STRATEGIC AND INTERTEMPORAL FEEDBACKS WHEN IMPACTS AND HUMAN RESPONSES TO CLIMATE CHANGE ARE HETEROGENOUS ACROSS COUNTRIES

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Overview

The projected impacts of anthropogenic climate change are highly heterogeneous across the globe. They can even, at least conceptually, be welfare-improving in some situations: Some level of warming may increase agricultural productivity and decrease energy consumption for space heating in a cold region, while deterring agricultural productivity and increasing energy consumption for space cooling in a warm one. In this disaggregated view, climate change is no longer the archetype of a global public bad: It generates negative externalities to some of its contributors and positive externalities to some others. This creates conflicting incentives for climate change mitigation *versus* adaptation across regions and, since the climate change problem is essentially dynamic, over time. Even though the net impacts of climate change are likely negative, the possibility of some positive impacts can explain the reluctance of some countries to join a global agreement and engage in costly mitigation measures.

The goal of this paper is to examine the feedbacks across space and time faced by heterogenous regions of the world in the context of climate change, acknowledge their implications in terms of mitigation *versus* adaptation strategies, and integrate them to discuss optimal consumption pathways.

The exposition focuses on energy consumption for weatherization services, that is, space heating and cooling in buildings. The motivation is threefold. First, the figures at stake are substantial: Worldwide, the building sector is responsible for 33% of energy-related CO_2 emissions; the share of space heating and cooling in this figure, though poorly known at the global level, is likely to be 40 to 70%; these energy services are expected to grow threefold by 2100. Second, this techno-economic system provides a small-scale model of the broader human-climate retroactions: On the one hand, space heating and cooling needs are determined by outdoor temperature; on the other hand, they are satisfied through energy consumption, which generates CO_2 emissions and, ultimately, changes outdoor temperature. Third, heterogeneity across regions is exacerbated: Cold regions, in which energy consumption for space heating prevails, may derive net benefits from global warming, while warm regions, where cooling prevails, may incur net losses. This adds contrast to the feedbacks under scrutiny.

Methods

We build a differential game model of the problem. We assume a partition of the world into two players: A cold region, where energy consumption for space heating prevails over cooling (at least in the short term), and a warm one, where the reverse is true. Each player can engage in mitigation by investing in energy efficient capital (e.g. insulation). Adaptation corresponds to no investment. In addition, players have a second control over energy consumption: They can change the level of energy service (e.g. heating and cooling thermostat). This allows us to discuss rebound effects. The model incorporates three state variables: the level of energy efficient capital for heating, for cooling, and the atmospheric concentration of CO_2 due to past energy consumption for space heating and cooling.

We proceed in two steps. First, we decompose elementary mechanisms by discussing the following questions: *How does one region's actions affect the other's? What is the optimal timing of energy efficiency investment in each region? What is the optimal timing of energy service consumption in each region?*. Second, we integrate these feedbacks and discuss long-term closed-loop equilibria.

Results

First, we focus on the static, non-cooperative game played by two symmetric regions. We take coordinated adaptation as the baseline scenario, which yields zero payoff to both regions. Mitigation by only one country yields 1 to the warm region and -1 to the cold region, plus a mitigation cost of 0.5 to whichever region mitigates. Coordinated mitigation yields 2 to the warm region and -2 to the cold region, plus a mitigation cost of 0.5 to both regions. This leads to the following payoff matrix:

		Cold region	
		Mitigates	Adapts
Warm region	Mitigates	1.5; -2.5	0.5;-1
	Adapts	1;-1.5	0,0

A dominant strategy Nash equilibrium emerges in which the cold region adapts and the warm one mitigates. This equilibrium does not coincide with the Pareto equilibrium, in which both regions adapt. There will be less emissions under *laissez-faire* than would be socially optimal. Unlike the Nash equilibrium, the location of the Pareto equilibrium may change if the weights of the regions change. For instance, coordinated mitigation can be socially optimal if the warm region is big enough.

Second, we assume away interactions between regions and focus on the optimal mitigation effort in one region, over two periods. We find that the warm region will decrease its mitigation effort over time: In period 2, it does not take into account the implications of its action in the future and simply mitigates, to the extent that marginal mitigation costs equalize marginal energy expenditure savings; in contrast, in period 1, it mitigates in excess of its effort in period 2, in order to have persistent energy savings and mitigate the temperature increase in period 2. The cold region will behave like the warm one as long as the marginal effect of present emissions on future energy consumption is less than the effect of present energy efficiency investment on future energy consumption. Otherwise, the temperature increase due to past energy consumption is so high that it generates more energy savings in period 2 than energy efficiency investments undertaken in period 1. The mitigation effort will thus increase over time: It will be refrained in period 1 to allow for some warming in period 2; it will be important in period 2 to minimize current expenditure, regardless of the future.

Third, we complexify the model by focusing on the second control for each region: the heating/cooling service. We find that the warm region will cool more in the first period than in the second one to prevent high cooling needs in the future. Compared to the constant energy service case treated previously, this will lower the speed at which energy efficient investment decreases. In contrast, the cold region will do the opposite: Heat less in the second period than in the first one. Compared to the constant energy service case, this will speed up the “increasing investment” regime and slow down the “decreasing investment” regime.

Lastly, we integrate these feedbacks to discuss long-term equilibria. One interesting pathway involves coordinated mitigation towards an asymptotic steady state that can be seen as ‘the end of heating’. At the end of heating, global warming has fully cancelled out heating needs in the cold region. The world subsequently turns into a global cooler and both regions follow a mitigation strategy. Because of intertemporal feedbacks, the two regions will in fact coordinate their mitigation efforts so that the cold region converges towards the end of heating without ever passing it.

Conclusions

The focus on weatherization services has limitations. Most of them relate to the fact that the system considered in not physically closed. Global warming is caused by GHG emissions from all sectors, not only weatherization services; this dilutes the retroactions building managers can anticipate from their actions. In turn, climate change impacts go far beyond changes in weatherization needs: Droughts, storms or sea level rise, which are unambiguously negative impacts, are overlooked in this paper. Hence, our framework may overemphasize some feedbacks.

Despite these limitations, we consider our framework exhaustive enough to allow one to think broadly about human-climate interactions, with broad sectoral applications. For instance, our model suggests that cold regions may, at least in early years, want to let energy consumption for space heating go in order to reduce space heating needs in the future. This effect can easily be reframed as cold countries, such as Russia or Canada, delaying the implementation of costly decarbonization measures in their transportation sector to increase the productivity of their agriculture in the near future.