The Optimal Design of Climate Agreement

Inequality, Trade and Incentives for Climate Policy

Work in progress

Most recent version accessible here – Updated regularly

Thomas Bourany*
The University of Chicago

April 2024

Abstract

How can we design a climate agreement that implements the optimal climate policy? In the presence of inequality and policy constraints, the lack of climate cooperation and free-riding incentives are exacerbated. Through the lens of an Integrated Assessment Model (IAM) with heterogeneous countries and bilateral trade, I study the taxation of carbon when countries can deviate and exit climate agreements. Participation constraints create a policy tradeoff between an intensive margin – a "climate club" with few countries that implement large emission reductions – and an extensive margin – accommodating a larger number of countries at the cost of lowering the carbon tax. As in Nordhaus (2015), trade sanctions for non-participants are crucial to ensure the stability of the coalition. I solve for the optimal design of the club and show that with enough freedom in policy instruments – carbon tax and tariffs – one can reproduce the world's optimal policy: high abatement and large tariffs that induce participation of the entire world. However, in the presence of additional policy constraints – e.g. WTO rules for Carbon Border Adjustments – it can be optimal to leave several developing economies outside of the climate agreement.

*Thomas Bourany, *thomasbourany@uchicago.edu*. I thank my advisors Mikhail Golosov, Lars Hansen and Esteban Rossi-Hansberg for valuable guidance and advice. I also thank Jordan Rosenthal-Kay, Tom Hierons and other seminar participants at UChicago and Booth for stimulating discussions. All errors are mine.

Introduction

What is the optimal policy to fight climate change? Past climate agreements have been criticized for their repeated failures to implement binding targets for reducing carbon emissions. Alternative policies have been proposed to solve the free-riding problem such as Climate Clubs, c.f. Nordhaus (2015), for incentivizing climate cooperation and carbon pricing through trade sanctions. In this context, what should be the optimal climate agreement design to implement the largest reduction in fossil fuel use and carbon emissions?

Crucially, imposing a world carbon price has substantial redistributive effects that change the incentives and willingness of countries to join an agreement. First, low-income countries may not afford to pay the same tax level on fossil energy as developed economies. Moreover, countries may be exporters or importers of fossil fuels and taxation has a substantial impact on their energy rents. Finally, countries are connected through international trade, and imposing a carbon tax in one country reallocates economic activity toward other countries with less stringent climate policies – that is the "leakage effect". For all these reasons, countries are affected differently by carbon taxation, and the design of climate agreement should account for these differences.

In this context, would every country be willing to join a climate agreement with a high carbon tax? Under what conditions would they do so?What trade policy needs to be implemented to incentivize all the countries to join, reduce emissions and phase out fossil fuels? In summary, how can we design optimally a climate agreement that maximize welfare and fight climate change? This paper seeks to answer these questions.

As emphasized by Nordhaus (2015) and the climate linkage literature, c.f. Maggi (2016), climate policy suffers from a free-riding problem: the costs are local, while the benefits are global. No government has any incentive to implement a costly taxation and carbon abatement internalizing their climate externality on the rest of the world. As a result, economic and trade linkage are necessary: climate agreement needs to be associated with tariffs penalty or carbon border adjustment mechanism (CBAM) to incentive countries to reduce emissions.

However, the implementation of a climate agreement should account for the redistributive effects of the policies. Since countries have differing incentives to join an agreement, the decision on the optimal levels of the carbon tax and trade tariffs, as well as the choice of participants in the club should be made jointly. Indeed, the optimal design faces tradeoff between an intensive and an extensive margin. For a given set of participants in the climate agreement, a higher carbon tax makes the countries reduce further their emissions – at the intensive margin. However, a higher tax and lower tariffs also change the number of countries that find it profitable to participate in the agreement – affecting the extensive margin. How do we solve this tradeoff?

In this project, I tackle this policy question by building an Integrated Assessment Models (IAM) augmented with heterogeneous countries and trade patterns. This model accounts for multifaceted redistribution and leakage effects that arise in general equilibrium. It ressembles the standard climate-economics model of Nordhaus DICE, as in Golosov et al (2014). However, it includes several dimension of heterogeneity, i.e. differences in (i) productivity and income, (ii) temperature and impact of climate change, (iii) fossil energy extraction cost and hence position in energy markets as importer/exporter and (iv) the position in the network in international trade of goods and world allocation of production.

In this context, I address the following policy problem: a world social planner chooses optimally the design of a climate agreement that consists of three elements: (1) the set of countries that are included in the agreement – also called "club" or "coalition" – and that are subject to the climate and trade policies, (2) the level of the carbon tax that the club members charge on their own consumption of fossil energy and (3) the level of the uniform trade tariffs that the members imposes on the goods imported from non-member countries. Countries also make an individual choice to join or leave the agreements and hence those strategic participation constraints need to be accounted for in the design of the agreement. In addition, as in Nordhaus (2015), we consider the stability criterion of d'Aspremont, where the Nash equilibria we consider are robust to "coalition deviations", i.e. when a subset of countries decide jointly to deviate and leave the agreement.

In some aspect, this question resembles the combinatorial discrete choice problems (CDCP) that can arise in trade economics, but this time coupled with an optimal taxation and trade policy decision in a Nash equilibrium. We solve the problem numerically, first using exhaustive enumeration of potential coalitions and tax instruments choices and second by showing under what conditions tools from the CDCP literature may be applied.

I contrast this framework to two policy benchmarks. First, I consider the optimal energy policy when the coalition gather the entire world and participation constraints are absent. This case is treated extensively in Bourany (2024) where optimal carbon taxation is derived in a large class of climate-economics models, with or without transfer instruments. In particular, it shows how the choice of the carbon tax accounts for distributional motives – either due to the redistributive effects of the carbon tax itself, between rich and poor countries or fossil fuels exporters and importers for example, or due to inherent distributional objectives in the planner's welfare criterion.

Second, I also compare the "climate club" framework to the Nash equilibrium where each individual countries choose the "unilaterally optimal" carbon taxation and trade tariffs. We can see that carbon tax can resemble a subsidy to increase production and revenues, and use tariffs for increasing prices. Both choice are aimed a manipulating terms-of-trade. In comparison, climate agreements provide an "issue linkage" by coupling the implementation of climate policy with a reduction in tariffs, as there would be free-trade among coalition members.

In the main result, the optimal climate agreement can attain the world optimal climate policy with sufficiently high penalty tariffs. Aggressive trade policy foster the participation of the entire world by distorting the outside options of each country in their participation constraints. Therefore, when there is a complete freedom of trade policy instruments, I show that any potential coalition can be sustained. The reason for the effectiveness of this issue linkage is that the gains from trade –

i.e. the welfare loss associated with large tariffs from the rest of world – are larger than the welfare costs from carbon taxation.

Indeed, the costs of unilateral carbon taxation are relatively small, due to four facts: (i) the distortive effects of carbon taxation are not quantitatively large since they scale with the cost shares of fossil energy in national production, which tends to be lower than $5-6\%$ of GDP for most developed economies, (ii) the revenues of the carbon tax are redistributed lump-sum to the household, which avoid any additional redistributive effects, (iii) carbon taxation reduces energy use and therefore production, as well as pushing the domestic price higher. This benefits the country taxing unilaterally its fossil fuel, as now the price of its export is higher compared to the price of its imports. This leakage mechanism is analogous to a beneficial terms-of-trade manipulation, further lowering the cost of taxation. And finally, (iv) most countries imposing unilateral carbon policy are individually small relative to the world price of energy and climate. As a result, it avoids some of the negative effects – for example on fossil exporters or cold countries. We will see that these general equilibrium effects have heterogeneous impacts.

If the costs of carbon taxation are small compared to the cost of trade tariffs, global coordination in a climate agreement is still remarkable. For many countries, this comes from the increasing gains from coordination through two channels. First, if the countries are energy importers, being part of a large coalition is actually beneficial. When the other countries are taxing carbon, the world demand for fossil fuels decline along with its equilibrium price. This effect relates to what the literature calls the "price-channel" of the leakage effect. In our context, this makes the imposition of carbon tax less harmful in large coalition compared to small ones. Second, an additional channel through the trade linkage increases the impact of tariffs for countries deviating from the climate agreement. In general equilibrium if the club members represents a larger share of the economy, the welfare cost of tariffs on non-members in general equilibrium are exacerbated.

Due to these different effects, the necessary tariffs that the club member need to impose on the rest of the world are around 5%, while the tax on fossil fuel can be set at the optimal level, i.e. around 10$ per ton of CO_2, which is equivalent to roughly 10% of the price of fossil energy[1] I provide intuition on this result and the strength of these different channels with a welfare decomposition of the model, to the first order for small taxes and tariffs. This result shows how coordination, leakage effects through trade in goods and energy and the cost from trade penalties strengthen the incentives for countries to participate in climate agreements.

To analyze the robustness of that main result, I consider several extensions. First, I study the case where countries outside the climate-trade agreement could retaliate with individual penalty tariffs. In that case, we see that the penalty tariffs need to be increased fivefold to foster cooperation. The reason for this mechanism is that now, coalition members have more to lose from participating if non-members retaliate one-for-one. Moreover, tariffs retaliation also generate terms-of-trade

[1] Note that the carbon may be lower than the Social Cost of Carbon, as taxation account for redistributive effects through general equilibrium effects, as explained extensively in Bourany (2024).

manipulation, improving the outside options of countries not participating.

Second, I consider constraints to the implementable trade policies. One could object that high trade tariffs may not be compatible with World Trade Organization (WTO) rules. Indeed, unless explicit agreements are signed and formally expose the rules underlying retaliatory penalties, country may not be free to impose large tariffs. One option would be to tax foreign goods based on their carbon-content, following the carbon tax implemented domestically. This is analogous to *Carbon Border Adjustment Mechanisms* (CBAM). This constraints significantly the range of policies available in the climate agreements. In such cases, the extensive-intensive margins tradeoff reappears: a higher carbon tax reduces emissions of current club members but deter participation, which cannot be incentivized with an independent trade policy anymore. In that case, it may be optimal to leave several small countries outside the agreement – typically fossil-fuel exporters, which also tend to have the lowest gains from trade – while maintaining a carbon tax close to the optimal level.

Third, we consider refinement of the stable Nash equilibria available in the design of the agreement. Since the main result relies strongly on the ability of the agreement members to penalize each other's outside options, we consider the notion of "trembling hand perfect equilibrium" that take the outcome of the off-equilibrium plays into account. It assumes that players may, through a "slip of the hand", choose sub-optimal strategies with small probabilities. For political economy reasons, it can be realistic that government officials may unreasonably exit climate agreements, despite that decision being inferior for the representative household of the economy. In such cases, the equilibrium "full participation" / "high-penalty out of equilibrium" is unstable and suboptimal. This naturally constraints the trade tariffs that the coalition can use,

More extensions could be considered, like the lack of enforceability of carbon policies in emerging economies, or the lack of commitment of club members for the implementation of trade retaliation. Moreover, the dynamic building of the climate agreement – as suggested in the coalition formation and dynamic games literatures – can also be studied in the same framework and will be the object of future research.

Literature

This works compare to the macroeconomics of climate change by bridging a gap with the international trade policy and the game theoretical literature. First, I contribute to the debate on the formation of Climate Club, since the pioneering contribution of Nordhaus (2015). The implementation of climate policy suffers from a free-riding problem and Nordhaus proposed a simple framework to evaluate the principle of issue linkage, i.e. linking the enforcement of a climate/abatement policy with trade tariffs. He shows with the C-DICE model that for different – exogenously set – carbon prices and tariffs rates, we can achieve varying participation to a climate club. In particular, with low carbon price – up to $25\$/tCO_2$ – and high tariffs – 10%, the climate club can achieve a club with all the 15 regions he considers. I depart from his framework for three reasons and recover this main result: First, I show that when a Social Planner chooses endogenously and optimally both the carbon tax and the uniform tariffs, we can also achieve full participation and maximum reduction in emissions. Second, I depart from the C-DICE model that use ad-hoc functions for the carbon abatement – inspired from DICE – and the gain from trade and costs of tariffs – a quadratic approximation of the results of Ossa (2014). I show that modeling the energy market – both with heterogeneity in demand and supply of fossil and renewable energy – and trade in goods, with an Armington structure and accounting for leakage effects and terms-of-trade manipulation, we can understand the different channels that spurs participation or deviation from the optimal climate policy.

Farrokhi, Lashkaripour (2021), Kortum, Weisbach (2023), Bohringer, Carbone, Rutherford (2012, 2016), Hsiao (2022) also explore the difference between unilateral policies implemented at the country level and the potential for climate cooperation using trade policies. Farrokhi, Lashkaripour (2021) explores the sequential construction of a climate club, where European Union starts a coalition, implements the unilaterally optimal trade-climate policy and iteratively grows the participation to the club. In contrast, I show how should the club *design* the trade-climate policy strategically to spur participation. Other articles in this trade literature explore the underpinnings of optimal trade policies, e.g. Costinot, Donalson, Vogel, Werning (2015), Ossa (2014), Adao, Costinot (2022), Antras, Fort, Gutierrez, Tintelnot (2022), in particular the choice of trade tariffs for different objectives, like terms of trade manipulation for example. I show how these policy instruments can be used for issue linkage.

Moreover, I also borrow from the theoretical literature on climate cooperation, with classical references such as Barrett (1994), Harstad (2012), Barrett (2013), Nordhaus (2015), or the older literature collected in Batabyal (2000) or summarized in Maggi (2016). There is also a large literature on dynamic games and coalition formation games, that focus on the building of agreements, either through coordination games or through bargaining procedures, or summarized in Ray, Vohra (2015) or Okada (2023) more recently. Iverson (2024) and Hagen Schneider (2021) are more recent reference in static settings, exploring the stability result and the set of supportable climate coalitions with different feature of climate clubs, where trade policies are crucial. Similarly, Nordhaus (2021), Harstad (2023) or Maggi, Staiger (2023) study those questions as well as other dynamic features, such as technical change, the path of climate dynamics or intertemporal decision making. I draw inspiration from many of these references, and allow the trade framework I study to be easily extended to dynamic settings.

Indeed, in the continuity of Bourany (2024), I show that the optimal carbon policy should account several general equilibrium channels, as well as macroeconomic dynamics – in the spirit of IAMs. Starting from a static version of the classical DICE/RICE models, c.f. Nordhaus (1996, 2016), Barrage, Lint (2023), I study an extension with optimal fossil fuel taxation, as in Golosov et al (2014) and with heterogeneous countries/regions, c.f. Krusell, Smith (2022), Cruz, Rossi-Hansberg (2022, 2023), Kotlikoff et al (2021, a, b).

When the policy instruments are limited – as in our setting we only consider one uniform level of carbon and penalty tariffs against non-members and no transfer instruments – we need to change endogenously the choice of these instruments, like Hassler, Krusell, Olovsson (2021) or Douenne, Hummel, Pedroni (2022) in the case of climate policy, Davila and Walther (2022) or Chari, Nicolini, Teles (2023) in more general cases. This follows a large literature on optimal policy in heterogeneous agents models, c.f. Bhandari et al (2021, 2022, 2023), Le Grand, Martin-Baillon, Ragot (2022) or Davila, Schaab (2023) among many others.

In the next section, I outlay a simple version of the model. In section 2, I present the policy problem for setting up the climate agreement. In section 3, the model is extended to include realistic features aimed at capturing important quantitative implications. In section 4, I present a summary of the main result. In section 5, I propose different extensions.

1 Model

We study a static economy with I countries indexed by $i \in \mathbb{I}$, Each country is composed of five agents: (i) a representative household that consumes the final goods, (ii) a final-good firm that produces using labor and energy, (iii) a fossil energy firm that extract fossil-fuels and (iv) a firm that produce renewable energy and (v) a government that sets taxes and tariffs. This framework is the simplest model that includes both climate externality, a non-trivial energy market for fossil energy, and a realistic trade structure that reproduces the leakage effects of taxation. In the next section, we talk in detail about the policy instruments considered in the design of the climate agreement.

1.1 Household

The representative household in country i imports from country $j \in \mathbb{I}$ and consumes the quantity c_i. We consider an Armington structure, c.f. Armington, Henderson, Costinot, Rodriguez Clare, where each country produces its own variety. The utility of consumption has a structure with Constant Elasticity of Substitution (CES) θ over goods from different countries.

$$\max_{\{c_{ij}\}} u\big(\{c_{ij}\}_j\big) = u(c_i) \qquad\qquad c_i = \Big(\sum_{j\in\mathbb{I}} a_{ij}^{\frac{1}{\theta}} c_{ij}^{\frac{\theta-1}{\theta}}\Big)^{\frac{\theta}{\theta-1}} \tag{1}$$

where a_{ij} are the preference of country i on the good purchased from country j, which also include the home-bias a_{ii}.[2] They also earn labor income and energy rent, and the budget constraint writes:

$$\sum_{j\in\mathbb{I}} c_{ij}\,(1+\mathrm{t}_{ij}^b)\tau_{ij}\mathrm{p}_j = w_i\ell_i + \pi_i^f + \ \mathrm{t}_i^{ls} \tag{2}$$

where w_i is the wage rate, ℓ_i the exogenous labor supply, π_i^f the profit earned from the ownership of the energy firms and t_i^{ls} the lump-sum transfer received from the government. On the expenditure

[2]We assume that preferences $\{a_{ij}\}$ and iceberg trade costs $\{\tau_{ij}\}$ are policy-invariant, in particular, they are not sensitive to price changes and tariffs.

side, the household in i imports quantities c_{ij} from j, purchased at price p_j, and subject to iceberg cost τ_{ij} and to trade-tariffs $1{+}\mathrm{t}^b_{ij}$. The choice of trade policy will be made explicit below.

The optimal consumption choice of the household yields the following quantities and Armington trade shares:

$$\begin{aligned} c_{ij} &= a_{ij} c_i \Big(\frac{(1{+}\mathrm{t}^b_{ij})\tau_{ij}\mathrm{p}_j}{\mathbb{P}_i}\Big)^{-\theta} \\ s_{ij} \equiv \frac{c_{ij} p_{ij}}{c_i \mathbb{P}_i} &= a_{ij} \frac{((1{+}\mathrm{t}_{ij})\tau_{ij}\mathrm{p}_j)^{1-\theta}}{\sum_k a_{ik}((1{+}\mathrm{t}_{ik})\tau_{ik}\mathrm{p}_k)^{1-\theta}} \end{aligned} \tag{3}$$

where $p_{ij} = (1{+}\mathrm{t}^b_{ij})\tau_{ij}\mathrm{p}_j$ is the effective price for variety from country j sold in country i, and $\mathbb{P}_i$ is the price index of country i:

$$\mathbb{P}_i = \Big(\sum_{k \in \mathbb{I}} a_{ik}((1{+}\mathrm{t}_{ik})\tau_{ik}\mathrm{p}_k)^{1-\theta}\Big)^{\frac{1}{1-\theta}}$$

As a result, we summarize the budget as $c_i \mathbb{P}_i = \sum_{j \in \mathbb{I}} c_{ij}\,(1{+}\mathrm{t}^b_{ij})\tau_{ij}\mathrm{p}_j$, and the welfare is summarized with the indirect utility as the income discounted by the price level:

$$\mathcal{V}_i = u(c_i) = u\Big(\frac{w_i \ell_i + \pi^f_i + \mathrm{t}^{ls}_i}{\mathbb{P}_i}\Big) \tag{4}$$

1.2 Final good firms

The final good producer in country i is producing competitively the domestic variety at price p_i. The firm solves the following maximization of profits:

$$\max_{\ell_i, e^f_i, e^r_i} \; \mathrm{p}_i \, \mathcal{D}_i(T_i)\, z_i\, F(\ell_i, e^f_i, e^r_i) - w_i \ell_i - (q^f {+} \mathrm{t}^f_i) e^f_i - q^r_i e^r_i$$

where the production function $\bar{y}_i = F(\ell_i, e^f_i, e^r_i)$ is Constant Return to Scale and concave in all inputs, and uses labor ℓ_i, at wage w_i, fossil energy e^f_i purchased at price q^f, and renewable energy e^r_i at price q^r_i. Fossil energy e^f_i differs from renewable in the sense that its uses emit greenhouse gases, as we will see in the next section. As a result, there is a motive for taxing fossil energy with the carbon tax t^f.

The productivity of the domestic good firm $y_i = \mathcal{D}(T_i)\, z_i \bar{y}_i$ can be decomposed in two terms. First, the TFP residual z_i represents productivity as well as institutional/efficiency differences between countries. Invariant to prices and policy, this technology wedge explains the existence of income inequalities across countries. This translates into differences in consumption that create redistribution motives for taxation policy.

The second difference in productivity comes from the climate externality on local temperature T_i. This damage affect productivity: $\mathcal{D}(T) \in (0,1]$ and $\mathcal{D}(T) \to 0$ if $T \to \pm\infty$. We follow Nordhaus to summarize the effect of climate in one reduced-form function. Note that the damage function is country-specific due to potential differences in cost and adaptation. In the quantification section, we detail how we calibrate this function for each country i.

The input decisions solve the optimality conditions:

$$\begin{cases} \mathrm{p}_i \mathcal{D}(T_i)\, z_i F_{e^f}(\ell_i, e_i^f, e_i^r) & =: \mathrm{p}_i MPe_i^f = q^f + \mathrm{t}_i^f \\ \mathrm{p}_i \mathcal{D}(T_i)\, z_i F_{e^r}(\ell_i, e_i^f, e_i^r) & =: \mathrm{p}_i MPe_i^r = q_i^r \\ \mathrm{p}_i \mathcal{D}(T_i)\, z_i F_{\ell}(\ell_i, e_i^f, e_i^r) & =: \mathrm{p}_i MP\ell_i = w_i \end{cases} \tag{5}$$

Moreover, the private decision of the firms does not internalize the climate externality. In particular, if the energy tax is null t_i^f

1.3 Fossil energy firms

In each country $i \in \mathbb{I}$, a competitive energy producer extracts fossil fuels – oil, gas, and coal – e_i^x and sells it to the international market at price q^f. The energy is extracted at convex cost $\mathcal{C}_i^f(e_i^x)$, where the convex costs are paid in the unit of the consumption bundle of the household.[3]. The energy firm's profit maximization solves:

$$\pi_i^f = \max_{e_i^x} q^f e_i^x - \mathcal{C}_i^f(e_i^x)\mathbb{P}_i \tag{6}$$

Since the extraction costs are convex, the production function has decreasing return to scale[4], and hence, even with competitive firms, taking the fossil price as given, a positive energy rent can exist. Moreover, for the sake of simplicity, we do not consider that energy firms have market power in the setting of energy prices – for example in the case of OPEC for example – even though this framework could easily allow for such extension. Any sources of misallocation – in the sense of Hsieh and Klenow – could be accounted for in the calibration of the cost function $\mathcal{C}_i^f(\cdot)$ as we see in the quantification section.

Naturally, the optimal extraction decision follows from the optimality condition:

$$q^f = \mathcal{C}_i^{f\,\prime}(e_i^x)\mathbb{P}_i \tag{7}$$

which yields the implicit function $e^{x\star} = e^x(q^f/\mathbb{P}_i) = \mathcal{C}_i^{f\prime\,-1}(q^f/\mathbb{P}_i)$. Finally, the energy rent comes from fossil firms' profits $\pi^f(q^f, \mathbb{P}_i) = q^f e^x(q^f/\mathbb{P}_i) - \mathcal{C}_i^f\left(e^x(q^f/\mathbb{P}_i)\right)\mathbb{P}_i > 0$ and depends on the marginal costs as well as the elasticity $\nu_i = \frac{\mathcal{C}_i^{f\,\prime\prime}(e^x)}{\mathcal{C}_i^{f\,\prime}(e^x)e^x}$.

As we will see below, the profit $\pi^f(q^f, \mathbb{P}_i)$ and its share in income $\eta_i^{\pi f} = \frac{\pi_i{}^f}{y_i \mathrm{p}_i + \pi_i{}^f}$ are key indicators for the vulnerability of a country to carbon taxation. Indeed, reducing carbon emission and the phasing out of fossil fuels will reduce demand and price q^f and hence affect the welfare of large oil, gas and coal producers.

[3] This allows to account for international inputs in goods and services for building capital for resources extraction

[4] Note that one can find a production function with inputs ι such that $e^x = g(\iota)$ and profit $\pi = q^f g(\iota) - \iota\mathbb{P}_i$ instead of $\pi = q^f e^x - \mathcal{C}(\iota)\mathbb{P}_i$, in which case $g(\iota) = \mathcal{C}^{-1}(\iota)$

1.4 International Fossil Energy Market

In the previous sections, we outlaid both the demand side and the supply of the energy market. We consider that energy is traded frictionlessly on international markets.[5] The market clears such that:

$$E^f = \sum_{i \in \mathbb{I}} e_i^f = \sum_{i \in \mathbb{I}} e_i^x \tag{8}$$

In particular, countries have different exposure to energy markets, as importers or exporters $e_i^x - e_i^f$. First, larger, richer and more productive countries use larger quantities of energy and tend to have higher energy share $\frac{q^e e_i}{\mathrm{p}_i y_i}$. Moreover, countries i that export final goods and are central in international trade networks – due to low iceberg cost τ_{ki} or high preferences a_{ki} for all $k \in \mathbb{I}$ – would have higher prices p_i and hence use more energy.

Second, countries export energy if their cost of extraction is low $\mathcal{C}_i'$ which can represent either (i) low marginal cost of production per unit of fossil reserve, (ii) large reserves of fossil fuels lowering the cost of the endowment or (iii) institutional factors that allow for higher production. These factors will be crucial in the participation of countries in climate agreements.

1.5 Renewable energy producers

The final good firm also uses renewable and other low-carbon energy sources, such as solar, wind or nuclear electricity. This provides a way of substituting away from fossil fuel in the production function $F(\ell, e^f, e^r)$. As mentioned above, the demand for renewable energy e_i^r follows from the First-Order Conditions $\mathrm{p}_i MPe^r = q_i^r$.

The supply of renewable energy is local at country-level i. This assumption follows from the fact that electricity is rarely traded across countries – and if it is, it only suggests temporary differences in electricity production in due to intermittency, rather than large structural imbalances. The production $\bar{e}_i^r$ from the representative clean energy firm is Constant Return to Scale and uses final good inputs, paid in the consumption bundle at price $\mathbb{P}_i$.

$$\max_{e_i^r} q_i^r \bar{e}_i^r - \mathcal{C}_i^r \mathbb{P}_i$$

where $\mathcal{C}_i^r$ is now simply a constant, as implied by constant return (CRS). As a result, the price of renewable and the market clearing write simply

$$q_i^r = \mathcal{C}_i^r \mathbb{P}_i \qquad\qquad \bar{e}_i^r = e^r \tag{9}$$

[5]For the sake of simplicity, I refrain from considering a general Armington structure, where fossil demand combines varieties from different sources $e_i^f = \left(\sum_j (e_{ij}^f)^{\frac{\Theta-1}{\Theta}}\right)^{\frac{\Theta}{\Theta-1}}$. I make the simplifying assumption that fossil fuels produced in different countries are not distinguishable – crude oil from Nigeria, Saudi Arabia or Russia are not differentiated varieties – and consider the limiting case $\Theta \to \infty$

1.6 Climate system

We consider a reduced-form climate model determining the temperature T_i as a function of world carbon emission $\mathcal{S}$. First, we consider a linear relationship between carbon concentration in the atmosphere $\mathcal{S}$, which is simply the cumulative CO_2 emissions of the entire world, and global temperature $\mathcal{T}$ anomaly compared to preindustrial level.

$$\mathcal{T} = \chi \mathcal{S} = \chi\left(\mathcal{S}_0 + \sum_{\mathbb{I}} e_i^f\right)$$

where χ is the climate sensitivity parameters, i.e. how much warming does a ton of CO_2 cause, and where e_i^f are measured in carbon units, and the $\mathcal{S}_0$ is the initial stock of carbon before all the policy decision are made – i.e. in 2020. This specification is rationalized by a large climate-sciences literature that shows that both historical data and a large class of climate model display an approximately linear relationship between $\mathcal{S}$ and $\mathcal{T}$, as is shown is the following figure: Second,

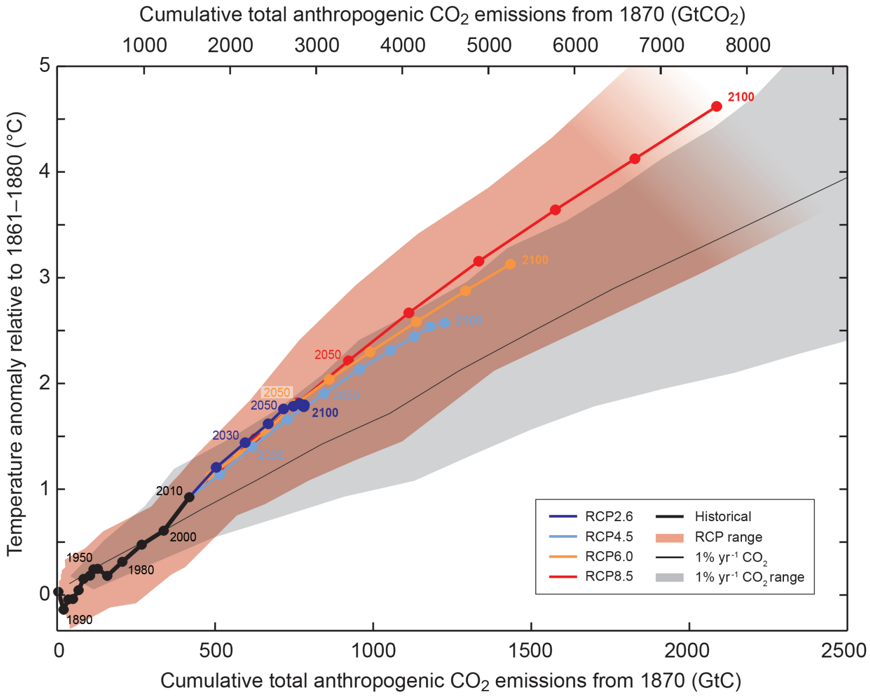

Figure 1: Linearity – Cumulative emissions and temperature

we also consider linear relation between global temperature and local temperature, which affect the local damages:

$$T_i = \bar{T}_{i0} + \Delta_i \mathcal{T} = \bar{T}_{i0} + \Delta_i \chi\left(\mathcal{S}_0 + \sum_{\mathbb{I}} e_i^f\right)$$

where Δ_i is a linear pattern scaling parameter that depends on geographical factor such as albedo or latitude.

1.7 Market clearing and equilibrium

To close the model, we need to determine the distribution of prices for the final good of each country p_i and we consider the market clearing for each good i

$$\begin{aligned} y_i &= \sum_{k\in\mathbb{I}} \tau_{ki} c_{ki} + \sum_{k\in\mathbb{I}} \tau_{ki}(x^f_{ki} + x^r_{ki}) \\ \mathrm{p}_i \underbrace{y_i}_{=\mathcal{D}(T_i) z_i F(\cdot)} &= \sum_{k\in\mathbb{I}} \frac{s_{ki}}{1+\mathrm{t}^b_{ki}} \left(\mathrm{p}_k y_k + q^f(e^x_k - e^f_k) + \mathrm{t}^{ls}_k\right) \end{aligned} \tag{10}$$

where x^f_{ki} and x^r_{ki} are the good inputs used by country k and imported from country i to produce fossil and renewable energy respectively.

To summarize, the competitive equilibrium (C.E.) of this economy is defined as follow:

For a specific vector policies $\{\mathrm{t}^f_i, \mathrm{t}^b_{ij}, \mathrm{t}^{ls}_i\}_i$ across countries, a C.E. is a set of decisions $\{c_{ij}, e^f_i, e^r_i, e^x_i\}_{ij}$, states $\{T_i\}_i$ and prices $q^f, \{\mathrm{p}_i, w_i, q^r_i\}_i$ such that
(i) Household choose consumption $\{c_{ij}\}_{ij}$ to maximize utility eq. (1) s.t. budget constraint **??**, yielding trade shares eq. (3)
(ii) Final good firm choose inputs $\{\ell_i, e^f_i, e^r_i\}_i$ to maximize profit, resulting in decisions eq. (5)
(iii) Fossil energy firm maximize profit eq. (6) and extract/produce $\{e^x_i\}_i$ given by eq. (7)
(iv) Renewable energy supply $\{e^r_i\}$ is given by eq. (9) by firms maximizing profit
(v) Energy market clear for fossils as in eq. (8) and for renewable in eq. (9)
(vi) Good market clear for final good for each country as in eq. (10)

1.8 Inequality: dimension for heterogeneity

I consider multiple dimensions of heterogeneity, either in final good production, in vulnerability of climate change, or in position in the international trade network of goods and energy. I list them in the following table as a summary.

Table 1: Model: Inequalities and dimensions of heterogeneity

Dimension	**Model parameters and observables**
Population	Country size $\mathcal{P}_i$
Income/production inequalities	Productivity/TFP z_i and output $y_i\mathrm{p}_i$
Impact of climate change	Temperature T_i and Damage $\mathcal{D}_i(T_i)$
Place in international	and trade cost τ_{ki} and preferences a_{ki}
trade network	Trade shares $s_{ij} = \frac{c_{ij} p_{ij}}{c_i \mathbb{P}_i}$
Reliance of energy	Energy share $s^e_i = \frac{e_i q^e}{y_i \mathrm{p}_i}$ in $F(\cdot)$
and fossil energy	Fossil share in energy mix $s^f_i = \frac{e^f_i q^f}{e_i q^e}$
Energy exporter status	Cost of fossil fuel $\mathcal{C}_i(\cdot)$
	Energy rent share $\eta^{\pi f}_i = \frac{\pi_i^f}{y_i \mathrm{p}_i + \pi_i^f}$

2 Policy benchmark

Before turning to the optimal design of the climate agreement, let us consider the benchmarks for the choice of the policy instruments $\{\mathrm{t}_i^f, \mathrm{t}_{ij}^b\}$. The first benchmark consists of the perfect coordination equilibrium where all countries follow the social planner policy. The second benchmark consists of the complete lack of cooperation where the equilibrium lead to free-riding.

2.1 World optimal policy

Consider a social planner maximizing the world's welfare:

$$\mathcal{W} = \max_{\{\mathbf{t},\boldsymbol{c},\boldsymbol{e}\}_i} \sum_{i\in\mathbb{I}} \omega_i \ u(c_i) = \textstyle\sum_{\mathbb{I}} \mathcal{V}_i$$

We consider the case where the planner chooses a single carbon tax t^f for all the country $i \in \mathbb{I}$, i.e. $\mathrm{t}_i^f = \mathrm{t}^f$.

This exercise is studied extensively in Bourany (2024). I show there that the optimal level of that carbon tax depends on the availability of redistribution instruments, i.e. lump-sum transfers t_i^{ls} across countries. More specifically, in the First-Best allocation, or in economies without heterogeneity or without redistribution motives, the optimal Pigouvian carbon tax should simply be $\mathrm{t}^f = SCC$ where SCC is the social cost of carbon.

Otherwise, in case where international transfers are absent, the lump-sum transfers are simply the revenues from the carbon tax $\mathrm{t}_i^{ls} = \mathrm{t}_i^f e_i^f$. In that case, the optimal carbon tax should account for the redistributive effects. Indeed the level of the carbon tax accounts for (i) Local Damage LCC_i, (ii) energy supply terms-of-trade effects, (iii) energy demand distortions, (iv) all of them weighted by an index $\phi_i \propto \omega_i u'(c_i)$

$$\mathrm{t}^f = \underbrace{\textstyle\sum_i \phi_i \, LCC_i}_{=SCC} \ + \textstyle\sum_i \phi_i \, \text{Supply Distortion}_i \ + \ \textstyle\sum_i \phi_i \, \text{Demand Distortion}_i$$

As a result, this may imply that the optimal level of the energy tax may differ than the standard Social Cost of Carbon, in particular be lower.

2.2 Nash-equilibrium of unilaterally optimal policies

In another extreme, we consider the case where countries choose optimally their carbon policy t_i^f and trade policy t_{ij}^b. Again, we are ruling out the possibility of transfers across countries. The full exposition of these result is forthcoming, but the main result is that tariffs and energy taxation are used for terms-of-trade manipulations.

3 Optimal agreement design: Ramsey Problem with participation constraints

Definition A climate agreement is a set $\{\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b\}$, with $\mathbb{J} \subseteq \mathbb{I}$ countries and a competitive equilibrium $\{\boldsymbol{c}, \boldsymbol{e}, \boldsymbol{q}\}$ such that:

- Countries $i \in \mathbb{J}$ are subject to a carbon tax t^f on fossil energy e_i^f
- Countries can leave the climate agreement:
  If j exits, club members $i \in \mathbb{J}$ charges uniform tariffs $\mathrm{t}_{ij}^b = \mathrm{t}^b$ on goods from j. They still trade with club members in energy at price q^f.
  <u>*Extension 1:*</u> The club $\mathbb{J}$ can also impose a tax t^{bf} on energy.
- Exit decision:
  Subcoalition exit: only $\hat{\mathbb{J}}$ stay in the agreement, "Coalitional-Nash" / "Core"

Participation constraints. Indirect utility $U_i(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b) \equiv u(c_{i(\mathbb{J},\mathrm{t}^f,\mathrm{t}^b)})$

$$U_i(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b) \geq U_i(\hat{\mathbb{J}}, \mathrm{t}^f, \mathrm{t}^b) \qquad \forall\, \hat{\mathbb{J}} \subseteq \mathbb{J}\backslash\{i\} \qquad \text{[Coalition-Nash equilibrium]}$$

Coalitional Nash eq. (or "core") $\mathbb{C}(\mathrm{t}^f, \mathrm{t}^b)$: robust to deviation of sub-coalitions. No country i would be better off than in the current agreement $\mathbb{J}$. Note: the "core" $\mathbb{C}(\mathrm{t}^f, \mathrm{t}^b)$ can be empty

Objective: search for the optimal climate agreement

$$\max_{\mathbb{J},\mathrm{t}^f,\mathrm{t}^b} \mathcal{W}(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b) = \max_{\mathrm{t}^f,\mathrm{t}^b} \max_{\mathbb{J}} \mathcal{W}(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b)$$

$$s.t. \qquad \mathbb{J} \in \mathbb{C}(\mathrm{t}^f, \mathrm{t}^b) = \left\{\mathcal{J} \mid {\scriptstyle U_i(\mathbb{J},\mathrm{t}^f,\mathrm{t}^b) \geq U_i(\hat{\mathbb{J}},\mathrm{t}^f,\mathrm{t}^b)\ \forall i \in \mathcal{J}\ \&\ \forall\ \hat{\mathbb{J}} \subseteq \mathcal{J}\backslash\{i\}}\right\}$$

Welfare, for coalition $\mathbb{J}$, weighting all countries $i \in \mathbb{I}$

$$\mathcal{W}(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b) = \sum_{i \in \mathbb{I}} \omega_i\, U_i(\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b)$$

Current design:
(i) inner problem: given $\{\mathrm{t}^f, \mathrm{t}^b\}$, choose coalition $\mathbb{J}(\mathrm{t}^f, \mathrm{t}^b)$ s.t. participation constraints holds
(ii) outer problem: choose taxes $\{\mathrm{t}^f, \mathrm{t}^b\}$ to maximize welfare

4 Main results

Before turning to the main result for the optimal agreement, we present to set of independent results from our model: first the impact of retaliatory trade tariffs and second the impact of carbon taxation (absent trade penalty). In a third section, we bring both of them together to see how issue linkage can be implemented in a climate agreement.

4.1 Gains from trade

In the following figure, we see the welfare costs of tariffs for the targeted countries. For each country i, I consider the welfare loss, in consumption equivalent percentage changes, of country i when all countries $j \neq i$ impose a tariff on country i. I consider two values of uniform tariffs, first 10% which is a policy that is achievable in practice, and second 500%, which is a good representation of the upper bound on welfare cost of tariffs – and is virtually identical for higher values of tariffs. It is closely related to the cost of autarky which is the case where both countries j impose tariffs on i and i imposes tariffs on countries j as well – which tend to be in the order of magnitude. For example, we see that advanced asian countries – Japan, Korea and Asian Dragon economies – have the most to lose to be in subject to tariffs – respectively 2% and 7.5% consumption loss . This is in part due to the large trade shares of these countries with China, the US, and South-East Asia.

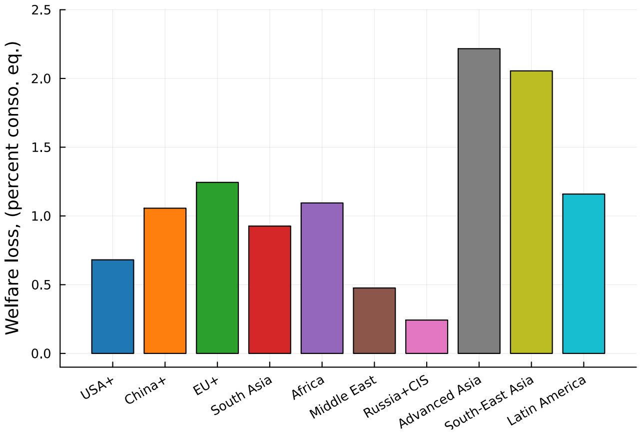

Figure 2: Losses for country i of country $j \neq i$ imposing a 10% tariff on country i

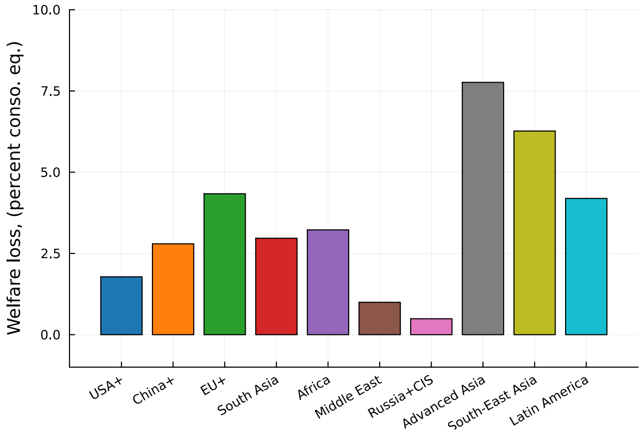

Figure 3: Losses for country i of country $j \neq i$ imposing a 500% tariff on country i

4.2 Collective and unilateral gains from carbon taxation

In this section, we consider the welfare gains from a unique tax on fossil fuels for all countries $i \in \mathbb{I}$. We consider of 10.5$ tax, which is welfare maximizing for a world social planner $\mathcal{W}(\mathbb{I}, \mathrm{t}^f, 0) = \sum_{i \in \mathbb{I}} \omega_i \; U_i(\mathbb{J}, \mathrm{t}^f, 0)$. The Pareto weights ω_i are chosen to shut down redistributive concerns – and hence any motives for energy taxation – in the case without climate externality. That level of tax is notably small since the tax is chosen to offset some of the negative effects that arises in general equilibrium on trade – through leakage – and energy market – through energy rent. In particular, this is lower than the Social Cost of Carbon that summarize the monetary value of the welfare cost of climate change – i.e. a marginal increase of carbon in the atmosphere – for the world welfare.

On the LHS, I plot the welfare gains, for different countries, of that 10% tax imposed on the whole world, i.e. $U_i(\mathbb{I}, \mathrm{t}^{f\star}, 0), \forall i \in \mathbb{I}$ and $\mathcal{W}(\mathbb{I}, \mathrm{t}^{f\star}, 0)$, in comparison to the competitive equilibrium $U_i(\emptyset, 0, 0), \mathcal{W}(\emptyset, 0, 0)$. We first see that the effect is very heterogenous across countries. Europe is the region that benefits the most, for two reasons: it has the highest Local Cost of Carbon LLC_i, the monetary value of climate change for one region, $LCC_i = \frac{du(\cdot)}{dS}/u'(c_i)$. It also has additional benefits of a lower equilibrium price q^f of fossil fuels when all the other countries are imposing a carbon tax and reduce their energy demand – that is the price-effect of the leakage effect. This effect is similar for Asian and Latin-American economies. For other regions, like the Middle East or Former Soviet economies like Russia, this leakage effects dries the rent from fossil. Even if this lower price q^f would benefit the economy and production, the disappearance of part of energy profits π_i^f that would benefit the representative household. This effect is similar for the US or China – who produces, and consumes, a large share of the coal extraction. Overall the effects almost cancel out for aggregate welfare $\mathcal{W}$.

Second, we see that all these effects are indeed small for most countries, between -0.5% and $+0.27\%$, which one order of magnitude smaller than the cost of trade tariffs. This is because (i) the tax considered is small, $\sim 10\%$ of the price of fossil energy, (ii) the cost of energy taxation scales – up to a first order – with the energy cost share in production $\frac{q^f e_i^f}{\mathrm{p}_i y_i}$ which tend to be small for most countries, around $5-6\%$, and (iii) energy taxation reduces production y_i and increase domestic price p_i. This acts as a terms-of-trade manipulation since now exports commands more import. However, this effect only applies if the policy is applied unilaterally, which relates to the experiment we cover next.

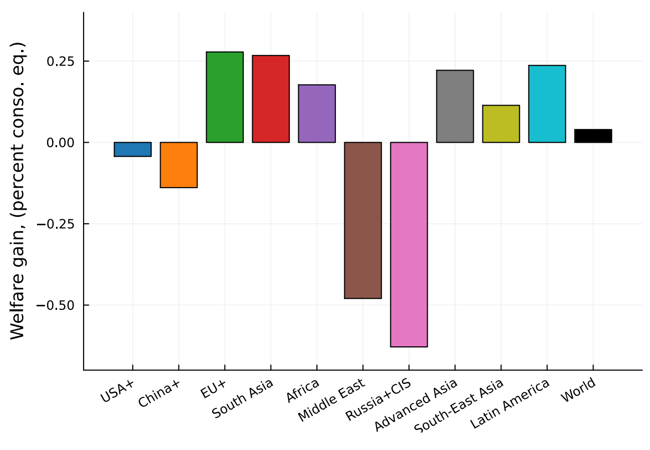

Figure 4: Welfare gain for country i of the world setting a 10$ fossil fuel tax, compared to laissez faire

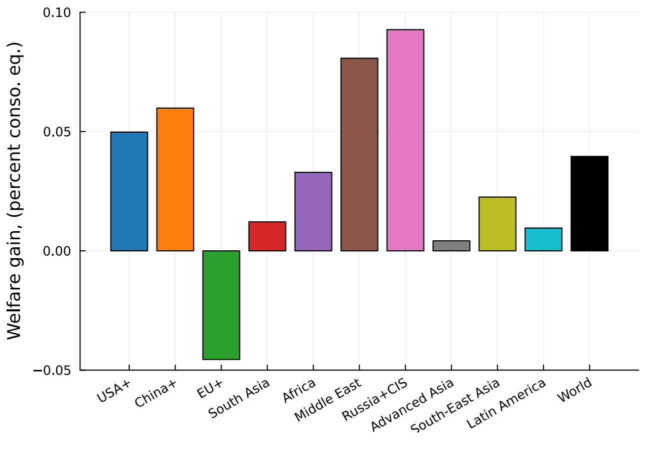

Figure 5: Welfare gain for country i of unilaterally deviating from a world agreement setting a 10$ fossil fuel tax

On the RHS, I present an additional experiment, where all countries $j \in \mathbb{I}$ are implementing the optimal level of fossil-fuel taxation, except for country i, which deviates from that optimal policy, setting the taxes and tariffs to zero. For each country i, we plot, in consumption-equivalent unit, the welfare gain of such "deviation" compared to the case where the country i stays in this "agreement". We assume that there is no retaliatory tariffs from the other countries j, who also keep applying the optimal carbon tax. We see first that such gain from "deviating" is again an order of magnitude smaller to the previous experiment, between -0.05% and 0.1% of local welfare. In that case, Russia and Middle East have the biggest gain from deviating, as it would restore part of their energy rent. Conversely, Europe actually loses from unilateral deviation – despite the distortionary cost of taxation. This is caused by the general equilibrium effect increasing world's energy price and the terms-of-trade effect lowering the price of their export, which is especially costly for this region very open to trade as mentioned above.

We see that the cost of energy taxation is smaller to the – nevertheless small – cost of trade tariffs. We turn now to the main result of the optimal design of climate club.

4.3 Optimal design of climate agreement

We bring the two instruments together to analyze the linkage of climate policy with trade penalty. In the next two figures, I plot for different values of fossil fuel tax t^f and uniform final good tariffs t^b – from the club member to the non-members. On the LHS, I plot the number of countries $\#\mathbb{J}(\mathrm{t}^f, \mathrm{t}^b)$ that choose to join the climate agreement, i.e. their participation constraint is satisfied. We see that for low values of tariffs, there are few countries that would be incentivized. This replicates the result from Nordhaus (2015), where in cases without linkage, i.e. without trade penalty for deviation from a climate club, the coalition is naturally unstable and collapse to a small number. However, to sustain larger agreements – up to maximum participation, as we have 10 regions in our numerical experiment – one can increase the retaliatory tariffs, around 3.5%. We saw before that the welfare costs of small tax on energy are relatively mild, hence the very small tariffs necessary to make it stable globally.

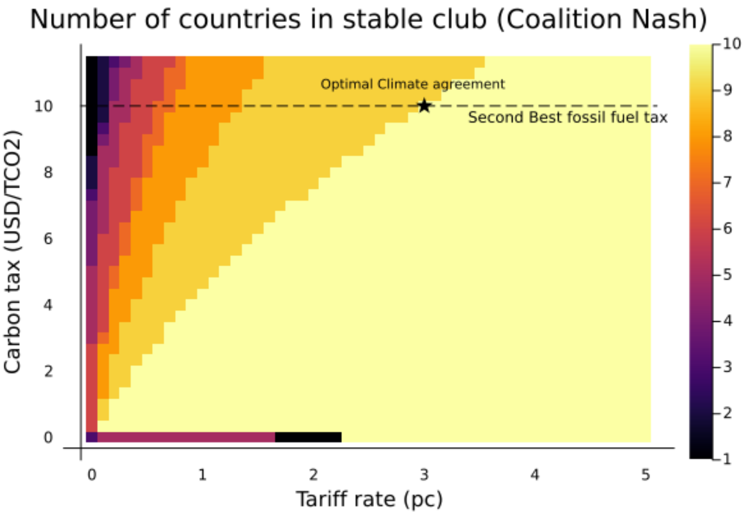

Figure 6: Agreement participation $\#\mathbb{J}(\mathrm{t}^f, \mathrm{t}^b)$, for different fossil fuel tax t^f and tariffs t^b

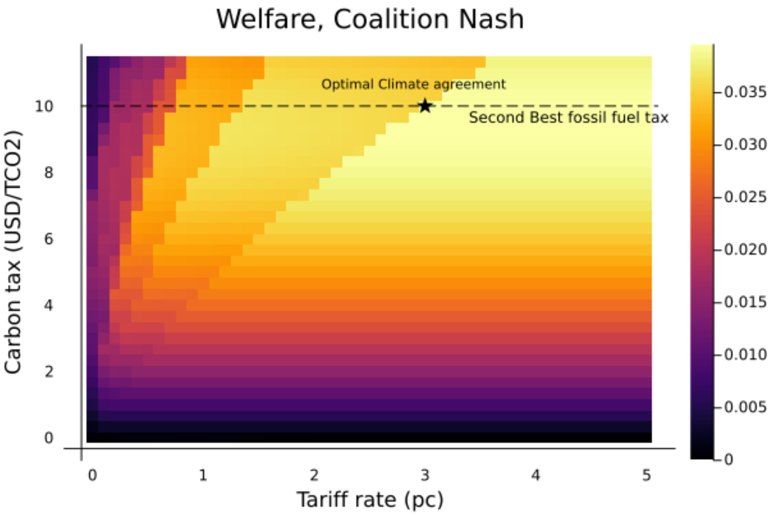

Figure 7: World welfare $\mathcal{W}(\mathbb{J}_{(\mathrm{t}^f,\mathrm{t}^b)}, \mathrm{t}^f, \mathrm{t}^b)$, for different fossil fuel tax t^f and tariffs t^b

As a result, the optimal agreement $\{\mathbb{J}, \mathrm{t}^f, \mathrm{t}^b\}$ replicates the second-best policy for the entire world, i.e. $\{\mathbb{I}, \mathrm{t}^{f\star}, \mathrm{t}^{b\star}\}$, where tariffs $\mathrm{t}^{b\star}$ are set to values above 3.5% to incentivize full participation. For lower tariffs, the first region to deviate is the one composed of Russia and former Soviet countries. They have the most to lose from carbon taxation, being fossil fuel exporters with cold climate and a relatively closed economy. The next region is the Middle-East, which includes most of OPEC members, which would also lose their energy rent from their own taxation of fossil fuels, despite a warm climate. For lower values of tariffs, the coalition rapidly collapses, replicating Nordhaus' "small coalition" result.

On the RHS, I show the world social planner welfare $\mathcal{W}(\mathbb{J}(\mathrm{t}^f, \mathrm{t}^b), \mathrm{t}^f, \mathrm{t}^b)$ for endogenous club participation. We see that, for the area with full participation $\mathbb{J}(\mathrm{t}^f, \mathrm{t}^b) = \mathbb{I}$, the welfare increases with higher fossil fuel tax up to the second-best level $\mathrm{t}^{f\star}$ at which point it decreases. In that case, since participation is complete, no country is affected by the high tariffs. For lower participation, the welfare decreases due to higher carbon emissions and higher equilibrium price of fossil energy.

5 Conclusion and extensions

We propose three extensions to test the robustness of that baseline result and we include them in the next version of the draft. First, I consider the case where countries outside the club behave optimally when choosing their energy and tariff policies. In that case, they maximize their terms-of-trade, increasing the gain of being unilaterally outside the club but would also increase the gains from coordination as now a climate agreement provides an additional "free-trade" advantage. This case is studied in Farrokhi Lashkaripour (2021): this is one reason why their stable club does not produce complete participation – in addition of not being "optimal" in the sense of social-planner maximization. Otherwise, we consider the case of tit-for-tat retaliatory tariffs where countries outside react one-for-one against the tariffs of the club members. In that case, the costs of a climate agreement increase and much larger penalty tariffs are needed to sustain a club.

Second, I study the case where additional political and regulatory constraints set a maximum bound on the applicable trade policy. In the case where the climate agreement only have access to "CBAM" type of policy, i.e. $\mathrm{t}^b_{ij} = \frac{e_j}{y_j}\mathrm{t}^f_i$ against countries j, the "large" tariffs can not be implemented. As a result, the intensive-extensive margin trade-off reappears as full-participation cannot be reached unless drastically lowering the carbon tax. This implies that it is optimal to lower participation – leaving the former Soviet and Middle Eastern economies out of the coalition and keeping a higher tax.

Third, I explore equilibrium refinements, in particular the "trembling-hand" perfect equilibrium. In this equilibrium, each country play a mixed-strategy, with an ε probability of leaving the club in case of participation and conversely. In that context, the imposition of high tariffs are potentially affecting all the countries, as we now include the off-equilibrium path and the cost of high tariffs $\mathrm{t}^{b\star}$ in welfare. That makes an additional trade-off appear as now large tariffs not only incentivize participation but also hurt the coalition welfare with small probability.

References

Adao, Rodrigo, Arnaud Costinot and Dave Donaldson (2023), 'Putting Quantitative Models to the Test: An Application to Trump's Trade War'.

Antras, Pol, Teresa C. Fort, Agustin Gutierrez and Felix Tintelnot (2024), 'Trade Policy and Global Sourcing: An Efficiency Rationale for Tariff Escalation', *Journal of Political Economy Macroeconomics* **2**(1), 1–44. Publisher: The University of Chicago Press.

Arkolakis, Costas, Arnaud Costinot and Andres Rodriguez-Clare (2012), 'New Trade Models, Same Old Gains?', *American Economic Review* **102**(1), 94–130.

Arkolakis, Costas and Conor Walsh (2023), 'Clean Growth'.

Atkeson, Andrew and Patrick J Kehoe (1999), 'Models of energy use: Putty-putty versus putty-clay', *American Economic Review* **89**(4), 1028–1043.

Barrage, Lint and William Nordhaus (2024), 'Policies, projections, and the social cost of carbon: Results from the DICE-2023 model', *Proceedings of the National Academy of Sciences* **121**(13), e2312030121. Publisher: Proceedings of the National Academy of Sciences.

Barrett, Scott (1994), 'Self-Enforcing International Environmental Agreements', *Oxford Economic Papers* **46**(Supplement 1), 878–894.

Barrett, Scott (2001), Strategic Environmental Policy and International Trade, *in* 'The Economics of International Trade and the Environment', CRC Press. Num Pages: 11.

Barrett, Scott (2003), *Environment and Statecraft : The Strategy of Environmental Treaty-Making: The Strategy of Environmental Treaty-Making*, OUP Oxford. Google-Books-ID: uqrey86neSIC.

Batabyal, Amitrajeet, ed. (2017), *The Economics of International Environmental Agreements*, Routledge, London.

Belfiori, Elisa, Daniel Carroll and Sewon Hur (n.d.), 'Unequal Climate Policy in an Unequal World'.

Belfiori, Maria Elisa (2018), 'Climate change and intergenerational equity: Revisiting the uniform taxation principle on carbon energy inputs', *Energy Policy* **121**, 292–299.

Bhandari, Anmol, David Evans and Mikhail Golosov (n.d.), 'Efficiency, Insurance, and Redistribution Effects of Government Policies'.

Bhandari, Anmol, David Evans, Mikhail Golosov and Thomas J. Sargent (2021), 'Inequality, Business Cycles, and Monetary-Fiscal Policy', *Econometrica* **89**(6), 2559–2599. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.3982/ECTA16414.

Bhattarai, Keshab, Sushanta K. Mallick and Bo Yang (2021), 'Are global spillovers complementary or competitive? Need for international policy coordination', *Journal of International Money and Finance* **110**, 102291.

Bilal, Adrien and Esteban Rossi-Hansberg (2023), 'Anticipating Climate Change Across the United States'.

Bohringer, Christoph, Jared C. Carbone and Thomas F. Rutherford (2012), 'Unilateral climate policy design: Efficiency and equity implications of alternative instruments to reduce carbon leakage', *Energy Economics* **34**, S208–S217.

Bohringer, Christoph, Jared C. Carbone and Thomas F. Rutherford (2016), 'The Strategic Value of Carbon Tariffs', *American Economic Journal: Economic Policy* **8**(1), 28–51.

Bornstein, Gideon, Per Krusell and Sergio Rebelo (2023), 'A World Equilibrium Model of the Oil Market', *The Review of Economic Studies* **90**(1), 132–164.

Carleton, Tamma A, Amir Jina, Michael T Delgado, Michael Greenstone, Trevor Houser, Solomon M Hsiang, Andrew Hultgren, Robert E Kopp, Kelly E McCusker, Ishan B Nath, James Rising, Ashwin Rode, Hee Kwon Seo, Arvid Viaene, Jiacan Yuan and Alice Tianbo Zhang (2020), Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits, Working Paper 27599, National Bureau of Economic Research. Series: Working Paper Series.

Castro-Vincenzi, Juanma, Gaurav Khanna, Nicolas Morales and Nitya Pandalai-Nayar (2024), 'Weathering the Storm: Supply Chains and Climate Risk'.

Chari, V. V., Juan Pablo Nicolini and Pedro Teles (2023), 'Optimal Cooperative Taxation in the Global Economy', *Journal of Political Economy* **131**(1), 95–130. Publisher: The University of Chicago Press.

Chen, Zhiqi (1997), 'Negotiating an Agreement on Global Warming: A Theoretical Analysis', *Journal of Environmental Economics and Management* **32**(2), 170–188.

Chichilnisky, Graciela and Geoffrey Heal (1994), 'Who should abate carbon emissions?: An international viewpoint', *Economics Letters* **44**(4), 443–449.

Clausing, Kimberly A. and Catherine Wolfram (2023), 'Carbon Border Adjustments, Climate Clubs, and Subsidy Races When Climate Policies Vary', *Journal of Economic Perspectives* **37**(3), 137–162.

Copeland, Brian R., Joseph S. Shapiro and M. Scott Taylor (2021), 'Globalization and the Environment'.

Costinot, Arnaud, Dave Donaldson, Jonathan Vogel and Ivan Werning (2015), 'Comparative Advantage and Optimal Trade Policy *', *The Quarterly Journal of Economics* **130**(2), 659–702.

Cruz, Jose-Luis and Esteban Rossi-Hansberg (2022), 'Local Carbon Policy'.

Cruz, Jose-Luis and Esteban Rossi-Hansberg (2024), 'The Economic Geography of Global Warming', *The Review of Economic Studies* **91**(2), 899–939.

Davila, Eduardo and Andreas Schaab (2023), 'Optimal Monetary Policy with Heterogeneous Agents: Discretion, Commitment, and Timeless Policy'.

Davila, Eduardo and Ansgar Walther (2022), 'Corrective Regulation with Imperfect Instruments'.

Dietz, Simon, Frederick van der Ploeg, Armon Rezai and Frank Venmans (2021), 'Are Economists Getting Climate Dynamics Right and Does It Matter?', *Journal of the Association of Environmental and Resource Economists* **8**(5), 895–921. Publisher: The University of Chicago Press.

Dingel, Jonathan I., Kyle C. Meng and Solomon M. Hsiang (2019), 'Spatial Correlation, Trade, and Inequality: Evidence from the Global Climate'.

Douenne, Thomas, Albert Jan Hummel and Marcelo Pedroni (2023), 'Optimal Fiscal Policy in a Climate-Economy Model with Heterogeneous Households'.

Ernst, Anne, Natascha Hinterlang, Alexander Mahle and Nikolai StÃ¤hler (2023), 'Carbon pricing, border adjustment and climate clubs: Options for international cooperation', *Journal of International Economics* **144**, 103772.

Falkner, Robert (2016), 'The Paris Agreement and the new logic of international climate politics', *International' Affairs* **92**(5), 1107–1125.

Falkner, Robert, Naghmeh Nasiritousi and Gunilla Reischl (2022), 'Climate clubs: politically feasible and desirable?', *Climate Policy* **22**(4), 480–487. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/14693062.2021.1967717.

Farrokhi, Farid and Ahmad Lashkaripour (2024), 'Can trade policy mitigate climate change', *Econometrica* .

Fontagne, Lionel and Katheline Schubert (2023), 'The Economics of Border Carbon Adjustment: Rationale and Impacts of Compensating for Carbon at the Border', *Annual Review of Economics* **15**(Volume 15, 2023), 389–424. Publisher: Annual Reviews.

Golosov, Mikhail, John Hassler, Per Krusell and Aleh Tsyvinski (2014), 'Optimal Taxes on Fossil Fuel in General Equilibrium', *Econometrica* **82**(1), 41–88. eprint: https://onlinelibrary.wiley.com/doi/pdf/10.3982/ECTA10217.

Hagen, Achim and Jan Schneider (2021), 'Trade sanctions and the stability of climate coalitions', *Journal of Environmental Economics and Management* **109**, 102504.

Harstad, BÃ¥rd (2023), 'Pledge-and-Review Bargaining: from Kyoto to Paris', *The Economic Journal* **133**(651), 1181–1216.

Harstad, BÃ¥rd, Francesco Lancia and Alessia Russo (2022), 'Prices vs. quantities for self-enforcing agreements', *Journal of Environmental Economics and Management* **111**, 102595.

Hassler, John, Per Krusell and Anthony A Smith Jr (2016), Environmental macroeconomics, *in* 'Handbook of macroeconomics', Vol. 2, Elsevier, pp. 1893–2008.

Hassler, John, Per Krusell and Conny Olovsson (2010), 'Oil monopoly and the climate', *American Economic Review* **100**(2), 460–64.

Hassler, John, Per Krusell and Conny Olovsson (2019), Directed technical change as a response to natural-resource scarcity, Working Paper 375, Sveriges Riksbank Working Paper Series.

Hassler, John, Per Krusell and Conny Olovsson (2021), 'Presidential Address 2020 Suboptimal Climate Policy', *Journal of the European Economic Association* **19**(6), 2895–2928.

Hoel, Michael (1991), 'Global environmental problems: The effects of unilateral actions taken by one country', *Journal of Environmental Economics and Management* **20**(1), 55–70.

Hoel, Michael (1994), 'Efficient Climate Policy in the Presence of Free Riders', *Journal of Environmental Economics and Management* **27**(3), 259–274.

Hsiao, Allan (n.d.), 'Coordination and Commitment in International Climate Action'.

Iverson, Terrence (2024), 'Tiered Climate Clubs: Global Abatement Without Global Agreement *'.

Kortum, Samuel S. and David A. Weisbach (2021), 'Optimal Unilateral Carbon Policy'.

Kotlikoff, Laurence, Felix Kubler, Andrey Polbin, Jeffrey Sachs and Simon Scheidegger (2021), 'Making Carbon Taxation a Generational Win Win', *International Economic Review* **62**(1), 3–46. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/iere.12483.

Kotlikoff, Laurence J., Felix Kubler, Andrey Polbin and Simon Scheidegger (2021), 'Can Today's and Tomorrow's World Uniformly Gain from Carbon Taxation?'.

Krusell, Per and Anthony A. Smith Jr (2022), 'Climate change around the world'.

Maggi, G. (2016), Issue Linkage, *in* 'Handbook of Commercial Policy', Vol. 1, Elsevier, pp. 513–564.

Maggi, Giovanni and Robert W. Staiger (2022), 'International Climate Agreements and the Scream of Greta'.

Mahdiraji, Hannan Amoozad, Elham Razghandi and Adel Hatami-Marbini (2021), 'Overlapping coalition formation in game theory: A state-of-the-art review', *Expert Systems with Applications* **174**, 114752.

Nordhaus, William (2015), 'Climate Clubs: Overcoming Free-riding in International Climate Policy', *American Economic Review* **105**(4), 1339–1370.

Nordhaus, William (2021), 'Climate Club Futures: On the Effectiveness of Future Climate Clubs', *Cowles Foundation Discussion Papers* .

Nordhaus, William D. and Zili Yang (1996), 'A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies', *The American Economic Review* **86**(4), 741–765. Publisher: American Economic Association.

Okada, Akira (2023), 'A dynamic climate negotiation game achieving full cooperation', *Journal of Economic Behavior & Organization* **214**, 657–669.

Ossa, Ralph (2014), 'Trade Wars and Trade Talks with Data', *American Economic Review* **104**(12), 4104–4146.

Pickering, Jonathan, Steve Vanderheiden and Seumas Miller (2012), '"If Equity's In, We're Out": Scope for Fairness in the Next Global Climate Agreement', *Ethics & International Affairs* **26**(4), 423–443.

Ray, Debraj and Rajiv Vohra (2015), Chapter 5 - Coalition Formation, *in* H. P.Young and S.Zamir, eds, 'Handbook of Game Theory with Economic Applications', Vol. 4, Elsevier, pp. 239–326.

Rudik, Ivan, Gary Lyn, Weiliang Tan and Ariel Ortiz-Bobea (2021), 'The Economic Effects of Climate Change in Dynamic Spatial Equilibrium'.

Shapiro, Joseph S (2021), 'The Environmental Bias of Trade Policy*', *The Quarterly Journal of Economics* **136**(2), 831–886.

Tarr, David G., Dmitrii E. Kuznetsov, Indra Overland and Roman Vakulchuk (2023), 'Why carbon border adjustment mechanisms will not save the planet but a climate club and subsidies for transformative green technologies may', *Energy Economics* **122**, 106695.

Weisbach, David A., Samuel Kortum, Michael Wang and Yujia Yao (2023), 'Trade, Leakage, and the Design of a Carbon Tax', *Environmental and Energy Policy and the Economy* **4**, 43–90. Publisher: The University of Chicago Press.

Weitzman, Martin L. (2003), Prices vs. Quantities 1 , 2, *in* 'The Theory and Practice of Command and Control in Environmental Policy', Routledge. Num Pages: 15.

Weitzman, Martin L. (2015), 'Internalizing the Climate Externality: Can a Uniform Price Commitment Help?', *Economics of Energy & Environmental Policy* **4**(2), 37–50. Publisher: International Association for Energy Economics.