The Climate Rent Curse: New Challenges for Burden Sharing

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Abstract

The literature on the "resource curse" has strongly emphasized that large incomes from resource endowments may have adverse effects on the growth prospects of a country. Conceivably the income generated from emission permit allocations, as suggested in the context of international climate policy, could have a comparable impact. Effects of a "climate rent curse" have so far not been considered in the design of permit allocation schemes. In this study, we first determine when to expect a climate rent curse conceptually by analyzing its potential channels. We then use a numerical model to explore the extent of consequences that a climate rent curse would have on international climate agreements. We show that given the susceptibility to a curse, permit allocation schemes may fail to encourage the participation of recipient countries in an international mitigation effort. We present transfer schemes that enhance cooperation and limit adverse effects on recipients.

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1 Introduction

In the past, extensive resource rents have often caused more harm than good. Even though they provide financial inflows that could potentially foster economic growth and enable investment, raise factor productivity and/or reduce distortionary taxes, particularly in poor countries (Van der Ploeg and Venables,

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2011; Fuss et al., 2016), empirical evidence implies that revenues generated by natural resources can significantly reduce growth prospects of a country, a phenomenon termed the "natural resource curse" (see Van der Ploeg, 2011, for a detailed review of the literature).

Other rent incomes with similar characteristics might also induce negative effects on growth prospects. Examples include inflows from foreign aid (Svensson, 2000; Rajan and Subramanian, 2008, 2011; de Ree and Nillesen, 2009) or foreign direct investments (Alfaro et al., 2004). In this study, we ask whether rents created by climate policy are likely to have similar adverse effects and, if so, how they affect the attractiveness to be part of an international mitigation effort.

Climate policy induces rents in particular when mitigation policy is enforced by an international emissions trading scheme, and thus creating a new scarcity. Trading schemes are attractive because they generally achieve cost efficient emission reductions and have the flexibility to implement different burden sharing schemes. Today, domestic trading schemes are the most widely used instrument to regulate emissions (Meckling and Hepburn, 2013). For the future, linking regional trading schemes (Flachsland et al., 2009; Fankhauser and Hepburn, 2010b) or setting up a global emissions trading scheme (Gollier and Tirole, 2015; Bosetti and Frankel, 2011; Messner et al., 2010) are commonly proposed ways forward for climate policy. Even though it might be doubted that a global trading scheme will be established (Newell et al., 2013), the recently negotiated Paris Agreement principally allows for international emissions trading (UNFCCC, 2015, Article 6) and domestic permit trading schemes are among the proposed instruments to fulfill the obligations under the agreement.

Within an international carbon market the scarcity price of allowances assigns a significant monetary value to the permit volume. The regional share of the carbon market value is determined by the initial allocation of allowances among participants, e.g. based on population or historic emission (Luderer et al., 2012b). Subsequent trade in permits equalizes marginal abatement costs and implicitly induces transfers among countries. The revenues of a net seller of permits constitute a 'climate rent' whenever they exceed the corresponding costs for abating emissions (Jakob et al., 2015).

The allocation scheme and resulting transfers can address different distributional concerns between countries. First, proposed allocations are often related to normative principles connected to equity or fairness, such as a per-capita allocation of permits or an allocation based on historic responsibility of emissions (Edenhofer et al., 2010b). Consequently, significant climate rents occur in developing countries, which sometimes even show gains rather than costs when participating in the international mitigation effort (Calvin et al., 2012; Edenhofer et al., 2010a; Luderer et al., 2012a).

Second, transfers can be used to encourage the participation of countries in a coordinated international climate policy. When countries form coalitions under an international climate agreement, free-riding incentives impede cooperation because the abatement of emissions represents a global public good (Carraro and Siniscalco, 1993; Barrett, 2003). While many studies conclude that climate coalitions may remain small and ineffective without additional means (Barrett, 1994; Rubio and Ulph, 2006), Carraro et al. (2006) demonstrate that transfers enable the members of an agreement to share the gains of cooperation, possibly making cooperation more attractive for the entire coalition (see also Brechet

et al. 2011, Lessmann et al. 2015).
Transfers to developing countries could therefore be a game changer from a normative and strategic point of view. Studies that numerically estimate potential transfers to developing countries find inflows in a carbon market to be in the range of resource incomes in the past (Jakob et al., 2015; Bowen et al., 2014). Nordhaus (2007) remarked that the generation of this rent by climate policy has the potential to damage economic growth especially in low-income countries. Expecting a climate rent curse may therefore reduce the incentive to receive transfers when assuming governments to be benevolent. In this study, we quantitatively assess how adverse effects from permit revenues affect the decision to participate in an international carbon market.[1]
This paper combines insights from the resource curse literature with coalition theory. By exploring the trade-off between additional revenues versus reduced growth, we analyze how climate transfers should be designed to enhance the success of climate agreements. As there is no empirical evidence on adverse effects of climate rents, we draw on the analogy to natural resource rents: First, we characterize the causes of the natural resource curse qualitatively and then explore in how far the income from permit exports may cause comparable adverse effects as observed for natural resources. We then use the analogy to inform our numerical implementation of the climate rent effects, and study how a 'climate rent curse' reduces the desire for large permit allocations from a quantitative perspective. The results indicate that the climate rent curse requires transfer schemes which take into account these adverse effects as the cooperative effort might otherwise fail.
The text is structured as follows: In section 2 we recapitulate the most important mechanisms of the resource curse. In section 3 we compare climate- to resource rents and discuss whether effects that have been observed for natural resources can also be expected for climate rents. Based on these insights we evaluate the trade-off posed by the climate rent curse in an extended version of the numerical Model of International Climate Agreements (MICA) (Lessmann et al., 2009), which is introduced in section 4. In section 5, we use the model to discuss the implications of a climate rent curse on the incentive to participate. Section 6 concludes.

2 The Resource Curse in the Literature

A broad empirical literature on the "curse" of abundant resources, initiated by Sachs and Warner (1995) and Sachs and Warner (1997), empirically shows that the growth rate of a country is negatively affected by increasing shares of resource exports in its economic output. Sachs and Warner test a linear relationship between resource export shares and a reduction of the growth rate in a cross country regression analysis. The coefficient of proportionality is a measure of the aggregate strength of the adverse effect, an information we will use in our model in sections 4 and 5. The subsequent literature has analyzed

[1]Note that in this study we assume that governments aim to maximize the long-term benefit of their countries. This might agruably not always be the case; governments that maximize their personal profit and rent-seeking might be tempted by additional transfers. We revisit this point in more detail in our conclusions and outlook in the final section of this study.

distinct causes that contribute to or soften the resource curse. Adverse effects of abundant resources are thus not inevitable, and examples such as Norway and Botswana attest to this. In the following, we shortly introduce the most important channels: Dutch Disease, price volatility, and the quality of institutions and rent seeking.

Dutch Disease

Dutch Disease generally refers to additional revenues from resource exports having a negative effect on the (exporting) manufacturing sector, mainly due to an appreciation of the real exchange rate (Corden and Neary, 1982; Corden, 1984). The "spending effect" leads to a contraction of the traded goods sector and an expansion of the non-traded sector. Depending on the characteristics of the exporting country's economy, its industrial structure can suffer a long-lasting effect of lower growth rates (van Wijnbergen, 1984). However, while empirical studies generally find support for a contraction of the traded sector within a country after additional international revenue (see Van der Ploeg 2011 for a review), the exact long term consequences of an initial appreciation of the real exchange are country specific (Torvik, 2001).

Volatility

Prices of commodities have been shown to be more volatile than those of manufactures (Jacks et al., 2011). According to Van der Ploeg and Poelhekke (2009, 2010), an economy that largely depends on volatile revenues from resource exports exhibits increased macroeconomic variability. The instability of economic output then induces negative effects on long term growth prospects (Ramey and Ramey, 1995). The magnitude of the negative impact is dependent on the general level of economic variability and the respective institutions in place (Van der Ploeg and Poelhekke, 2010), with a positive influence of natural resource abundance possible. However, if financial markets are less developed, borrowing constraints hinder investment in the face of an unstable growth rate. As a consequence, innovation and development are reduced causing adverse effects on growth.

Rent Seeking, Institutions, and Governance

Resource rents induce rent seeking, which hurts innovative activities and thus distorts long term growth (Murphy et al., 1993). Given an aggregate demand externality, income is lowered by more than the extra income from resources (Murphy et al., 1989). Weak institutions encourage rent-seeking activities and corruption in times of high resource inflows, in turn leading to even worse institutions (Murphy et al., 1993). In contrast, good institutions, e.g. characterized by a highly developed legal system and transparency, increase the likelihood that more people engage in productive activities rather than rent-seeking, now benefiting from the aggregated demand externality and avoiding a curse (Mehlum et al., 2006a,b).

Negative effects of resource incomes, in particular rent-seeking, are inversely related to the technological complexity of extracting, selling and transporting a particular resource at a given low level of institutional quality (Boschini et al., 2007). Mavrotas et al. (2011) show empirically that natural point-sources as for example diamonds, but also coffee and cacao retard democratic and institutional development. One major reason can be attributed to the fact that they fuel distributional conflicts (Wick and Bulte, 2006; Schollaert and Van de Gaer, 2009; de Ree and Nillesen, 2009). Conflicts – as an extreme form of rent seeking – generally become more likely with high resource incomes as the increased availability of finance makes rebellion feasible (Collier and Hoeffler, 2004).

Finally, the quality of institutions is also related to the governance dimension of resource incomes. Governments might be tempted to raise public expenditure to a degree that is unsustainable once resource incomes decrease or vanish (Robinson et al., 2006). Hence, this might lead to a political lock-in into granted benefits, which is hard to overcome.

Lessons from the literature

Despite challenges to the initial discovery that there is a universal natural resource curse (Brunnschweiler and Bulte, 2008)[2], the general finding that resource wealth is – under certain conditions – associated with surprisingly low or even negative growth rates, has proven very robust (Van der Ploeg, 2011). It is challenging to disentangle the importance of the different channels of the natural resource curse in the empirical magnitude of reduced growth prospects found by Sachs and Warner (1997) and subsequent studies, especially since their specific importance may differ from case to case. Modeling the resource curse to study the effects of a curse on climate cooperation will thus build on an aggregate, i.e. an economy-wide perspective. Furthermore, two aspects that the discussion so far has highlighted will be important: First, the adverse effects from conventional resources strongly depend on the characteristics of the individual countries. Second, and related, the resource curse is not inevitable. Rather, stable institutions, including in particular well-developed financial institutions, seem to harness an economy against the potentially negative effects.

3 Characteristics of the Climate Rent

This section analyzes the characteristics of climate rents from permit exports as resource exports determine the curse effects found in the empirical literature. Whether permit exports impose a threat to growth prospects largely depends on the institutional design of a carbon market and regional characteristics.[3] We first discuss the analogy between resources and carbon permits and subsequently discusses which regions might potentially be vulnerable to a climate rent curse, taking a more detailed look at

[2]The results of Brunnschweiler and Bulte have subsequently been rejected by Van der Ploeg and Poelhekke (2010), and the more recent literature indeed shows that whether resources have a negative or positive influence on long term growth depends largely on numerous circumstances (Van der Ploeg, 2011).

[3]See (Jakob et al., 2015) for a detailed discussion of rents in various climate finance settings.

different channels discussed in section 2.

3.1 Permits as Resources

Constituting a (tradable) right to emit, a carbon permit becomes a valuable asset in any fossil fuel based economy. If the carbon market induces scarcity and a firm's emissions exceed its current permit holdings, production either needs to be cut down or additional permits have to be purchased. In the context of the European market (EU-ETS), Benz and Trück (2009) characterize a CO_2-permit as a basic input factor to production with specific characteristics: they can only be used once; they are substitutable by switching to a different, i.e. less carbon-intensive technology; arbitrary amounts can be traded; the transport cost of permits is negligible. Permits therefore exhibit considerable similarities to traditional resources.

There are crucial differences of carbon allowances and conventional resources as well, which we also highlight in the discussion below. Perhaps most importantly, the permit creates only an *artificial* scarcity (which would also be true for other issue areas, where policy restricts the use of resources, as for example forest conservation). Subsequent political decisions will thus have a substantial influence on supply- and demand dynamics in a carbon market (Koch et al., 2016). Owners of conventional resources can decide independently when to sell their assets. In a carbon market, by contrast, permits could lose their value, e.g. by governmental decision when a commitment period ends.

3.2 Rents from Permit Exports

If a carbon market is sufficiently integrated in space (Flachsland et al., 2009; Fankhauser and Hepburn, 2010b), a country can sell arbitrary amounts of their initial permit holdings to other countries. If export revenues exceed mitigation costs, the inflow represents a climate rent.[4,5] The exact consequences of adverse effects from permit exports will depend on the domestic design of the international carbon market. Under free allocation of permits the entire climate rent is obtained by the producers. However, if permits are auctioned, large parts will accrue to the government, raising public revenues.

Revenues from permit exports may be substantial: Depending on the allocation scheme, Jacoby et al. (2008) using the EPPA model find that financial inflows to developing countries could be in the range between USD 14 billion to USD 900 billion in the year 2020 (when global emissions are to be cut by 50% in 2050 relative to 2020). Using different models, Jones et al. (2013), Bowen et al. (2014) and Jakob et al. (2015) find regional inflows to reach maxima (all in Sub Saharan Africa) between 11% (Jones et al., 2013, using the MiniCam model) and 41% of economic output (Bowen et al., 2014, using WITCH). The allocation scheme determines whether inflows are significant or negligible (Us-

[4] We distinguish these climate rents from any rent in a carbon market in which the initial allocation is cost-efficient and rents occur due to the scarcity of permits.

[5] This is a crucial difference to e.g. a carbon tax: while for the implementation of a tax on emissions financial transfers could be implemented through direct transfers of money, in an emissions trading scheme the sale of surplus permits induces financial flows indirectly.

ing ReMind-R, Jakob et al., 2015, find ranges to vary between <1% for Sub Saharan Africa in a grandfathering-like approach to 14.5% in an equal per capita regime). Bowen et al. (2015) find annual North-South financial flows of up to USD 2 trillion in the year 2050 when applying an equal-effort burden sharing in several integrated assessment models.

3.3 Climate Rents and the Resource Curse

Although transfers within a carbon market potentially exceed revenues from resources, it can be debated whether climate rents are necessarily prone to Dutch Disease, volatility, and rent seeking. As there is basically no empirical evidence we limit the discussion to estimating which channels are more likely to be important, with a view to implementing the climate rent curse in our numerical model.

First, Dutch Disease can majorly be attributed to inflows of foreign currency from trade, hence permit exports would function in a comparable way. However, the severity seems to be largely ambiguous and country specific and we cannot assign a definite negative effect.

Second, carbon prices are known to be volatile, as prices in the EU Emissions Trading Scheme (EU-ETS) have proven (Lutz et al., 2013), also compared to other commodities like crude oil or minerals (see table 1). Adverse impacts of carbon price volatility are therefore plausible. The extend of volatility will largely depend on the market design. Geographical integration of heterogeneous countries will likely decrease volatility[6], even though regular causes of price instability like business cycles, technology shocks or fuel prices will remain. Taking advantage of the freedom in when to emit, variability of the carbon price could be greatly reduced by increasing the duration of the commitment periods or allowing for banking between them (Fankhauser and Hepburn, 2010a).[7]

Third, one could argue that permits fulfill characteristics that seem to facilitate rent seeking, being presumably easy to "extract"[8] as well as a point resource, at least when issued to governments (as for example within the Kyoto Protocol). However, due to international control selling permits would probably be difficult on informal markets, reducing the possibility for rent-seeking activities and conflicts. Also, permits do not necessarily fulfill the negative characteristics of point-resources. For instance, it is debatable whether permits administrated by a central government induce grievance by parts of the population that might not have access to the resource in the same way as it has been observed for other natural resources.

Whether climate rents can be absorbed and potential negative effects can be mitigated will crucially hinge on the institutional quality of receiving countries. Jakob et al. (2014) demonstrate that countries with lowest values for institutional quality and control of corruption would also receive the largest financial inflows, if a per-capita allocation scheme was adopted in a global carbon market. In contrast,

[6] Jacks et al. (2011) show that world market integration has a positive impact on the stability of commodity prices.

[7] In the case of the EU ETS a remarkable decrease of the permit price was observed towards the end of the first commitment period.

[8] Exporting allocated permits above the level of uncontrolled emissions exhibits only transaction costs. When exporting permits below that level, the costs of extracting include mitigation costs.

Table 1: Volatilities of specific goods

Good	Volatility
EUAs[a,b]	0.099[c]
Crude oil[a]	0.102[d]
Steel[a]	0.042[d]
All Commodities	0.080[e]
Food	0.084[e]
Agricultural raw materials	0.061[e]
Minerals ores and metals	0.099[e]

a Volatilities are calculated as in Jacks et al. (2011) as the standard deviation of logged monthly price ratios, that is, the standard deviation of the percentage changes in price over a given period
b December 12
c ECX (2012); 51 observations, 2008–2012
d IndexMundi (2012); 51 observations, 2008–2012
e Jacks et al. (2011); 2005–2008

when looking at countries that managed large resource incomes relatively well, it can be found that their institutional quality is comparably high (see also Table A in the Appendix).

When we now turn to modeling the magnitude of adverse effects when countries cooperate on climate change in our model MICA, it is therefore important to take into account in how far countries are susceptible to a potential climate rent curse. First, there is a distinction between countries that have been able to prevent the curse and those that suffered from it. Secondly, for those countries that are vulnerable to adverse effects, the strength will be country-specific with different relevance of the channels discussed above. In MICA each region is represented from an aggregate perspective. In order to represent a climate rent curse, we therefore aggregate the different effects of the natural resource curse into one parameter that is positive for those regions that are vulnerable. Looking at institutional quality and proxies for the quality of financial markets (Table 2) for aggregated regions used in our numerical model MICA, we find that mostly the regions Africa (AFR), Middle-Eastern, North-African, and central Asian countries (MEA), other Asian countries (OAS), Russia (RUS), Latin-America (LAM), and India (IND) show levels of institutional quality that might not cope with large levels of financial inflows. When modeling the influence of a climate rent curse on cooperation in the next sections, we will therefore assume adverse effects to occur only these regions, marked with a 'yes' in the last row of Table 2. For China (CHN), institutional quality is low in some dimensions. However, the indicators for the quality of financial markets show that the capacity to deal with the volatility of permit prices is good and we therefore assume that CHN does not experience adverse effects.

Concerning the strength of the curse, we focus on a constant value for all vulnerable regions, which is arguably a strong assumption. We therefore complement our analysis by two parameter variations that explore the overall strength and regional heterogeneity of the curse: In section 5, we vary the curse strength for all vulnerable regions to give an indication of the effect of different strengths of the curse. Then in Appendix B, we explore the implications of regional heterogeneity in the strength of the curse effect on attractiveness of transfers and coalition stability.

4 The Climate Rent Curse in a Coalition Formation Model

In the next two sections, we study the quantitative incentive of regions to participate in an international carbon market and receive transfers that lead to adverse growth effects. The incentive to participate is derived from the standard two-stage game for international environmental agreements (Carraro and Siniscalco, 1993; Barrett, 1994). In the first stage regions choose to participate in the agreement, which is followed by the decision on economic strategies in the second stage. Members to a coalition maximize their aggregate social welfare, thus internalizing the emission externality among themselves, while non-members maximize their individual welfare. Given a particular coalition, regions have an incentive to participate if they are better off being a member than leaving the agreement. If all regions have a positive incentive to participate, the coalition is termed internally stable.[9]

To derive numerical estimates on the incentive to participate, we apply the Model of International Climate Agreements (MICA).[10] MICA allows to quantify the trade-off between receiving additional revenues when being part of an international mitigation effort and suffering from adverse consequences on growth. Changes in economic variables in the second stage due to a potential curse will affect cooperation in the first stage. This section provides an introduction to the main features of MICA, while a detailed description of model equations and solution techniques are found in Appendix C.

The Climate Rent Curse in the MICA model

For each of the eleven world regions i differentiated in MICA (see table 7), growth in economic output of a generic good over time t follows a Ramsey-type modeling of endogenous capital accumulation (Ramsey, 1928). A region's social welfare aggregates the discounted utility of its population over time, for which utility is a function of per capita consumption.

Global warming is driven by carbon-dioxide emissions, which are modeled as a side effect of production. A climate module computes the increase in global mean temperature that arises from aggregate emissions. The loop with the economy is closed by a climate change damage function which translates temperature rise into a fraction of domestic output that is lost. Climate change mitigation takes the form of an aggregate mitigation option that allows to reduce emissions at increasing marginal costs for each region.

[9] We do not consider external stability as we are interested in the incentive of regions to participate and receive transfers.

[10] MICA has been introduced and used in Lessmann et al. (2009); in this paper we present an updated version with heterogeneous players calibrated to eleven world regions.

Table 2: Top rows: Data on institutional quality in year 2014 based on the World Governance Indicators WorldBank (2016) in different categories: Voice and accountability,political stability, government effectiveness, regulatory quality, rule of law and control of corruption. Bottom rows: Standard deviation of GDP per capita growth rate (1980-2014) as well as a financial development indicator in year 2014. Note that national data for institutional quality, standard deviation and financial development are aggregated and weighted by population to match with aggregated regions used in MICA.

Indicator	AFR	CHN	EUR	IND	JPN	LAM	MEA	OAS	ROW	RUS	USA
Indicators for institutional quality											
Voice and Accountability	-0.72	-1.53	1.16	0.42	1.04	0.08	-1.23	-0.47	0.38	-1.04	1.05
Political Stability and Absence of Violence/Terrorism	-1.23	-0.45	0.62	-0.96	1.02	-0.31	-1.10	-0.85	-0.26	-0.84	0.62
Government Effectiveness	-0.93	0.35	1.19	-0.20	1.82	-0.18	-0.51	-0.28	0.56	-0.08	1.46
Regulatory Quality	-0.79	-0.25	1.21	-0.45	1.14	-0.08	-0.82	-0.40	0.54	-0.40	1.27
Rule of Law	-0.80	-0.32	1.25	-0.09	1.60	-0.42	-0.65	-0.47	0.40	-0.71	1.62
Control of Corruption	-0.92	-0.32	1.02	-0.46	1.73	-0.51	-0.64	-0.60	0.28	-0.87	1.32
Indicators for quality of financial markets											
Standard deviation of growth rate of GDP per capita (World Bank)	5.44	2.71	2.42	2.27	2.32	3.70	6.61	2.93	4.44	7.02	1.94
Domestic credit to private sector (% of GDP) (World Bank)	17.07	142.33	93.81	51.58	187.57	48.33	40.02	54.21	96.36	59.31	197.12
Is the region vulnerable to a climate rent curse?											
	yes	no	no	yes	no	yes	yes	yes	no	yes	no

Economic output net of climate damages hence covers consumption, saving, emission mitigation expenditures and international net exports. When regions form a coalition and establish a carbon market, permit trade can be an additional source of income. Emissions for each region have to be covered by the initial allowance net of exports. Given an exogenous initial allocation of permits, regions trade until their marginal abatement costs are equalized. Those regions that are over-allocated with permits are able to sell the excess to those that demand them, thus receiving an export revenue $\pi(i,t)$ proportional to the endogenous carbon price.

When revenues from exporting permits are received, a potential climate rent curse adversely affects endogenous growth in economic output. As discussed in section 3 we take a macroeconomic perspective and aggregate the different channels of the curse in one parameter, following empirical estimates of Sachs and Warner (1997): A positive share of export revenues π relative to the gross domestic product *GDP* reduces the growth rate in a vulnerable region i (see section 3.3) from the counterfactual g_0 to g^* according to[11]

$$g^*(i,t) = g_0(i,t) - \varphi \cdot \frac{\pi(i,t)}{GDP(i,t)}. \tag{1}$$

Growth rates of *GDP* per economically active person g_0 and g^* (in percentage points) at time t are averages over twenty years, and the parameter φ determines the severity of the 'curse' effect. For our first analysis the strength of the curse effect φ takes on the value of 9.43 as estimated by Sachs and Warner (1997) in their basic regression with only the initial *GDP* and the resource income controlled for in the empirical analysis. $\varphi = 9.43$ is the highest value we assume for the strength of adverse effects in our model to demonstrate the extent adverse effects can have. We reduce the strength of the curse in a parameter study in section 5.3. According to equation (1), increasing the share of resource exports in the *GDP* of a country by 10% reduces its average annual growth rate by 0.943 percentage points for our highest estimate ($0.943 = 0.1 \cdot 9.43$).

Within MICA, the counterfactual $GDP(i,t)$ is known and taken from a model run assuming no climate rent curse over that period. This also defines the associated growth rates $g_0(i,t)$. With the revenues from permit-trade $\pi(i,t)$, $g^*(i,t)$ can directly be calculated. We adjust the total factor productivity until growth rates in MICA are equal to the reduced growth rate g^*.[12] The model is re-run with adjusted total factor productivities to produce results that include the climate rent curse. Evaluating their welfare under reduced growth, regions take the adverse effect into account when deciding about their participation without preventing its cause.

Therefore, regions in our model do not optimize with respect to the full set of strategies available to

[11]The linear relationship between decreases in growth rates and export shares assumes that the first dollar induces adverse effects on recipients, which is a questionable assumption. As the relationship is most likely non-linear, our modeling approach most likely overestimates the adverse effect of small inflows and might in turn underestimate the negative effect of large transfers.

[12]This modeling assumption is in line with the most prominent channels inducing the curse: unproductive rent-seeking as well as low investment due to credit constraints. In addition, unsustainable investment decisions from governments can also be attributed to less total factor productivity.

them. Decision makers of each region are assumed to take the adverse effects of a climate rent curse into account without taking measures to prevent it. This neglects that some of the adverse effects could be addressed by policy instruments to manage the revenues.[13] In this sense, our analysis can be understood as a second-best setting, in which institutional changes to mitigate the effects of a curse are hard to realize.

We relax the strength of the climate rent curse from its first magnitude, $\varphi = 9.43$, by performing a parameter study in section 5.3. Firstly, the analysis acknowledges the fact that the carbon permit is not entirely congruent to resources and that depending on the econometric specification the estimates of the strength of the curse differ. Secondly, mitigating the influence of certain adverse effects may be possible in the long run – relaxing the assumptions on our second-best setting. Lastly, we take into account that governments may not be fully benevolent in the sense that they refuse to receive the revenues and drop out of the agreement in anticipation of the climate rent curse, but that some countries may still participate in the coalition. It is an interesting field of future research to incorporate the political economy aspects of the problem into our analysis.

5 Implications of the Climate Rent Curse for Climate Coalition Formation

This section presents the numerical incentive to participate in the MICA model. We first discuss internal stability under four different transfer schemes when adverse effects from permit trade are absent. The results are contrasted to the impacts of a climate rent curse on cooperation presented in the second part. Statistics of the entire number of coalitions in which different regions cooperate (amounting to 2037 distinct ones) will determine general findings, while specific examples concerning the grand coalition, comprising all regions, will demonstrate the effects in more detail.

5.1 Stability Analysis without the Climate Rent Curse

Stable cooperation in MICA typically involves only few regions and achieves little in terms of mitigating climate change, see table 3. 54 internally stable coalitions emerge, which on average abate 5% of the emission reductions that the grand coalition would realize. The internally stable coalition with the best performance in environmental terms achieves 17% (188 GtC over 190 years) of the abatement undergone in the grand coalition.

[13] Rodrik (2007) discusses in great detail how policy reforms should be designed in order to enhance the growth prospects in the face of various economic and institutional constraints. In our model, an endogenous choice of the strength of the resource curse is not considered.

Table 3: Characteristics of the four transfer schemes (HR: Historic Responsibility, PC: Equal-Per-Capita, PCC: Per-Capita-Convergence, OT: Optimal Transfers): a) Basic setting without adverse effects from exporting and b) with taking the climate rent curse into account

	No-transfer	HR	PC	PCC	OT
a)Without climate rent curse					
Avg.[a] total transfers received (Tr USD)[b]	-	0.76	0.37	0.14	0.02
Max. total transfer (Tr USD)[c]	-	6.23	1.84	0.61	0.08
Max.[a] transfer (percent of current GDP)	-	14.2	5.3	2.2	1.0
Internally stable coalitions:					
Number	54	16	24	36	481
Max. participation	4	3	3	3	6
Max. Abatement (percent of GC)[d]	17.0	9.4	9.4	16.2	31.4
Regions stabilized by transfer:[e]					
Number	-	2042	2718	2932	900
Avg.[a] total transfer received (Tr USD)[b]	-	0.86	0.48	0.19	0.02
Max.[a] transfer (percent of current GDP)	-	13.7	5.3	2.2	1.0
b)With climate rent curse, regions stabilized by transfer					
Destabilized regions, number:	-	2004	2690	2468	581
Remaining positive					
Vulnerable regions	-	34	12	26	3
Non-vulnerable regions	-	4	16	438	316

a Over whole ensemble

b Discounted sum of transfers over entire time horizon

c Discounted sum of transfers over entire time horizon, maximum of whole ensemble

d Percentage of abatement that the grand coalition comprising all regions would realize

e Participation in an agreement is encouraged by receiving a payment from another member

Transfers are able to encourage participation in the agreement. When some members gain from the joint abatement effort while others experience large mitigation costs and lose from cooperating, transfers can distribute the gains. We study the influence of four transfer schemes, three conventional mechanisms and one optimized for coalition stability:

1. Historic-Responsibility (HR): permits are handed out inversely proportional to the emission-population ratio of the regions in the starting year weighted with the current population (based on Altamirano-Cabrera and Finus, 2006).

2. Equal-Per-Capita (PC): permits are handed out proportional to the population (based on Altamirano-Cabrera and Finus, 2006).

3. Per-Capita-Convergence (PCC): starting with the permits being allocated by grandfathering in the first period, it gradually (with a weighted sum) converges to the equal-per-capita permit scheme; transition is completed after 50 years (based on Leimbach et al., 2010).

4. Optimal Transfers (OT): this transfer scheme achieves internal stability in MICA if feasible by transferring the gains of some regions to regions that do not have an incentive to participate in the agreement. The left-over surplus, free to be allocated inside the coalition, is equally shared among the members so as to leave everyone of them with a positive incentive to participate.

While the conventional transfer schemes (Historic-Responsibility, Equal-Per-Capita, Per-Capita-Convergence) are based on distributing the available amount of permits through an exogenously given rule, finding the optimal transfers requires an additional calculation. We follow the algorithm proposed in Kornek et al. (2014) and take the consumption paths over time of each member of a specific coalition and the welfare levels when each member leaves the coalition from the solutions of MICA. The algorithm allows consumption to be transferred between all members and maximizes the discounted sum of consumption goods that can be deducted from each member subject to the constraint that the welfare of all members is at least as high as their welfare when leaving the coalition. If the discounted consumption is positive, the transfers at the optimum achieve internal stability of the coalition and the positive surplus is distributed. Hence, the optimal transfers are calculated outside of MICA. For the analysis with the climate rent curse below, we assume that the OT-transfers stay at their level as calculated without any adverse effects taken into account. We hence do not analyze the first-best transfers in the presence of a curse, but only compare the performance of the different transfer schemes. It is an interesting future research topic to optimize transfers with respect to different objectives while taking the curse effects into account.

Turning to the results in MICA, we first look at the conventional transfer schemes, which are motivated by equity considerations and distribute the burden of abatement costs based on normative criteria. They address the incentives of developing regions to participate in the cooperative abatement effort. Table 3 displays the number of individual regions across all possible coalitions, for which the participation in an agreement is encouraged by receiving a transfer from another member: after the transfer, these regions are internally stable. Notably, 99.9 % (99.4 %, 84.8 %) of the regions stabilized by the conventional transfer schemes are developing regions in the case of Historic-Responsibility (Equal-Per-Capita, Per-Capita-Convergence).[14] The transfers are of quite significant magnitude: up to 14.2 % of current GDP are received, similar to transfers observed in the previous literature (see section 3.2). However, the burden on members that pay is too large and only few coalitions remain internally stable as a whole.[15]

[14] Developing regions are identified according to the list given by ISI (2012). A region in MICA counts as 'developing' if more than 50 % of its GDP is made up of developing countries.

[15] Looking at the timing of transfer payments as a share of GDP, conventional transfers schemes that encourage participation

The optimal transfer scheme (OT, see Carraro et al. 2006; McGinty 2007; Weikard 2009) avoids large transfers that reduce the incentive of paying regions to participate in the agreement.[16] Table 3 shows the average magnitude of transfers for all four burden sharing schemes: optimal transfers that induce internal stability of entire coalitions demand much less payments from members than conventional transfer schemes, in line with Lessmann et al. (2015). We find 481 coalitions in MICA that are internally stable under the optimal transfer scheme, among which the largest include six regions, see table 3. The maximum environmental effectiveness almost doubles compared to the internally stable coalitions in the no-transfer case.

While cooperation can be enhanced by transfers, either for developing regions under the conventional transfer schemes or for entire coalitions under the optimal transfer scheme, adverse effects caused by receiving revenues could alter this positive assessment of transfers. The effects of a climate rent curse on the incentive to participate are investigated next.

5.2 The Influence of the Climate Rent Curse

We start by characterizing the performance of transfers when the magnitude of adverse effects of a curse is at our highest value $\varphi = 9.43$. Regions, for which the transfer scheme would otherwise encourage cooperation, almost exclusively switch to a negative incentive to cooperate when taking the climate rent curse into account – for all four transfer schemes (see table 3). For Historic-Responsibility (Equal-Per-Capita, Per-Capita-Convergence, Optimal Transfers) out of 2038 (2702, 2494, 584) regions, which are vulnerable to the climate rent curse and receive transfers in order to cooperate, only 34 (12, 26, 3) still remain with a positive incentive to participate after taking the adverse effects on growth from transfers into account. For the optimal transfer scheme, only 30 affected coalitions remain internally stable under a climate rent curse.

To track the reasons for the almost exclusive negative effect in more detail, it is worthwhile to analyze in which way the climate rent curse affects the welfare of vulnerable regions. When economic output is negatively affected, regions have to change their expenditures on the options consumption, saving, mitigation costs, damage costs, and net exports (see equation (17) in the Appendix). Figure 1 displays the change in expenditures when the climate rent curse is introduced inside the grand coalition and with the Equal-Per-Capita-scheme in place: the discounted sum (over the entire time horizon) of the difference in each expenditure option as a share of GDP with a climate rent curse and without any adverse effects.

Each expenditure option is negatively influenced for regions affected by the climate rent curse, i.e. Africa (AFR), India (IND), Latin-America (LAM), and Other-Asian (OAS), which reflects the fact that

are on average especially high within the 21st century, with significant declines from 2050 on. The Historic-Responsibility and the Equal-Per-Capita scheme on average attain the highest value in the beginning of the time horizon, while the peak is in 2050 for the Per-Capita-Convergence scheme.

[16] The timing of the optimal transfer schemes that encourage participation varies, but as a trend for the average higher shares of GDP are attained in the the 22nd century.

production without the curse is, as expected, higher. Interestingly, the figure depicts that this change in production is over-proportionally transformed into a cut in consumption. The allocation in efficient saving is changing comparably less. Due to the dynamics of our model, losses in capital from decreases in production in one period can be compensated by international trade and paid for later. The interest rate, governing the savings decision, is determined by the production of all regions and is therefore only marginally affected by the decrease in total factor productivity of vulnerable regions. In consequence, saving decreases moderately for vulnerable regions, which in turn leads to less production in later periods and overall to sharp decreases in consumption.[17]

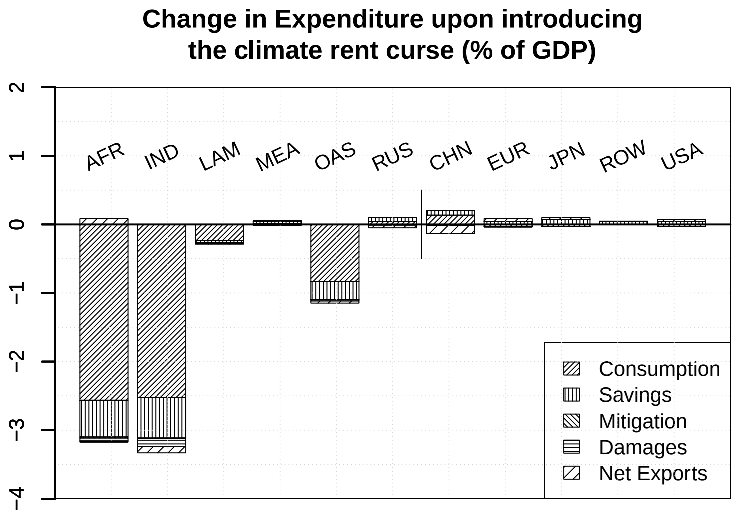

Figure 1: Discounted sum of difference in budget-decisions as a share of GDP when no adverse effects occur ($\varphi = 0$) to when the climate finance curse is taken into account ($\varphi = 9.43$) (entire time horizon), inside the grand coalition and with the Equal-Per-Capita-scheme implemented

While transfers are able to encourage participation and compensate for additional mitigation costs in the absence of adverse effects, we find that regions do not gain an incentive to participate through transfers when including the climate rent curse with a strength of $\varphi = 9.43$. Rather, decreased growth prospects induce an overall negative effect on climate coalition formation when receiving permit revenues.

5.3 Varying the Strength of the Climate Rent Curse

In this subsection we vary the strength of the resource curse. Our systematic reduction of the overall strength relative to the maximum curse strength ($\varphi = 9.43$) reflects the several points we have dis-

[17]The negative contribution from damages is due to the fact that without a climate rent curse, production in vulnerable regions is higher. This in turn leads to higher damages as these are proportional to the output, see equation (5).

cussed in sections 3 and 4 that justify different strengths of a climate rent curse: differences between natural resources and permits; country-specific strengths of the different channels; different econometric estimates of the strength of the curse; implementation of measures to mitigate adverse effects; non-benevolent governments. Reducing the strength, receiving transfers is more likely to encourage participation as growth is reduced to a lesser extent. Figure 2 shows this effect by displaying the percentage of times in which vulnerable regions were encouraged to participate through transfers and the climate rent curse destabilized at different strengths of $\varphi = (2, 4, 6, 8, 9.43)$. The points '$\varphi = 9.43$' represent the data from table 3.

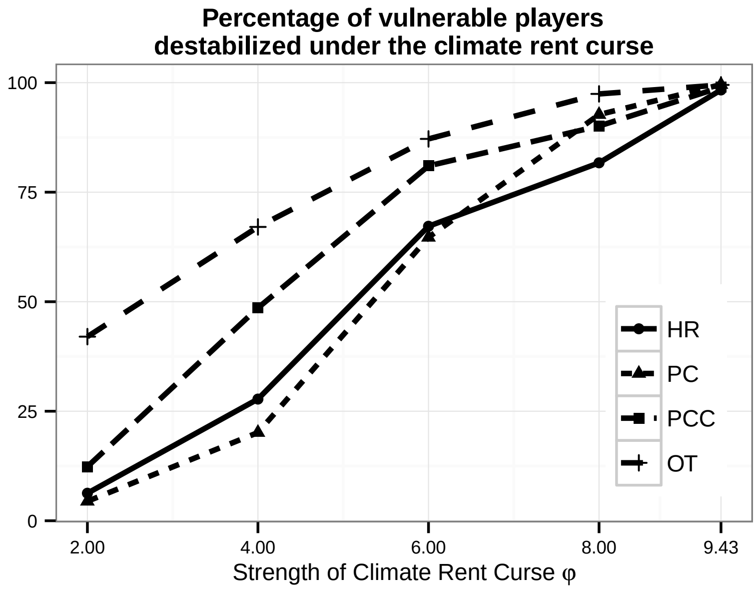

Figure 2: Percentage of affected regions encouraged to participate by the transfer scheme without any adverse effect and destabilized under different strengths of the climate rent curse (for φ see equation 1); transfer schemes HR: Historic Responsibility, PC: Equal-Per-Capita, PCC: Per-Capita-Convergence, OT: Optimal Transfers

For strengths of the curse $\varphi \geq 8$, over 75% of internally stabilized regions switch to a negative incentive to participate under a curse. For the three conventional transfers a negative outcome is more likely with larger magnitudes of the transfer in the beginning of the time horizon for $\varphi \geq 8$ (not shown). Due to the saving dynamics of MICA, if a transfer is received during the first period, it will not solely influence consumption in the beginning but also at later periods (see the discussion of figure 1). All conventional transfer schemes perform badly as they induce large transfers especially in the first century.
Lowering φ further, the negative effect of the curse on the incentive to participate is greatly reduced. Decreasing φ from 6 to 4 seems to induce the largest number of regions to change to a positive incentive to stay inside the agreement for the conventional transfer schemes. The timing of transfers is now less important. When φ decreases to a value of 4, the majority of vulnerable regions, which the conventional

transfer scheme encouraged to participate, remains with a positive incentive to stay inside the agreement even if the climate rent curse is taken into account.

For the optimal transfer scheme the number of regions destabilized remains high when reducing the strength φ. By design the OT-mechanism leaves the regions only with a slightly positive incentive to stay inside the coalition without a curse. Inducing only moderate negative effects can therefore reduce the value of the stability function to negative signs.[18] However, the number of internally stable coalitions increases greatly when the strength of the curse is reduced. Table 4 shows the maximum size and environmental effectiveness of internally stable coalitions that are affected by a climate rent curse in the form of reduced growth rates.[19] At a strength of $\varphi = 4$, 174 internally stable coalitions exist with the best performing one reaching an abatement of 23.9 % of the social optimum and with a maximum participation of 5 regions. Due to the greatly stabilizing characteristics of this transfer scheme, cooperation remains significantly enhanced for moderate strengths of the curse.

Table 4: Performance of internally stable coalitions under the optimal transfer scheme that are affected by the climate rent curse under varying strengths φ

φ	0	2	4	6	8	9
Nb. of internally stable coalitions	430	269	174	96	46	30
Max. abatement (percent of GC)[a]	31.4	26.6	23.9	21.7	17.0	17.0
Max. participation	6	6	5	5	4	4

a Percentage of abatement that the grand coalition comprising all regions would realize

Arguably the strength can also vary across regions, e.g. as a consequence of different regional levels of institutional quality. An exploratory analysis that looks into regionally-specific strengths of the curse can be found in Appendix B. The qualitative results presented so far do not change when taking this into account: for $\varphi > 8$ the climate rent curse destabilizes regions to a large extend while the severity decreases significantly when reducing the strength. We can hence conclude that our study provides an insight into the order of magnitude of adverse effects from transfers under climate policy. The parameter study suggests that the strength of the climate rent curse needs to be at approximately 4 in order for the transfers to largely preserve their intended effects. Especially the optimal transfer scheme performs well in terms of enhancing cooperation.

6 Discussion and Conclusion

To mitigate climate change internationally coordinated action at unprecedented scales would be required (Meinshausen et al., 2009; Kriegler et al., 2014). Developing countries play a central role for the joint mitigation effort as they would carry a significant burden of policy costs (Tavoni et al., 2013) and

[18] Additionally, as highlighted above, we do not find the optimal transfers with anticipation of the climate rent curse taken.

[19] The best performing internally stable coalition under the OT-scheme that is not affected by the curse achieves an abatement of 19.3 % of the social optimum.

may need compensation to encourage their participation. Luckily – one might think – the costs of mitigation are comparably low or even negative for developing countries if climate policy is enforced via a carbon market and an allocation scheme based on equity principles is applied (Luderer et al., 2012a). Revenues from exporting permits could therefore encourage the participation of countries in an international climate agreement. In this respect, transfers may be pivotal to enhance cooperation on climate change (Dellink, 2011).

In light of our analysis we conclude that climate rents induced by international carbon markets show characteristics comparable to resource rents that have been harmful for long-term economic growth in the past. Even though not totally congruent, all channels of the resource curse might be relevant for, and contribute to, a potential climate rent curse. Volatility of permit prices observed today is comparable to volatility observed on resource markets. Institutional quality in countries potentially receiving the climate rent based on ethical considerations is at present significantly lower than in countries that managed to absorb resource rents relatively well in the past, and rent-seeking can be expected to be high.

In how far an over-allocation with permits is a blessing or a curse for countries susceptible to this 'climate rent curse' is a trade-off between the revenues from permit sales and the adverse effects associated with it. Given our assumptions on how vulnerable economies are affected, and how severe the effect on growth is, our numerical experiments suggest that for a range of equitable, pragmatic and incentive compatible allocation schemes the influence of transfers is negative for large magnitudes of adverse effects that have been observed in the past.

As a consequence, based on our coalition model, we find the incentives to participate to decrease significantly when countries anticipate the climate rent curse. This of course assumes rational behavior of agents and – maybe more important – benevolent behavior of negotiators and governments whose explicitly damaging – i.e. rent seeking – behavior is a major driver of the curse. Therefore, in a climate negotiation game, countries that are identified to be vulnerable to a curse might nevertheless participate in a climate coalition. However, we interpret our results from a different angle. Reasonably expecting a climate rent curse, how should climate policy be designed to avoid negative effects on developing countries' long term growth prospects while ensuring significant mitigation of climate change?

Based on our analysis we can derive different answers to this question. When assuming a carbon market involving transfers to developing countries it is crucial to bring down the severity of the curse in those countries. Trying to neutralize particular channels of the resource curse might be a way to achieve this goal.

The quality of institutions seems to be a pivotal prerequisite to control rent-seeking and to provide the necessary quality of financial markets to control for volatility. As it can be assumed that institutional quality increases with economic development it may be reasonable to postpone transfers in time until developing countries have reached a particular level of institutional quality. In this respect the design of a carbon market can have an impact on the severity of the resource curse. Integrating a maximum number of heterogeneous countries in combination with a flexible design regarding the freedom in when to emit (e.g. by allowing for banking) can bring down price volatility significantly.

Choosing a different allocation scheme implying less trade, e.g. grand-fathering or optimal transfers, can be less problematic with respect to rent seeking, but is however difficult to justify from an equity perspective. This raises the general question whether developing countries can and should be integrated into an international carbon market or whether other instruments are preferable.

Observing that transfers have potentially damaging effects, a carbon tax regime might generally be preferable over a quantity instrument. Raising a carbon tax would give less room for rent seeking, reducing the influence of artificial scarcities (Nordhaus, 2007). Spending effects implied by Dutch-Disease can probably be avoided and volatility concerns raised in a carbon market can be eased. However, a carbon tax in developing countries implies that mitigation costs would need to be covered by themselves, which again raises questions of equity and justice and might even slow down poor countries' growth prospects (Jakob and Steckel, 2014).

It is also conceivable that transfers could be collected and managed internationally. For example, a fund could be used to provide necessary additional investments needed to finance low-carbon technologies (Jakob et al., 2015) or foster investments in infrastructure needed to avoid lock-ins (Mattauch et al., 2015). Also, revenues generated by an international carbon market could be used to buy down the costs of low carbon technologies.

In any case, simply integrating developing countries into a – Kyoto like – global carbon market and designing climate policy in a way that would leave them with extraordinary climate rents might corrupt their long term growth prospects. Transfers could fail to enhance international cooperation on climate change and might even hamper the success of negotiations.

A Institutional quality of selected countries

Table 5: Governance indicators in 2014 for countries that have not experienced negative growth effects from large resource inflows (top rows) and that have suffered from the resource curse in the past (bottom rows); Source: WorldBank (2016)

Country	Voice and Accountability	Political Stability/No Violence	Government Effectiveness	Regulatory Quality	Rule of Law	Control of Corruption
Indicators for institutional quality in countries that have avoided the natural resource curse						
Australia	1.37	1.08	1.59	1.87	1.93	1.87
Botswana	0.44	1.02	0.32	0.64	0.63	0.80
Canada	1.43	1.18	1.76	1.83	1.89	1.82
Netherlands	1.58	1.05	1.83	1.78	1.98	2.00
Norway	1.71	1.13	1.81	1.64	2.05	2.23
United States	1.05	0.62	1.46	1.27	1.62	1.32
Indicators for institutional quality in countries that have experienced the natural resource curse						
Angola	-1.14	-0.27	-1.15	-0.96	-1.10	-1.45
Dem Rep Congo	-1.31	-2.27	-1.59	-1.34	-1.43	-1.29
Nigeria	-0.65	-2.11	-1.19	-0.82	-1.08	-1.27
Venezuela	-1.07	-0.83	-1.23	-1.81	-1.89	-1.38
Yemen	-1.34	-2.53	-1.41	-0.84	-1.17	-1.55

B Analysis with regionally-specific strengths of the curse

In our main text, we assumed the same strength of adverse effects in all regions that are vulnerable to the curse (namely AFR, LAM, IND, MEA, OAS and RUS). We made this simple yet strong assumption to study the effects of curse strength in isolation, and to present our finding in the clearest way possible. This section presents an exploratory analysis with regionally-specific values for φ to check whether we are missing a critical aspect in our main results. We calculate a region specific average value for institutional quality based on the six indicators of Table 2 (first set of rows). The region with the lowest average value experiences the highest strength of the curse of $\varphi = 9.43$, while the value decreases linearly for the other vulnerable regions (see Table below). We do not assume the curse to apply ($\varphi = 0$)

if institutional quality on average is larger than zero (the World Development Indicators are normalized so that their average value is equal to zero). The analysis is therefore only indicative as our derivation of the regionally-specific strengths is crude because (i) taking the average of the indicators for institutional quality assumes that the strength of the curse is determined equally by all indicators, (ii) we leave out indicators for volatility of a country, (iii) assuming a linear decline is an ad-hoc approximation.
We apply the Equal-Per-Capita transfer scheme and calculate how often the curse discourages participation for each region (a region-specific analysis as in figure 2). The results are summarized in table 6. The table shows that the results we present in Figure 2 of the main part are to a large degree consistent with the data we derived with regionally-specific strengths: destabilization is high for large $\varphi = 9.43$ and decreases significantly as the strength decreases. In particular, we do not find any large interacting effects among regions.

Table 6: Percentage of affected regions encouraged to participate by the transfer scheme without any adverse effect and destabilized under regionally-specific strengths of the climate rent curse (for φ see equation 1) and with the Equal-Per-Capita transfer scheme in place

	AFR	MEA	RUS	OAS	IND	LAM
φ	9.43	8.70	6.92	5.40	3.06	2.48
Number of times the transfer scheme encouraged participation without the curse in all coalition structures	1018	132	9	906	16	621
Share when the presence of the curse destabilized (percent)	100.0	95.5	44.4	25.9	0.0	23.3

C Model Equations

In this section, we present the details of our numerical model. The model builds on Lessmann et al. (2009) and Lessmann and Edenhofer (2011) but uses eleven world regions as players, instead of nine symmetric players in cited studies. In the following, we first describe the model equations, their calibration, and the numerical procedure to solve the model.

Preferences

We model the world economy as a set of $N = 11$ regions (or players), see table 7. Players decide in an intertemporal setting which share of income to consume today and which share to save and invest for future consumption. Intertemporal welfare W_i and instantaneous utility function U based on per capita consumption are given by:

$$W_i = \int_0^\infty p_{it} U(c_{it}/p_{it}) e^{-\rho t} \, \mathrm{dt} \quad (2)$$

$$U(c_{it}/p_{it}) = \log(c_{it}/p_{it}). \quad (3)$$

Here, c_{it} and p_{it} denote consumption and population in region i at time t, respectively. Parameter ρ is the pure rate of time preference.

Table 7: Regions as defined in MICA and corresponding world regions

Model region	Countries
AFR	Sub-Saharan Africa w/o South Africa
CHN	China
EUR	EU27 countries
IND	India
JPN	Japan
LAM	All American countries but Canada and the US
MEA	North Africa, Middle Eastern and Arab Gulf Countries, Resource exporting countries of FSU, Pakistan
OAS	South East Asia, both Koreas, Mongolia, Nepal, Afghanistan
ROW	Non-EU27 European states w/o Russia, Australia, Canada, New Zealand and South Africa
RUS	Russia
USA	USA

Technology

The economic output y_{it} in each region is produced with a constant elasticity of substitution (CES) production technology F with share parameter γ and elasticity of substitution ρ_F. α_{it} is the total factor productivity. Climate change damages (defined below in Equation 16) destroy a fraction Ω_{it} of the production. Economic output is further reduced by abatement costs Λ_{it} (defined in equation 9). F is calibrated using the initial values of output, labor productivity, labor, and capital (y_{i0}, λ_{i0}, l_{i0}, and k_{i0}).

$$y_{it} = (1 - \Lambda_{it} - \Omega_{it}) F(l_{it}, k_{it}) \quad (4)$$

$$F(l_{it}, k_{it}) = \alpha_{it} y_{i0} \left[(1-\gamma) \left(\frac{\lambda_{it} l_{it}}{\lambda_{i0} l_{i0}} \right)^{\rho_F} + \gamma \left(\frac{k_{it}}{k_{i0}} \right)^{\rho_F} \right]^{(1/\rho_F)} \quad (5)$$

Labor l_{it} is given exogenously, as is labor productivity λ_{it}. Capital k_{it} accumulates with investments i_{it} and is depreciated at rate δ_i.

$$
\begin{aligned}
\frac{d}{dt}k_{it} &= i_{it} - \delta_i k_{it} && (6) \\
& && (7)
\end{aligned}
$$

Emissions and Emission Allowances

Greenhouse gas emissions e_{it} are a byproduct of economic activity y_{it}. We assume that the emission intensity σ_{it} falls exogenously due to technological progress: $\sigma_{it} = \sigma_0(i)\left[\cdot(1-\sigma_{min}(i))\exp^{v_1(i)\cdot t+v_2(i)\cdot t^2} + \sigma_{min}(i)\right]$. Beyond this, emissions may be reduced by abatement a_{it} at the cost of Λ_{it}, where the generic functional form is taken form Nordhaus and Yang (1996).

$$
\begin{aligned}
e_{it} &= y_{it}\,\sigma_{it}\,(1-a_{it}) && (8) \\
\Lambda_{it} &= b^1_{it}\cdot(a_{it})^{b^2_i} && (9)
\end{aligned}
$$

Emission allowances may be traded internationally (z_{it} denotes import or exports of allowances by region i), but we exclude intertemporal banking and borrowing of allowances, i.e. total imported and exported allowances must be balanced in every period, with initial allowances equal to q_{it}.

$$
\begin{aligned}
e_{it} &\leq q_{it} - z_{it} && (10) \\
\sum_j z_{jt} &= 0, \qquad \forall t && (11)
\end{aligned}
$$

Climate Dynamics

Global warming is driven by total global emissions of CO_2 into the atmosphere, which are equal to cumulative total emission allowances Q_t.

$$
\begin{aligned}
\frac{d}{dt}C_t &= \zeta Q_t - \kappa(C_t - C_0) + \psi E_t && (12) \\
\frac{d}{dt}E_t &= Q_t && (13) \\
Q_t &= \sum_i q_{it} && (14)
\end{aligned}
$$

Equation 12 translates global emissions into carbon concentration in the atmosphere C. Concentration C rises with global allowances (same as emissions), where ζ converts emissions into a change in concentration, and it decreases due to the carbon uptake of the oceans proportional (κ) to the increase above the pre-industrial level C_0. The final term limits the ocean carbon uptake (to the fraction $1-\psi/\zeta\kappa$ in equilibrium). For more details on the climate equations see Petschel-Held et al. (1999).

$$\frac{d}{dt}T_t = \mu \log(C_t/C_0) - \phi(T_t - T_0) \tag{15}$$

Equation 15 transforms concentration levels into a global mean atmospheric temperature increase T. Here, parameter μ controls the strength of the temperature reaction to a change in concentration, whereas parameter ϕ is related to its timing. Together, they have an interpretation as the "climate sensitivity" ($\mu/\phi \cdot \log 2$), i.e. the equilibrium temperature increase for a doubling of the concentration. In view of the inertia of the climate system, we run the model for 200 years in steps of 10 years.
The climate change damage function is taken from Dellink et al. (2004):

$$\Omega_{it} = \theta_{2i}(T_t)^2 \tag{16}$$

Two sets of "book keeping" equations complete the model: the budget constraints for consumption and investments for each region at every point in time, as well as the intertemporal budget constraint ensuring that over the entire time horizon, the import value must equal the export value in each region.

$$y_{it} + m_{it} = c_{it} + i_{it} + b_{it} + x_{it} \tag{17}$$

$$\int_0^\infty p_t\, m_{it}\, \mathrm{dt} = \int_0^\infty p_t\, x_{it} + p_t^z\, z_{it} \mathrm{dt} \tag{18}$$

Variables m_{it} and x_{it} are imports and exports of region i, respectively, and p_t and p_t^z are the prices of goods and allowances, respectively.

Algorithm to implement the curse

We calculate the unaffected growth rates $g_0(i,t)$ by extracting the the time-path of $GDP(i,t)$ as the sum of production $(1-\Lambda_{it})F(l_{it}, k_{it})$ and the revenues from permit trade $\pi(i,t)$. The average growth rate per economically active person over twenty years is then determined. The target growth rate $g^*(i,t)$ can be calculated according to equation (1). For time period t, we adjust the total factor productivity twenty years ahead $\alpha(i,t+20)$ to reduce $GDP(i,t+20)$ such that the growth rate drops to $g^*(i,t)$. The growth rates $g_0(i,t' > t)$ are updated to take this new value into account. We find that adjusting $\alpha(i,t)$ has only a small influence on the growth rate of the previous steps, and we can therefore apply this algorithm successively for all times t. The specified way implicitly assumes that the reduction in total factor productivity is not permanent but that countries recover from it fully within a decade after the revenue from resources vanishes. This view is optimistic and represents a lower bound to the negative effects of the climate rent curse.

For the optimal transfer scheme, the revenues $\pi(i,t)$ are given exogenously through the algorithm described in section 5.1. We do not change the transfers $\pi(i,t)$ from their calculation without the climate rent curse and add the transfers to the consumption paths of each region outside of the MICA-model in line with the algorithm proposed in Kornek et al. (2014).

Model Calibration

The focus of this model is on the incentive of regions to participate in the international abatement effort. For the calibration of the model, two aspects are therefore of primary importance: the costs of emissions reductions and associated benefits, i.e. foregone damages.

For an estimate of mitigation costs, we calibrate our model to a large scale integrated assessment model, REMIND-R (Leimbach et al., 2010). MICA and REMIND-R share some important features, resulting in similar economic dynamics: both are multi-region optimal growth models driven by the maximization of intertemporal utility, and both allow for intertemporal trade. Thus, when using the same initial values (k_{i0}, l_{i0}, y_{i0}), exogenous population scenario (l_{it}), and parameter values where possible (i.e. in the utility function: ρ, η, in the production function: γ, ρ_F, and in capital dynamics: δ_i), and calibrating the labor productivity (λ_{it}), the economic dynamics in absence of climate policy or climate change damages are in "good agreement." We measure this agreement by computing the coefficient of determination R^2 for y_{it}, and c_{it} over the first 10 decades. With rare exceptions, the resulting R^2 are large (columns 1-2 of Table 8). The exogenous decline in emission intensity σ_{it} was chosen by calibrating the parameters ($\sigma_0(i)$, $\sigma_{min}(i)$, $\nu_1(i)$, $\nu_2(i)$) such that emissions over the century coincide. Here we report remaining difference as the deviation of cumulative emissions over the first century, with values around 5 % in all regions (see column 4 in table 8).

The actual costs of reducing emission by a_{it} percent versus these baseline dynamics are defined by the cost function Λ (equation 9). We calibrate its parameters, b^1_{it} and b^2_i, to reproduce the abatement costs in REMIND-R, such that both models reduce emissions by the same amount over the century under the two carbon tax scenarios (high tax and low tax). For this, the b^1_{it} follow the generic equation ($b^1_{it} = b^0_i \cdot e^{\vartheta_i \cdot t} + b^{\inf}_i$), whose parameters ($b^0_i$, ϑ_i, $b^{\inf}_i$) are then found to best fit to the abatement of REMIND-R. The remaining difference is reported in columns 5-6 in table 8.

Information on climate change damages is available in the literature in form of damage functions. We use the damage function from Dellink et al. (2004), which we rescale to the spacial layout of our eleven regions (see (Nordhaus, 2002) for a discussion of spatial rescaling).

Solving the Model for the Game's Equilibrium

We are considering a two stage game of, first, *membership* in an international environmental agreement (IEA), and second, an *emission game* where players choose their emission allowances.

The game is solved numerically by backward induction, i.e. first we compute partial agreement Nash equilibria (PANE, cf. Chander and Tulkens 1995) for all possible coalitions, then we test these coalitions

Table 8: Remaining errors in the calibration of MICA. We measure the goodness-of-fit by the R^2 value, except for emissions where the difference in their cumulative amount over the century is reported.

	No climate damages			Tax Abatement	
Region	Product	Consumption	Emissions (%)	low tax	high tax
AFR	0.971	0.961	6.514	0.939	0.950
CHN	0.938	0.932	1.341	0.865	0.958
EUR	0.981	0.922	1.806	0.932	0.923
IND	0.998	0.957	1.723	0.954	0.973
JPN	0.988	0.852	-0.158	0.945	0.966
LAM	0.987	0.990	0.849	0.901	0.911
MEA	0.990	0.984	2.893	0.983	0.993
OAS	0.993	0.932	3.309	0.895	0.909
ROW	0.993	0.919	4.274	0.895	0.943
RUS	0.982	0.835	0.617	0.984	0.911
USA	0.991	0.954	2.341	0.980	0.992

for internal and external stability according to the following criteria:

$$W_i\big|_S \geq W_i\big|_{S\setminus\{i\}} \text{ for } i \in S \quad \text{(internal stability)} \tag{19}$$

$$W_j\big|_S > W_j\big|_{S\cup\{j\}} \text{ for } j \notin S \quad \text{(external stability)} \tag{20}$$

The computation of the PANE for the second stage is complicated by the fact that we are looking at an intertemporal optimization model featuring an environmental externality as well as international trade. To our knowledge, there are no out-of-the-box solvers available to solve such a model in primal form. Lessmann et al. (2009) suggest an iterative approach based on Negishi's approach (Negishi, 1972). For this study, we use a modified version of the iterative algorithm, which works as follows:

Negishi's approach searches for the social planner solution that corresponds to a competitive equilibrium by varying the weights ω_i in the joint welfare maximization:[20]

$$\max_{\{i_{jt},a_{jt},m_{jt},x_{jt},z_{jt}\ :\ j=1\ldots N\}} \sum_{i=1}^{N} \omega_i W_i \tag{21}$$

$$\text{subject to Equations 2–17} \tag{22}$$

Since this exploits the fundamental theorems of welfare economics, the approach cannot be applied for an economy with externalities. In principle, this problem is circumvented by making any external effect on other players exogenous to model (turning variables into parameters that are adjusted in an iteration).

[20]Note that the intertemporal budget constraint Equation (18), which contains the (*a priori* unknown) market clearing prices is omitted from the model.

Here, the externalities are climate change damages through aggregate global emissions. In Nash equilibrium, players will only anticipate the effect that their emissions have on their own economic output, not the effect onto other players' output. We can mimic this in a social planner solution by giving each player his own perception of the causal link between emissions and global warming. Instead of Equation (12), which describes one trajectory of concentration C_t, we introduce N equations for C_{it}:

$$\frac{d}{dt}C_{it} = \zeta\left(q_{it} + \sum_{j\neq i}\overline{q_{jt}}\right) - \kappa(C_t - C_0) + \psi E_t \qquad \forall_{i\notin S} \tag{23}$$

$$\frac{d}{dt}C_{it} = \zeta\left(\sum_{k\in S} q_{kt} + \sum_{j\notin S}\overline{q_{jt}}\right) - \kappa(C_t - C_0) + \psi E_t \qquad \forall_{i\in S} \tag{24}$$

Here, the allowance choices of other players enter as a fixed value (a parameter, indicated by the bar), set to the levels of the corresponding variables during the previous iteration (or some initial value). The sum of allowances in Equation (13) needs to be adjusted analogously, and the temperature Equation (15) will consequently have N instances for T_{it}, too. The temperature change T_{it}, anticipated by player i, will then enter in Equation (16) instead of T_t.

The thusly modified model is then solved in a nested iteration: In the inner iteration we solve the model for a given vector $\overline{q} = (\overline{q_{it}})$ of allowance choices repeatedly, updating $\overline{q_{it}} = q_{it}$ at the end of each iteration, i.e. we perform a fixed point iteration of the mapping $q = G(q)$ where G is the best response of players to the exogenously given strategy $\overline{q_{it}}$ of the other players. If the inner iteration converges, it converges to a Nash equilibrium in allowance choices. However, the international markets for allowances and private goods may not be a competitive equilibrium. This is what the outer iteration achieves.

The outer iteration follows the standard Negishi approach: we adjust the welfare weights ω_i in the joint welfare function (Equation 21) until the intertemporal budget constraint (Equation 18) is satisfied. The resulting equilibrium is the desired PANE.

Numerical Verification of the Equilibrium

We verify the resulting candidate PANE equilibrium strategies in emissions and trade numerically by comparing them to the results of the following maximization problems:

$$\begin{aligned} &\forall_i \max_{\{i_{it}, a_{it}, m_{it}, x_{it}, z_{it}\}} W_i \\ &\text{subject to Equations 2–18 and prices } \; p_t, p_t^z \end{aligned} \tag{25}$$

Deviations of this model from our solution should be within the order of magnitude of numerical accuracy only, which is what we find (not shown). In particular, simultaneous clearance of all international markets confirms the competitive equilibrium in international trade.

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