Climate change: who will take the heat

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Abstract

Climate change policies can regulate greenhouse gases (GHG) at a variety of points in the product cycle of fossil fuels: from fossil fuel suppliers based on the carbon content of extracted fossil resource to final emitters at the point of energy generation. This paper develops a general equilibrium model with trade between fossil resource abundant countries and capital abundant countries to show that the distributional impacts of a climate policy differ depending on where emission rights are allocated along the GHG supply chain. The allocation of rights among different entities along this supply chain impacts both factor prices and each country's endowments, hence it impacts the trade equilibrium. We provide an illustration of the distributional impacts of climate policy in the FPE equilibrium by comparing four allocation rules that are based on grandfathering or on equity concerns.

Keywords: upstream vs downstream, climate policy, fossil resource, grandfathering
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1. Introduction

According to the Stern review (Stern, 2007), to stabilize world climate, the amount of carbon dioxide equivalent (CO2e) by volume in the earth's atmosphere should not exceed 550 parts per million (ppm).[1] This corresponds to cuts in global emissions flows of at least 30%, and most likely, closer to 50% by 2050. Since carbon emissions result from the use of fossil resource (oil, gas and coal), emission cuts must lead to a reduction in the amount of fossil resource extracted. Most emissions trading programs implicitly assume that a cap on emissions is equivalent to a cap in fossil fuels extraction. However, fossil resource endowments are not evenly distributed, and allocating emission rights along the GHG supply chain may have implications for the international incidence of the economic burden of a given climate policy.

This paper uses an international trade lens to focus on the distributional implications of a global climate agreement. The model represents a world economy comprised of two countries or regions: North is capital abundant and South is fossil resource abundant. Each country can produce a non-traded intermediate product, electricity, which requires fossil resource and capital, and a manufacturing good whose production requires energy and capital.[2] Greenhouse gas emissions arise when producers burn fossil fuels for energy generation. Countries trade in both the industrial good and in the fossil resource.

The paper shows that South will likely suffer and North will likely benefit from a global climate policy that regulates GHG emissions, whereas South can benefit from a global climate policy that regulates fossil resource supply. In fact, we compare a regulation that imposes a cap on fossil resource extraction whereby allocating extraction rights to resource suppliers with a regulation that imposes a cap on the burning of fossil resource whereby allocating emissions rights to electric facilities. This dichotomy can also be referred to as 'upstream' versus 'downstream' regulation (Bushnell & Mansur, 2011), where regulation targets either the polluting input or the emissions related to its consumption.[3] The reason why allocating rights along the GHG

[1]Concentrations are currently around 430ppm CO2e, and are rising at around 2.5ppm CO2e per annum (Stern, 2007).

[2]A majority of the emissions in developed countries occur in non-traded sectors, such as electricity, transportation, and residential buildings (Aldy & Stavins, 2011).

[3]Bushnell & Mansur (2011) compares the cost-effectiveness of upstream versus down-

supply chain induces different impacts is that the climate policy affects the relative factor price and each country's resource endowments. By reducing the aggregate fossil supply, the climate policy raises the price of the fossil resource while lowering the price of capital, which can benefit the fossil suppliers as long as their resource endowment does not decrease dramatically. The tradable permit system also creates a new asset, emission permits, and by doing so, it induces excess supply on the fossil resource market, which transfers wealth away from fossil suppliers toward electric utilities.

To illustrate how distributional impacts vary with the allocation rule, we compare four rules that partially rest on the grandfathering approach where precedence endows rights. The first rule allocates extraction rights in proportion to historical resource endowment.[4] By reducing fossil resource endowment evenly across countries, this rule provides an interesting benchmark because the relative income loss is the same across countries. The second rule allocates emission cuts in proportion to prior income, which leads to a heavier economic burden on North compared to South. Assuming that North is richer than South, equity recommends imposing a heavier burden on North. The third rule thus imposes all emission cuts onto North, with a similar logic to the Kyoto Protocol. Finally, the fourth rule allocates emissions rights to electric facilities in proportion to their prior use of the fossil resource. Northern use of fossil resource might be larger than Southern use because trade in the fossil resource may cancel out the initial difference in fossil resource endowment. We use a numerical example to illustrate the impacts of the four allocation rules on fossil resource suppliers, on capital owners and on consumers within each country.

Much of the climate change literature has a welfare economics emphasis, evaluating alternative regulation and incentives to alter the behavior of economic agents that produce greenhouse gas (GHG) emissions (Nordhaus & Yang, 1996). We owe a large intellectual debt to Copeland & Taylor (2005) who presented a trade theory view of the Kyoto Protocol. They showed that

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stream regulation in a partial equilibrium framework where firms can reduce their emissions either by using less polluting inputs or by using an end-of-pipe technology. The authors emphasize differences in terms of transaction costs, leakage and offsets.

[4] Similarly, "historic catch" is an important criterion for distributing quotas in international fisheries management (Ringius et al., 2002), or in allocating water rights (Schoengold & Zilberman, 2007). Within OPEC, "historic production volume" serves a similar function (Gault et al., 1999).

unilateral emission reduction in the rich North can lead to self-interested emission reduction in the unconstrained poor South, and that a wide-range of treaty-imposed emission reduction rules (such as uniform reductions across countries) can be efficient when there is trade in goods. We relax the assumptions that pollution is an input in elastic supply (Copeland & Taylor, 2003) and that the supply of pollution depends on each country's environmental policy. Rather, emissions are generated by the use of fossil resource, and the climate policy affects the distribution of fossil endowments across countries. The decomposition of the world into net fossil resource importers and net fossil resource exporters can be found in Strand (2011) who argues that fossil fuel importers prefer to use a carbon tax instead of a cap-and-trade regime because the tax extracts more rents and lowers the price of offsets. In contrast to that dynamic partial equilibrium analysis, our model reflects the general equilibrium effect of the climate policy on factor prices and on economic sectors in each country, and it emphasizes the distributional issues of the climate policy across countries in a static framework. Our model can also shed some light on the distributional consequences of a U.S. cap-and-trade program between "low carbon" states and "coal abundant" states. Cragg & Kahn (2009) emphasize an endowment effect in the U.S., that is, the highest carbon emissions per capita are observed in regions that depend on coal for their electric generation; and those regions are mostly poor, rural and conservative, hence they are voting against any carbon policy. Our model suggests that the coal abundant states may suffer the most under specific climate policies.

The paper is organized as follows. Section 2 presents the economic structure of the model, and section 3 the trade equilibrium under laissez-faire. Section 4 compares the distributional impacts of a downstream and an upstream regulations. Section 5 provides concluding remarks.

2. The model

Consider a world economy consisting of two regions, North and South, both of which are endowed with capital and fossil resource.[5] We index by

[5]Because there are no scale economies (with the assumption of perfect competition) and because strategic trade behaviors that influence the terms of trade are ruled out, one could interpret a country as a large region comprised of many similar small countries.

"*" the variables corresponding to South.[6] Following the Heckscher-Ohlin-Samuelson (HOS) framework, North and South differ in their relative factor endowments. Denote by $\overline{K}$ (resp. $\overline{K}^*$) and $\overline{R}$ (resp. $\overline{R}^*$) Northern (resp. Southern) endowments in capital and in fossil resource. The fossil resource may be crude oil, natural gas or coal. We assume that the resource endowment is given and extraction is costless. North is capital abundant while South is resource abundant, and their national endowments are sufficiently similar (to avoid complete specialization in trade):

Assumption 1. $\overline{R}/\overline{R}^* < \overline{K}/\overline{K}^*$.

The capital abundant North can reflect the situation of developed countries, whereas South corresponds to developing countries which are abundant in fossil resource (e.g., Middle Eastern countries and Russia). Assuming a constant stock of fossil resource implies that the analysis is only relevant for the near future where major fossil resource suppliers can sustain a constant level of production. Dynamic issues that would require the modeling of the dynamic extraction of fossil resource are thus abstracted from.

Each economy is composed of two sectors: energy production (E) and manufacturing (Y). Only the energy sector uses fossil resource (R) as an input. The burning of fossil fuels generates greenhouse gas (GHG) emissions that drive anthropogenic climate change.[7] Both sectors use capital (K) as an input, and the manufacturing sector substitutes capital for energy. Energy is thus an intermediary good as in Vanek (1963). We build on the evidence of high transportation costs for electricity to assume that energy is a non-traded good in our model. However, fossil resource can be traded internationally.

More specifically, the energy sector uses capital, K_E, and fossil resource, R_E, which are both necessary factors. The production function of electricity is given by

$$E = R_E^{\alpha} K_E^{1-\alpha}. \tag{1}$$

The parameter $0 < \alpha < 1$ indexes the fossil resource use. The burning of fossil resource R_E generates $Z = Z(R_E)$ units of GHG emissions, with $Z' > 0$. GHG emissions harm all consumers, whatever their location, but there is no

[6] Most of the computations are made for North but are valid for South unless otherwise indicated.

[7] The primary source of the increased atmospheric concentration of carbon dioxide since the preindustrial period are fossil fuels (Solomon et al., 2007).

cross-sectoral externality. As pollution is transboundary, consumers' utility is affected by world pollution, Z^w, the sum of Northern and Southern emissions: $Z^w = Z + Z^*$. The energy product, e.g. electricity, is both an intermediate product that enters into the production process of manufacturing and a final good directly consumed by consumers.

The manufacturing sector Y requires capital K_Y and electricity E_Y as inputs. Assuming constant returns to scale, the industrial production function is given by

$$Y = K_Y^{1-\mu} E_Y^{\mu}. \tag{2}$$

where $0 < \mu < 1$ indexes the use of energy.[8] Given the vertical structure of production (electricity being an input in the industrial sector), manufacturing is more capital intensive than energy generation. We assume that the use of energy for manufacturing production does not emit additional GHG. Emissions are embodied in industrial products because their production requires electricity and producing electricity requires the burning of fossil fuels.

Denote by r (resp. r^*) and s (resp. s^*) the national prices of capital and fossil resource. In perfect competition, electric facilities and industrial producers make no profit at equilibrium. Given constant returns to scale, the total cost of the representative firm in the electricity sector is given by

$$CT(E) \equiv \min_{R_E, K_E} \left\{ sR_E + rK_E : E = R_E^{\alpha} K_E^{1-\alpha} \right\},$$

which corresponds to the following unit-cost function

$$c_E(r, s) = \kappa_E s^{\alpha} r^{1-\alpha}, \tag{3}$$

where $\kappa_E \equiv \alpha^{-\alpha}(1-\alpha)^{\alpha-1}$ is an industry-specific constant parameter. Denoting by p_E the market price of energy, the production cost divides among the inputs following the Euler's rule, i.e. we have:

$$sR_E = \alpha p_E E \tag{4a}$$
$$rK_E = (1-\alpha) p_E E. \tag{4b}$$

[8]Our results can be extended to a framework that includes a continuum of industries with varying energy intensity (Dornbusch et al., 1977). Free trade in both the fossil resource and industrial goods induce the Factor Price Equalization equilibrium and trade patterns similar to this version.

Similarly, the unit-cost function for manufacturing production is:

$$c_Y(r, p_E) = \kappa_Y r^{1-\mu} p_E^{\mu}, \tag{5}$$

where $\kappa_Y \equiv \mu^{-\mu}[1-\mu]^{\mu-1}$ is also an industry-specific constant parameter. Assuming that the market equilibrium price of manufacturing is the numeraire, the production cost divides among the inputs following the Euler's rule so that

$$p_E E_Y = \mu Y \tag{6a}$$
$$r K_Y = (1-\mu)Y. \tag{6b}$$

Assume consumers' preferences are homothetic and identical across countries. The representative consumer derives positive utility from consumption and suffers from global pollution, Z^w. Even though our results can be generalized to homothetic utility functions, we adopt the following consumer's utility function for analytical convenience:[9]

$$U = b_Y \ln D_Y + b_E \ln D_E - D(Z^w), \tag{7}$$

where D_Y and D_E denote the quantities of manufacturing goods and electricity consumed by the representative consumer, and b_Y and b_E are the corresponding shares of income spent in manufacturing goods and electricity, with $b_Y + b_E = 1$. The damage function $D(.)$ is increasing in the worldwide level of GHG emissions Z^w and it can be either linear or convex. The representative consumer takes her disposable income I as given and maximizes her utility U subject to the budget constraint $D_Y + p_E D_E \leq I$. At equilibrium the consumer's demands satisfy $D_Y = b_Y I$ for manufacturing and $D_E = b_E I/p_E$ for electricity. Hence, expenses must not exceed the national income, which is given by: $I \equiv r\overline{K} + s\overline{R}$, where

$$\overline{K} = K_E + K_Y, \tag{8}$$

because full employment of capital must be achieved at equilibrium. Because energy is a non-traded good, the following market clearing condition is always satisfied whatever the degree of trade openness:

$$E = E_Y + D_E. \tag{9}$$

[9]This analytic form is commonly used in the literature on trade and the environment (Copeland & Taylor, 1995).

Countries can potentially trade in fossil resource as well as in industrial goods in our framework. Hence, the full employment constraint for fossil resource would hold at the national level in autarky and at the worldwide level in trade.

3. Trade equilibrium under laissez-faire

In the absence of climate policy, countries trade according to their comparative advantage, and all factors are fully employed. See Appendix A.1 for the condition on comparative advantages. We find that the autarky relative factor price in North is higher than the autarky price in South if and only if $\overline{K}/\overline{R} > \overline{K}^*/\overline{R}^*$. Given assumption (1), the capital abundant country has a comparative advantage in producing the goods that are more capital intensive whereas the fossil resource abundant country has a comparative advantage in producing the goods that are more resource intensive. Whereas electricity is non-traded, both the fossil resource and manufacturing goods can be exchanged internationally. South can thus export fossil resource directly whereas North exports manufacturing products. Trade liberalization implies that all traded commodity prices equalize across countries, which gives the following conditions:

$$s = s^* \tag{10}$$

$$p_E^{\mu} r^{1-\mu} = p_E^{*\mu} r^{*1-\mu}. \tag{11}$$

Given that p_E is a combination of r and s, we obtain the classical result that factor prices equalize in trade. Even though electricity is non-traded, its price also equalizes across countries. Since the manufacturing good Y is the numeraire, we obtain

$$s = \left[\kappa_Y \kappa_E^{\mu} r^{1-\alpha\mu}\right]^{\frac{-1}{\alpha\mu}}. \tag{12}$$

The price of the resource is inversely proportional to the price of capital.

In a diversified trade equilibrium, Northern and Southern consumers demand manufacturing goods such that $Y + Y^* = b_Y[I + I^*]$ and electricity such that

$$p_E(E + E^*) = b_E(I + I^*) + \mu b_Y[I + I^*] = [1 - b_Y(1 - \mu)](I + I^*). \tag{13}$$

The full employment constraint for the fossil resource holds at the worldwide level:

$$R_E + R_E^* \leq \overline{R} + \overline{R}^*. \tag{14}$$

Using (4a), (4b), (6a), (6b), and (13) gives the relative factor price at the trade equilibrium

$$\frac{r}{s} = \frac{1 - \alpha[1 - b_Y(1-\mu)]}{\alpha[1 - b_Y(1-\mu)]} \frac{\overline{R} + \overline{R}^*}{\overline{K} + \overline{K}^*} \equiv \omega. \tag{15}$$

As shown in the appendix,

Lemma 1. *Under the FPE equilibrium where North and South trade in both industrial goods and fossil resource, North produces all manufacturing goods whereas South is a net fossil resource exporter that only produces electricity to meet its domestic final demand.*

Proof: see the appendix.

Trade in the fossil resource implies that fossil resource extraction is a third sector in each economy. The production cost of this extractive industry is zero because we assume no extraction cost. Given that electricity is non-traded, both North and South produce electricity, at least to meet their domestic final demand. North also produces all manufacturing goods whereas South is a net exporter of fossil resource. Hence, South represents the oil exporting countries in our model.

4. Sharing the burden of climate change policy

Abstracting from coordination failures, large damages from the burning of the fossil resource could be internalized through a global climate change policy. Then it will be no longer optimal to fully employ the worldwide fossil resource endowment. A global climate policy thus translates into making some assets being idle. A key feature of such a policy is thus how to share the burden among countries. An upstream regulation that distributes rights of extraction among fossil suppliers makes the burden sharing salient, whereas a downstream regulation that distributes rights of emissions transfers asset values from fossil suppliers to electric utilities. These alternative regulations have important implications for the international incidence of the economic burden of a given climate policy.

Assume a maximum level of fossil resource extraction $\widetilde{R}^w$ that would allow the climate to stabilize, and the aggregate reduction in GHG emissions is determined by $\overline{R}+\overline{R}^*-\widetilde{R}^w > 0$.[10] Holding constant the environmental benefit (same reduction in emissions), we compare the impacts on revenues and prices of a global climate policy that allocates either extraction rights to resource owners or emission rights to emitters. The climate policy translates either into a constraint on each country's factor endowments or into a constraint on the use of fossil resource. Let $\widetilde{R}$ denote the extraction quota allocated to Home and $\widetilde{R}^*$ the quota allocated to Foreign, with $\widetilde{R}^w = \widetilde{R} + \widetilde{R}^*$. Similarly, let $\widetilde{R}_E$ denote the tradable emission permits allocated to Home and $\widetilde{R}^*_E$ the permits allocated to Foreign, with $\widetilde{R}^w = \widetilde{R}_E + \widetilde{R}^*_E$. The tradable permit system leads to a single price of pollution, and nations are not required to meet their emission reduction obligations entirely within their borders with emission trading. We assume that under any allocation rule,

Assumption 2. $\overline{R} + \overline{R}^* > \widetilde{R}^w > \max\{\widetilde{R}, \widetilde{R}^*, \widetilde{R}_E, \widetilde{R}^*_E\}$.

This assumption allows both countries to have some fossil resource being extracted or some emission permits under the climate policy. One country cannot receive all extraction quotas or all emission permits.

4.1. Comparing upstream vs downstream regulations

We have three main results that stem from comparing the redistributive impacts of an extraction rights regulation with a tradable permit system.

First, the tradable emission permit system imposes a heavy burden on fossil resource suppliers. In our model, only electric utilities are responsible for emissions when they burn fossil fuels for electricity generation. Then each government can decide whether it allocates the permits to electric utilities free of charge or whether it puts the permits up for auction.[11] Let $\tilde{s}$ and $\tilde{s}^*$ denote the (auction) price of the permits in each country. Given that permits can be exchanged on international markets, we have $\tilde{s} = \tilde{s}^*$ at the equilibrium. Because the climate policy aims at reducing the use of fossil

[10] $\widetilde{R}^w$ can result from the maximization of the global social welfare or from a scientific consensus on a level of carbon dioxide concentration that would limit the risk of a catastrophic outcome.

[11] Whether the emission permits are allocated for free to electric utilities or whether each government put the permits up for auction, the difference is that the value of the permits is captured either by the utilities or by the government. The national income of each country is, however, the same in both cases. In most cases today, firms receive permits free of charge (Muller et al., 2011).

resource in the energy sector, utility companies demand $\widetilde{R}^w$ in equilibrium but fossil resource suppliers can supply up to $\overline{R} + \overline{R}^*$. Allocating emissions rights results in excess supply on the resource market, hence

Proposition 1. *Fossil resource suppliers lose all their rents under the tradable permit system because the price of the resource approaches zero (i.e., the marginal cost of extraction) when the climate policy allocates rights to emitters and reduces the aggregate use of the fossil resource to* $\widetilde{R}^w < \overline{R} + \overline{R}^*$.

This result rests on the discrepancy between the limited demand for fossil resource and the unconstrained supply of the resource. In our static model, the resource can be supplied up to its aggregate endowment but climate policy reduces the consumption of the resource. Proposition 1 states that the tradable emission permit system expropriates the fossil resource owners. Hence, it imposes a heavy burden on South which is a net resource exporting country. This suggests that net fossil resource exporters (e.g., Saudi Arabia or Western coal abundant states in the U.S. such as Montana) are likely to reject any global climate policy that allocates emission permits. Compensating them from the loss in their asset values might be necessary to reach an international agreement on climate change.

Second, an upstream regulation could by contrast benefit to fossil resource suppliers. Introducing an extraction right regulation implies a change in factor endowments and a change in the trade equilibrium, namely, in the relative factor and commodity prices. In fact, substituting $\widetilde{R}$ and $\widetilde{R}^*$ for $\bar{R}$ and $\bar{R}^*$ into (15) gives the new relative factor price. Hence, we can define $r/s \equiv \omega(\widetilde{R}^w)$, where $\omega'(\widetilde{R}^w) > 0$. The climate policy imposes a reduction in the aggregate resource endowment to stabilize the climate, it thus reduces the relative factor price r/s. Using (12) implies that the fossil resource price change is inversely proportional to the capital price change. The climate policy induces a decrease in r and an increase in s. The latter could benefit the fossil suppliers if it outweighs the reduction in their fossil resource endowment. Assuming an infinitely small reduction in the aggregate fossil resource, the impacts of the climate policy on Southern income can be approximated by

$$\frac{dI^*}{d\widetilde{R}^w} = \frac{dr}{d\widetilde{R}^w}\overline{K}^* + \frac{ds}{d\widetilde{R}^w}\overline{R}^* + s\frac{d\overline{R}^*}{d\widetilde{R}^w}. \tag{16}$$

The distributional impacts of the climate policy has two components: first the third term in the RHS of (16) corresponds to the endowment effect, which is the impact of a decrease in the national resource endowment holding factor prices constant; second the first two terms in the RHS of (16) correspond to the scarcity effect, which arises from the change in factor prices induced by the decrease in the aggregate resource endowment. South being abundant in the resource, we expect that the scarcity effect that affects its income is positive since the relative price of its abundant factor increases.

Proposition 2. *South benefits from an extraction rights regulation if the scarcity effect outweighs the endowment effect, i.e., if and only if*

$$d\overline{R}^*/d\widetilde{R}^w \leq \omega'(\widetilde{R}^w)[-\alpha\mu\overline{K}^* + (1-\alpha\mu)\overline{R}^*/\omega(\widetilde{R}^w)].$$

Proof: see the appendix.

The changes in factor prices affect all economic agents' revenues. Capital owners suffer from a loss in their asset values holding their stock of capital constant. By contrast, fossil resource suppliers could benefit from an increase in the price of the resource if the latter outweighs the loss in endowment. At the aggregate level, South can benefit from the extraction rights regulation if the reduction in fossil endowment is lower than the threshold given in proposition 2.

Northern income is affected by the extraction rights regulation likewise to (16). The scarcity effect arises from the change in factor prices while the endowment effect corresponds to the reduction in Northern fossil endowment. Because North is capital abundant, its scarcity effect rests more on the decrease in the returns on capital than on the increase in the resource price. As shown in Appendix A.3, the scarcity effect is negative if and only if

$$(1-\alpha\mu)\overline{R}/\alpha\mu\overline{K} < \omega(\widetilde{R}^w), \tag{17}$$

where the LHS is similar to Northern autarky relative factor price for $b_Y = 1$. Trade increases the relative factor price r/s in North, which implies that condition (17) can hold for a high r/s in trade despite the counteracting influence of the climate policy. If the scarcity effect is negative, Northern income is reduced by the climate policy whatever the reduction in fossil resource endowment. If the scarcity effect is positive, the same condition as in proposition 2 holds for Northern income to increase, but North being capital abundant makes it unlikely. Hence, North is more likely to lose from the extraction rights regulation than South.

Third, North could benefit from a tradable permit system. Under a downstream regulation, proposition 1 states that the fossil resource suppliers lose all their asset values because the price of the resource approaches zero. Electricity generation now requires three inputs: capital, fossil resource and emission permits. Under the zero-profit condition in the energy sector, the revenue from output is thus distributed among capital and emission permits at equilibrium. Given $\tilde{s} = \tilde{s}^*$ and (11), trade in industrial goods and in emission permits leads to the FPE equilibrium. At equilibrium, the price of the fossil resource under the extraction rights regulation is the same as the price of emission permits: $s = \tilde{s}$. This result arises from the environmental target being identical under both types of regulation: $\widetilde{R}^w = \widetilde{R} + \widetilde{R}^* = \widetilde{R}_E + \widetilde{R}_E^*$. The difference between upstream and downstream regulations rests in who receives the asset value associated to s. Under the extraction rights regulation, fossil resource suppliers sell their assets at price s whereas under the tradable permit system, electric utilities buy and sell emission permits at price s where permits are either freely allocated or auctioned initially. Hence, the impacts of the downstream regulation are similar to the scarcity and endowment effects that appear in the context of the extraction rights regulation, except that fossil endowments are replaced by emission permits quota. In the tradable permit system, assumption 1 on factor abundance difference becomes irrelevant because the value of the stock of fossil resource is zero. Rather, the allocation of emission permits across countries will determine national incomes and the patterns of trade. The comparative advantages are now determined by the relative abundance in capital and in emissions permits in each country.

Lemma 2. *The tradable permit system can reverse the comparative advantages of each region if and only if* $\overline{R}/\overline{R}^* < \overline{K}/\overline{K}^* < \widetilde{R}_E/\widetilde{R}_E^*$.

Given that North is capital abundant in laissez-faire, the downstream regulation that leads to a reversal in comparative advantages must allocate much more emission permits to North than to South. Northern emission quota could even be larger than its fossil resource endowment, which would lead to a positive endowment effect. Hence,

Proposition 3. *North benefits from the tradable emission permit system if and only if*

i/ the sum of the endowment and scarcity effects is positive when comparative advantages remain the same as in laissez-faire: $-d\overline{R}/d\widetilde{R}^w +$

$\omega'(\widetilde{R}^w)[-\alpha\mu\overline{K} + (1-\alpha\mu)\overline{R}/\omega(\widetilde{R}^w)] \geq 0$;

ii/ or comparative advantages are reversed.

The proof can be derived from Appendix A.3 for North. If comparative advantages remain the same as in laissez-faire, the scarcity effect is likely to be negative in North given (17), which would require that the endowment effect is positive for Northern income to increase. When comparative advantages are reversed, North becomes emission permit abundant while keeping its large stock of capital. It implies structural changes that cannot be approximated by derivation. Because the reversal in comparative advantages might require a strong positive endowment effect in North, and because the scarcity effect becomes positive if North is emission permit abundant, North will benefit from the climate policy.

Finally, the aggregate climate policy burden is the same under the upstream and downstream regulations. The aggregate income loss is given by

$$\frac{d(I+I^*)}{d\widetilde{R}^w} = \frac{dr}{d\widetilde{R}^w}(\overline{K}+\overline{K}^*) + \frac{ds}{d\widetilde{R}^w}(\overline{R}+\overline{R}^*) + s\frac{d(\overline{R}+\overline{R}^*)}{d\widetilde{R}^w}.$$

As in the Heckscher-Ohlin-Samuelson framework, changing the allocation of factors across countries does not modify the relative factor price (15), which only depends on aggregate endowments. Because the relative factor price is the same under the upstream and downstream regulations and because the environmental target is also the same, one regulation is not more cost efficient than the other. However, the two regulations differ in their distributional impacts and allocates bargaining powers differently to North and South. Propositions 1 and 3 state that South will likely suffer and North will likely benefit from the tradable permit system. By contrast, proposition 2 states that South can benefit from an extraction rights regulation. If reaching an agreement among Northern and Southern countries require monetary transfers to mitigate the adverse impacts of the climate policy, our results imply that transfers from North to South would be necessary under the tradable permit system whereas transfers from South to North could be implemented under the upstream regulation.

Changing the allocation of factors across countries, however, affects their relative income. Assuming that North is richer than South in laissez-faire implies $\overline{R}^* - \overline{R} < \omega(\overline{K} - \overline{K}^*)$, which, using (15), simplifies to

Assumption 3.

$$\frac{\overline{R}^*}{\overline{R}} < \frac{[2\alpha(1-b_Y(1-\mu))-1]\overline{K}^*+\overline{K}}{\overline{K}^*+[2\alpha(1-b_Y(1-\mu))-1]\overline{K}},$$

where the RHS is lower than $\overline{K}/\overline{K}^*$. Hence, a necessary condition for North being richer than South is that North owns a higher share of the aggregate capital endowment than Southern share of the aggregate fossil resource endowment. Substituting either $\widetilde{R}^*/\widetilde{R}$ or $\widetilde{R}_E^*/\widetilde{R}_E$ for $\overline{R}^*/\overline{R}$ into assumption (3) gives the condition for North to remain richer than South under the climate policy. North remains richer than South when the relative emission permits quota or the relative extraction quota is equal to or lower than the initial relative fossil resource endowment. If the climate policy is biased toward South so that the difference in emission permits or extraction quota across countries exceeds the initial endowment difference, then South can become richer than North. This income gap reversal makes the cooperative agreement on the climate policy very unlikely.

4.2. Comparing different allocation rules

To illustrate the previous results with specific endowment effects in each region, we compare four allocation rules: i/ grandfathering based on historical extraction; ii/ grandfathering based on prior income; iii/ the rich world takes the cuts; iv/ grandfathering based on prior consumption. The first three rules allocate extraction rights whereas the fourth rule allocates emission permits.

Grandfathering based on extraction. Denote by $\theta_R \equiv \overline{R}/(\overline{R}+\overline{R^*})$ Northern share of the aggregate resource endowment, and by $1-\theta_R$ Southern share. Assuming the burden of each region is proportional to its share of resource endowment, this extraction-based grandfathering rule implies

$$\widetilde{R} = \overline{R} - \theta_R[\overline{R}+\overline{R}^* - \widetilde{R}^w] = \theta_R\widetilde{R}^w,$$
$$\widetilde{R}^* = \overline{R}^* - (1-\theta_R)[\overline{R}+\overline{R}^* - \widetilde{R}^w] = (1-\theta_R)\widetilde{R}^w.$$

Because $\widetilde{R}/\widetilde{R}^* = \overline{R}/\overline{R}^*$, this allocation rule leaves the comparative advantages of each country unaffected. Both Northern and Southern resource endowments decrease by the same amount, which is equal to $(\overline{R}+\overline{R}^* - \widetilde{R}^w)/(\overline{R}+\overline{R}^*)$. Hence,

Proposition 4. *By reducing resource endowments evenly across countries, the extraction-based grandfathering rule imposes the same welfare loss on North and South.*

Proof: The relative income is unaffected by the extraction-based grandfathering rule, given $\omega(\widetilde{R}^w) = \omega\widetilde{R}^w/(\overline{R}+\overline{R}^*)$:

$$\frac{I}{I^*} = \frac{\omega\overline{K}\widetilde{R}^w/(\overline{R}+\overline{R}^*) + \theta_R\widetilde{R}^w}{\omega\overline{K}^*\widetilde{R}^w/(\overline{R}+\overline{R}^*) + (1-\theta_R)\widetilde{R}^w} = \frac{\omega\overline{K}+\overline{R}}{\omega\overline{K}^*+\overline{R}^*}.\bullet$$

Proposition 4 indicates that the extraction-based grandfathering rule provides an interesting benchmark by reducing Northern and Southern incomes evenly. Any extraction rule that imposes a higher burden on North due to equity concerns will reduce the income gap and favor South.

Grandfathering based on prior income. Denote by $\theta_I = I/(I+I^*)$ Northern share of world income in laissez-faire, and by $1-\theta_I$ Southern share. Assuming that the burden of each region is proportional to its initial share of world income, this income-based grandfathering rule implies

$$\widetilde{R} = \overline{R} - \theta_I[\overline{R} + \overline{R^*} - \widetilde{R}^w]$$
$$\widetilde{R}^* = \overline{R}^* - (1-\theta_I)[\overline{R} + \overline{R^*} - \widetilde{R}^w].$$

Equity recommends that the rich country makes a larger abatement effort. The relative reduction in fossil resource endowment is equal to $(I/I^*)(\overline{R}/\overline{R}^*)$, which is higher than the relative reduction imposed by the extraction-based grandfathering rule $\overline{R}/\overline{R}^*$ given assumption 3. If North is richer than South, the income-based grandfathering rule is less (more) favorable to North (South) than the extraction-based rule. Hence, Northern income would decrease more than Southern income. Southern income can even increase if the scarcity effect outweighs the endowment effect, as shown in proposition 2.

The rich world takes the cuts. Assuming that θ_I tends toward one implies that only North must reduce its resource extraction level to fulfill the global agreement. Under the rich-world-takes-the-cuts rule, Northern extraction allowance is $\widetilde{R} = \widetilde{R}^w - \overline{R}^*$, which is positive given assumption 2. The risk of carbon leakage is abstracted from in our cooperative agreement framework. Northern income decreases dramatically from the large negative endowment effect combined with the negative scarcity effect. By contrast, Southern income increases because its fossil resource endowment remains the same while the price of the resource increases. Given assumption 3, an ambitious climate change policy can reverse the income gap because the relative endowment increases sharply from $\overline{R}^*/\overline{R}$ to $\overline{R}^*/(\widetilde{R}^w - \overline{R}^*)$.

Allocating allowances can serve as a wealth transfer mechanism. An even decrease in the resource endowment leads to the same welfare loss across countries. An allocation rule that imposes more reduction in fossil resource extraction to North compared to South thus leads to a larger welfare loss in North. Because North is initially richer than South, equity recommends to impose a heavier burden on North. The income-based grandfathering rule may become a compromise between North and South because it does not inflict the largest cost to North while it potentially raises Southern income.

Grandfathering based on consumption. Denote by $\theta_{RE} \equiv R_E/(R_E + R_E^*)$ Northern share of the resource use in laissez-faire, and by $1 - \theta_{RE}$ Southern share. The consumption-based grandfathering rule allocates emission permits proportionally to the initial fossil resource use. Northern electric utilities receive $\theta_{RE}\widetilde{R}^w$ emission permits whereas Southern utilities receive $(1-\theta_{RE})\widetilde{R}^w$ permits. Given $R_E = \overline{R} + X_R$ and $R_E^* = \overline{R}^* - X_R$, Northern share of emission permits corresponds to $\theta_{RE} = (\overline{R} + X_R)/(\overline{R} + \overline{R}^*)$. The endowment effect is positive in North if and only if $\overline{R}(\overline{R} + \overline{R}^*) < (\overline{R} + X_R)\widetilde{R}^w$, whereas the endowment effect is always negative in South. Large fossil resource imports are necessary to induce a positive endowment effect in North when the climate policy has an ambitious emission reduction target. Lemma 2 implies that the climate policy reverses the comparative advantages of each country if and only if $X_R > [\overline{R}^*\overline{K} - \overline{R}\overline{K}^*]/(\overline{K} + \overline{K}^*)$, which using the equilibrium value for fossil exports obtained in Appendix A.2 simplifies to $\mu > 1/(2-\alpha)$. Proposition 3 states that if the positive endowment effect in North is sufficiently large to outweigh the scarcity effect or to reverse the comparative advantages of each country, Northern income increases.

The consumption-based grandfathering rule transfers property rights from the fossil resource suppliers toward the emissions permits holders, which leads to a potential increase in the resource importing country's income and to a decrease in the resource exporting country's income.

4.3. Numerical illustration

To compare the distributional impacts of the four allocation rules among countries and within countries, we provide a numerical example that illustrates the impacts of the climate policy on fossil resource suppliers, capital owners and consumers in each country. While there is some arbitrariness in the choice of the parameter values, we use data on U.S. technologies and preferences, and build two imaginary countries or regions, one being abundant in fossil resource and the other in capital. Assume that α, the output elasticity of the fossil resource in electricity, is set to 0.805, and that μ, the output elasticity of electricity in sector Y, is set to 0.624 (Pindyck, 1979). The share of US income spent in electricity is estimated to be 0.088 in 2007 (EIA, 2009), which corresponds to b_E.[12] Imagine two countries that differ in their capital and fossil resource endowments: North has three times more capital than South, while South has 1.4 times more fossil resource: $\overline{K} = 150$, $\overline{K}^* = 50$, $\overline{R} = 50$, and $\overline{R}^* = 70$. National incomes are thus initially $I = 174.7$ and $I^* = 129.8$, North being 25 percent richer than South. Assume the global climate policy aims at reducing 16.67 percent of the use of fossil resource, which result in $\widetilde{R}^w = 100$. The policy modifies the trade equilibrium, leading to a 8.7 percent decrease in the price of capital and to a 9.5 percent increase in the price of the resource (or of the emissions permit).

Table 1 illustrates the relative change in income for resource owners, capital owners and consumers computed at equilibrium under the climate policy. Since the exact resource use in North and South cannot be computed explicitly, we compare two values for Northern share of the resource use: either $\theta_{RE} = 0.77$, which implies that North receives 3.5 times more emission rights than South, thus $R_E/R_E^* > \overline{K}/\overline{K}^*$ (in Emission Rights 1); or $\theta_{RE} = 0.667$, which implies that North receives twice more emission rights than South, thus $R_E/R_E^* < \overline{K}/\overline{K}^*$ (in Emission Rights 2).

Table 1 allows us to further understand the impacts of the different allocation regimes within each country. The extraction-based grandfathering rule shares the burden of the climate policy evenly across countries and across economic agents. Fossil resource suppliers and capital owners suffer from the same reduction in income in both countries. Imposing a heavier burden on North than on South, as illustrated by the income-based grandfathering

[12] Source: U.S. Energy Information Administration: http://www.eia.gov/emeu/aer/txt/ptb0105.html.

Table 1: Comparison of the impacts of the climate policy under four allocation rules.

	North			South		
	Res. suppliers	Capital owners	National income	Res. suppliers	Capital owners	National income
Extraction-based grandfathering	-.095	-.095	-.095	-.095	-.095	-.095
Income-based grandfathering	-.185	-.095	-.128	-.039	-.095	-.054
Rich-takes-all-cuts	-.522	-.095	-.228	+.086	-.095	+.042
Emission rights 1	-1	-.095	+.173	-1	-.095	-.951
Emission rights 2	-1	-.095	+.109	-1	-.095	-.588

Note: In Emission rights 1, we assume $\theta_{RE} = 0.77$ whereas in Emission rights 2, $\theta_{RE} = 0.667$.

rule, implies that fossil resource suppliers's income decreases more (less) than capital owners' income in North (South). Southern resource suppliers and Southern consumers benefit from the rich-world-takes-the-cuts rule whereas Northern consumers suffer from a large income loss (23 percent decrease) as well as Northern resource suppliers (52 percent decrease in income). Allocating emissions permits transfers wealth away from fossil resource suppliers to utilities or to the government. The consumption-based grandfathering rule allocates more emission permits to North than to South, which leads to a sharp decrease in Southern income and to an increase in Northern income. When comparative advantages are reversed (as in Emission Rights 1) especially, the policy nearly expropriates South (95 percent income loss) to favor Northern consumers (17 percent income increase). When comparative advantages remain the same as in laissez-faire (as in Emission Rights 2), Southern income decreases by 58 percent whereas Northern income increases by 10 percent. The tradable emission system may not be feasible politically because of the objection of the resource abundant countries. Thus, some monetary transfers might be necessary to share the burden among fossil suppliers and emitters. Allocating less emissions permits to North and more to South could also balance the distributional impacts of the climate policy.

5. Discussion and concluding remarks

This paper illustrates the distributional challenges of a global climate change policy. Once both resource exporting and resource importing countries participate into the emission reduction effort, the burden sharing agreement has general equilibrium and trade implications that depend on where emission rights are allocated along the GHG supply chain. The upstream regulation that allocates extraction rights to fossil resource suppliers (e.g. oil producers and coal mining companies) is however as cost efficient as the downstream regulation that allocates emission permits to emitters (e.g. electric utilities). This result arises from the fact that each regulation induces the same aggregate welfare loss to achieve the same aggregate emission reduction. However, the economic burden of a given climate policy is differently shared among nations. Our model shows that the resource exporting countries will likely suffer and the resource importing countries will likely benefit from the downstream regulation. By contrast, the resource exporting countries could benefit from the upstream regulation when its national income increases thanks to the rise in the fossil resource price. This possibility arises when the scarcity effect (i.e., changes in factor prices) outweighs the endowment effect (i.e., reduction in fossil resource endowment). More precisely, our model shows that reducing evenly the resource endowment of each country provides an interesting benchmark where all countries suffer the same welfare loss. Therefore, any allocation rule that limits one country's extraction more than its trading partner's extraction imposes a higher welfare loss on this country. Assuming that the capital abundant North is richer than the fossil resource abundant South, equity recommends to impose a heavier burden on North. By doing so, the income-based grandfathering rule can, for instance, become a compromise between North and South.

Allocating emission rights is more common than allocating extraction rights in the real world. Our model reveals that the tradable permit system leads to often neglected drawbacks even when the climate policy is implemented cooperatively by resource exporting and resource importing countries. First, the price of the fossil resource approaches zero (i.e., the extraction cost) when the emission rights belong to emitters because there is excess supply on the fossil resource market. This may lead to enforcement difficulties because lowering the price of the fossil resource creates an incentive for increasing consumption, i.e., it fosters carbon leakage. Second, by allocating emission permits, the downstream regulation expropriates fossil resource suppliers who often have a large influence on policy makers. For instance, the Australian government is challenged to implement a carbon policy while the country is exporting coal and depending on it for 80 percent of its energy generation.[13] While some polluting industries will get compensation, Australia's coal mining companies denounce the nation's carbon policy that balances the interests of different industries unevenly.[14] By contrast, the upstream regulation offers the opportunity to fossil resource exporting countries to form a cartel. The global agreement to reduce fossil resource supply raises the resource price and eventually resource exporting countries' income.

One of the main implications of the model is the potential difficulty in establishing an agreement to share losses, which makes any solution that does not require the reduction of fossil resource extraction very appealing. For instance, the carbon sequestration technology could break down the relationship between the stock of fossil resource that is used and GHG emissions. Through technological change, e.g. carbon capture and storage or geo-engineering, the use of fossil resource could generate less emissions and then less radiative force on the climate. Improving energy efficiency or developing alternative clean energy can only reduce the welfare cost of the climate policy by affecting the relative factor price. Yet it will not be sufficient to reduce emissions without a global climate policy imposing a constraint on the burning of fossil fuels at the aggregate level.

The model could be extended to a dynamic model since extraction of the fossil resource is a dynamic process. Traditionally, the resource economics literature studies the non-renewable resource extraction in an optimal control framework (Withagen, 1994), and the debate on the green paradox reveals that a rising carbon tax or subsidizing clean energy may have counter-intuitive impacts on emissions by accelerating the fossil resource extraction (Van der Ploeg & Withagen, 2010). The question of the allocation of extraction or polluting rights remains however crucial at each period.

Appendix A. Appendix

Appendix A.1. Autarky equilibrium and comparative advantages

Under autarky, consumers only have access to domestic goods and producers can only use domestic inputs. The equilibrium on the industrial

[13] See http://www.bbc.co.uk/news/world-asia-pacific-14096750.

[14] See http://www.bloomberg.com/apps/news?pid=newsarchive&sid=a.pwSlfhIEc8&refer=environment.

market implies $Y = D_Y$, with $D_Y = b_Y I$. Given (6a) and the market clearing condition for energy (9), we have $p_E E = \mu Y + b_E I$. Using the Euler equations (4b) and (6b) and the full employment condition (8) gives $r\overline{K} = (1-\alpha)p_E E + (1-\mu)Y = (1 - \alpha(1 - b_Y(1-\mu)))\, I$. Similarly, the returns for the fossil resource are $s\overline{R} = \alpha p_E E = \alpha[1 - b_Y(1-\mu)]I$. Combining all factor returns leads to

$$r/s = \frac{1 - \alpha[1 - b_Y(1-\mu)]}{\alpha[1 - b_Y(1-\mu)]} \frac{\overline{R}}{\overline{K}}. \tag{A.1}$$

The patterns of trade stem from comparing (A.1) for North and South. We have $r/s < r^*/s^*$ if and only if $\overline{R}/\overline{K} < \overline{R}^*/\overline{K}^*$. As a result, North has a comparative advantage in producing the industrial goods whereas South has a comparative advantage in producing the resource intensive goods. Given that electricity is not traded internationally, South is a net exporter of the fossil resource.

Appendix A.2. Proof of Lemma 1

Using the definition of national incomes gives the income gap:

$$I/I^* = \frac{\omega\overline{K} + \overline{R}}{\omega\overline{K}^* + \overline{R}^*}, \tag{A.2}$$

which depends on factor endowments and on the relative factor price. Denoting by δ_Y the share of manufacturing goods produced in North, $\delta_Y \equiv Y/(Y + Y^*)$, we can express the income gap as a function of commodities consumed and exchanged internationally:

$$I/I^* = \frac{\delta_Y b_Y (I + I^*)/s - X_R}{(1-\delta_Y) b_Y (I + I^*)/s + X_R}, \tag{A.3}$$

where X_R denotes the fossil resource exported from South to North at the equilibrium price s. The aggregate income divided by the price of the resource equals $(I + I^*)/s = \omega(\overline{K} + \overline{K}^*) + \overline{R} + \overline{R}^*$. Using (4a) for North and South, given $R_E = \overline{R} + X_R$ and $R_E^* = \overline{R}^* - X_R$, gives

$$\frac{\overline{R} + X_R}{\overline{R}^* - X_R} = \frac{E}{E^*} = \frac{b_E I + \mu\delta_Y b_Y (I + I^*)}{b_E I^* + \mu(1-\delta_Y) b_Y (I + I^*)}, \tag{A.4}$$

which gives the level of exported fossil resource

$$X_R = \frac{\overline{R}^*[b_E\delta_I + \mu\delta_Y b_Y] - \overline{R}[b_E(1-\delta_I) + \mu(1-\delta_Y)b_Y]}{1 - b_Y(1-\mu)}, \tag{A.5}$$

where $\delta_I \equiv I/(I+I^*)$. Equalizing (A.2) with (A.3) given (15) and (A.5) determines the trade equilibrium, i.e., $\delta_Y \in [0,1]$. (A.2) is fixed for any δ_Y. However, (A.3) varies with δ_Y. We have

$$\frac{d(I/I^*)}{d\delta_Y} = \frac{b_Y[\omega(\overline{K}+\overline{K}^*) + \overline{R} + \overline{R}^*]\left\{b_Y[\omega(\overline{K}+\overline{K}^*) + \overline{R} + \overline{R}^*] - dX_R/d\delta_Y\right\}}{\left\{(1-\delta_Y)b_Y[\omega(\overline{K}+\overline{K}^*) + \overline{R} + \overline{R}^*] + X_R\right\}^2}, \tag{A.6}$$

where

$$\frac{dX_R}{d\delta_Y} = \frac{\mu b_Y(\overline{R}+\overline{R}^*)}{1 - b_Y(1-\mu)} > 0. \tag{A.7}$$

The sign of $d(I/I^*)/d\delta_Y$ is positive because

$$[1 - b_Y(1-\mu)]b_Y\omega(\overline{K}+\overline{K}^*) + b_Y(1-b_Y)(1-\mu)(\overline{R}+\overline{R}^*) > 0. \tag{A.8}$$

Thus (A.3) is increasing in δ_Y and it finds a negative minimum for $\delta_Y = 0$ because

$$I/I^*|_{\delta_Y=0} = -X_R/\left[b_Y[\omega(\overline{K}+\overline{K}^*) + \overline{R} + \overline{R}^*] + X_R\right] < 0 \tag{A.9}$$

whereas it finds a maximum for $\delta_Y = 1$ such that

$$I/I^*|_{\delta_Y=1} = \left[b_Y[\omega(\overline{K}+\overline{K}^*) + \overline{R} + \overline{R}^*] - X_R\right]/X_R, \tag{A.10}$$

which is equal to the value of (A.2) because $b_Y I^* = sX_R$ when $\delta_Y = 1$. Hence, the trade equilibrium implies that $\delta_Y = 1$.

Appendix A.3. Proof of Proposition 2

Using (12), we can express r as a function of s. (16) implies that Southern income increases under the extraction rights regulation if

$$\frac{ds}{d\widetilde{R}^w}\left[-\frac{\alpha\mu}{1-\alpha\mu}\omega(\widetilde{R}^w)\overline{K}^* + \overline{R}^*\right] \leq -s\frac{d\overline{R}^*}{d\widetilde{R}^w}.$$

By definition of $\omega(\widetilde{R}^w)$, we have

$$\frac{ds}{d\widetilde{R}^w} = \frac{-(1-\alpha\mu)s\omega'(\widetilde{R}^w)}{\omega(\widetilde{R}^w)}.$$

Southern income thus increases if and only if

$$\frac{d\overline{R}^*}{d\widetilde{R}^w} \leq \omega'(\widetilde{R}^w)\left[-\alpha\mu\overline{K}^* + (1-\alpha\mu)\overline{R}^*/\omega(\widetilde{R}^w)\right],$$

where $\omega'(\widetilde{R}^w) = [1-\alpha(1-b_Y(1-\mu))]/[\alpha(1-b_Y(1-\mu))(\overline{K}+\overline{K}^*)]$. An increase in I^* thus requires that the bracketed term is positive, i.e., $(1-\alpha\mu)\overline{R}^*/(\alpha\mu\overline{K}^*) > \omega(\widetilde{R}^w)$. Because South is fossil resource abundant, its relative factor price r/s is higher in autarky than in trade. $(1-\alpha\mu)\overline{R}^*/(\alpha\mu\overline{K}^*)$ is similar to Southern autarky relative factor price if $b_Y = 1$. Because ω is increasing in b_Y, the RHS is positive.

Similarly, the scarcity effect in North is negative if and only if

$$\frac{ds}{d\widetilde{R}^w}\left[-\frac{\alpha\mu}{1-\alpha\mu}\omega(\widetilde{R}^w)\overline{K} + \overline{R}\right] > 0, \tag{A.11}$$

which simplifies to $(1-\alpha\mu)\overline{R}/(\alpha\mu\overline{K}) < \omega(\widetilde{R}^w)$. Because North is capital abundant, its relative factor price r/s is lower in autarky than in trade. Because $(1-\alpha\mu)\overline{R}/(\alpha\mu\overline{K})$ is higher than Northern autarky relative factor price, the sign of the scarcity effect is ambiguous.

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