confirm that mitigation finance can play a role in incentivizing emission reductions. The results show a negative impact of public mitigation finance on emissions. We found that an inflow of \$1billion decreases a country's emission by $0,04 - 0,046\%$. These flows provide support to countries that are willing to contribute to global mitigation efforts, but are limited in their institutional and economic capacities. The regression of transfer inflows on the CO_2 intensity of GDP as compared to 1992 confirms this emission-reducing effect of public mitigation inflow. Estimating lagged versions of our econometric specification suggests that the effect of public mitigation finance decays over time, possibly through enabling economic development. Based on these findings, we recommend reinforcing the role of such financial transfers, which simultaneously address equity

[21] Again, estimations with a restricted sample show consistent results, which are available upon request.

concerns and contribute to mitigation efforts, but we also suggest requiring simultaneous development of national policies and measures in recipient countries to control emissions and improve the long term effectiveness of climate finance transfers on abatement.

Regarding adaptation finance, we find that it may enhance emissions and we hence suggest taking this potential adverse effects on emission reductions into consideration in the negotiations. The positive impact of adaptation finance on emissions, observed in both empirical specifications, likely arises from directly related construction efforts and enhanced economic activity due to improved infrastructures. While we recognize the necessity of such adaptation measures, especially in the most vulnerable countries, we recommend being aware of the potential adverse effects on carbon emission reductions. We hence suggest to design this adaptation support as well as adaptation projects and programs in a way that minimizes the resulting emission increase.

Regarding the role of private flows, the use of CDM flows as a proxy allows us to detect a positive effect on emissions, mainly driven by the development in China. This is consistent with the existing literature on the low effectiveness of the CDM to reduce emissions, in particular due to the lack of additionality of the corresponding projects. However, we find that the CDM inflow seems to decrease emissions after five years or more, suggesting that the CDM may contribute to long term emission reductions due to the capacity building it triggers. To ensure that private investment contributes to mitigation efforts both in the short and longer term, we suggest encouraging the development of regulatory frameworks (whether market or non-market based) to accurately control emissions. For example, with regard to the Paris Agreement Article 6.4 mechanism as a potential successor to the CDM, we suggest designing it in a way that ensures the additionality of the emission reductions which are claimed, and minimizes the potential short term emission increasing effect of the resulting climate finance flows.

Our results tend to encourage a granular discussion about how the various types of financial transfers can contribute to abatement. Policies should account for differences in effects between private and public finance as well as between mitigation and adaptation investments to enhance the effectiveness of international transfers in facilitating global emission reductions. Potential long term effects need to be recognized, as they may offset short term gains. As the policy community emphasizes institutional capacity as a major constraint for effective climate policies in developing countries, we highlight the importance of climate finance flows for supporting institutional development, as strong national governing bodies are a requirement for long term low-carbon development.

5 Appendix

5.1 Descriptive statistics

List of recipient countries included in the analysis

Antigua and Barbuda, Argentina, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cameroon, Chad, Chile, China, Colombia, Comoros, Congo, Rep., Costa Rica, Cote d'Ivoire, Cyprus, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Fiji, Gabon, Gambia, Georgia, Ghana, Grenada, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Indonesia, Islamic Republic of Iran, Iraq, Jordan, Kenya, Kiribati, Laos, Lebanon, Lesotho, Macedonia, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritania, Mauritius, Mexico, Mongolia, Morocco, Mozambique, Namibia, Nepal, Niger, Nigeria, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Seychelles, Sierra Leone, Singapore, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Tajikistan, Tanzania, Thailand, Togo, Tonga, Trinidad and Tobago, Tunisia, Tuvalu, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Vanuatu, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe

5.2 Robustness checks

Table 3: Regression on emissions - Lags

	(1)	(2)	(3)	(4)
Transfers				
RIO mitigation finance	-0.0403**			
	(0.047)			
L.RIO mitigation finance		-0.0439*		
		(0.069)		
L3.RIO mitigation finance			-0.0378	
			(0.275)	
L6.RIO mitigation finance				-0.0390
				(0.290)
RIO adaptation finance	0.173**			
	(0.016)			
L.RIO adaptation finance		0.224***		
		(0.004)		
L3.RIO adaptation finance			0.223**	
			(0.025)	
L6.RIO adaptation finance				0.133
				(0.346)
CDM Inflow	0.00368***			
	(0.000)			
L.CDM Inflow		0.00167		
		(0.133)		
L3.CDM Inflow			-0.00148	
			(0.298)	
L6.CDM Inflow				-0.00596***
				(0.002)
Controls				
ln(Population)	0.879***	0.918***	0.911***	0.949***
	(0.000)	(0.000)	(0.000)	(0.000)
ln(GDP)	0.504***	0.499***	0.509***	0.597***
	(0.000)	(0.000)	(0.000)	(0.000)
Vulnerability	-2.673*	-2.899*	-3.494**	-4.993***
	(0.054)	(0.061)	(0.032)	(0.005)
Industry share	0.00192	0.00248	0.00261	0.00274
	(0.243)	(0.127)	(0.129)	(0.207)
Forest Area	-0.0101	-0.00826	-0.00614	-0.00241
	(0.152)	(0.257)	(0.417)	(0.758)
Political stability	-0.00838	-0.00524	-0.0104	-0.0198
	(0.778)	(0.866)	(0.744)	(0.599)
Constant	-8.277**	-8.760**	-8.662**	-10.79**
	(0.024)	(0.019)	(0.022)	(0.010)
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2116	1997	1877	1507
R^2	0.661	0.648	0.627	0.588

p-values in parentheses
* Significant at the 10 percent level
** Significant at the 5 percent level
*** Significant at the 1 percent level

Table 4: Regression on CO_2 intensity - Lags

	(1)	(2)	(3)	(4)
Transfers				
RIO mitigation finance	-0.0000564*			
	(0.070)			
L.RIO mitigation finance		-0.0000569		
		(0.148)		
L3.RIO mitigation finance			-0.0000713	
			(0.303)	
L6.RIO mitigation finance				-0.0000411
				(0.289)
RIO adaptation finance	0.000193*			
	(0.070)			
L.RIO adaptation finance		0.000211*		
		(0.084)		
L3.RIO adaptation finance			0.000246*	
			(0.076)	
L6.RIO adaptation finance				0.000164
				(0.227)
CDM Inflow	0.00000300*			
	(0.058)			
L.CDM Inflow		0.000000920		
		(0.584)		
L3.CDM Inflow			-0.00000317	
			(0.166)	
L6.CDM Inflow				-0.00000944***
				(0.000)
Controls				
ln(Population)	0.000639***	0.000610***	0.000560***	0.000490***
	(0.000)	(0.000)	(0.000)	(0.001)
ln(GDP)	-0.000488***	-0.000472**	-0.000445**	-0.000303*
	(0.006)	(0.011)	(0.016)	(0.088)
Vulnerability	-0.00326*	-0.00359**	-0.00410**	-0.00500**
	(0.061)	(0.048)	(0.029)	(0.014)
Industry share	-0.00000159	-0.00000114	-0.000000825	2.52e-08
	(0.496)	(0.652)	(0.758)	(0.991)
Forest area	-0.00000624	-0.00000548	-0.00000445	-0.00000218
	(0.192)	(0.233)	(0.322)	(0.578)
Political stability	-0.0000230	-0.0000231	-0.0000290	-0.0000153
	(0.601)	(0.610)	(0.558)	(0.720)
Constant	0.00314	0.00334	0.00368	0.00176
	(0.456)	(0.446)	(0.412)	(0.713)
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Observations	2097	1978	1859	1495
R^2	0.174	0.161	0.156	0.112

p-values in parentheses
* Significant at the 10 percent level
** Significant at the 5 percent level
*** Significant at the 1 percent level

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