Volume Title: The Design and Implementation of U.S. Climate Policy

Volume Author/Editor: Don Fullerton and Catherine Wolfram, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-36914-0; 978-0-226-26914-6

Volume URL: http://www.nber.org/books/full10-1

Conference Date: May 13-14, 2010

Publication Date: September 2012

Chapter Title: Comment on "Markets for Anthropogenic Carbon within the Larger Carbon Cycle"

Chapter Author(s): Wolfram Schlenker

Chapter URL: http://www.nber.org/chapters/c12159

Chapter pages in book: (p. 102 - 105)

Location Matters: What have We Learned?" *Environmental and Resource Economics* 5:95–113.

Comment Wolfram Schlenker

The chapter by Severin Borenstein discusses how market-based approaches might have to be adjusted for human activities that impact the carbon flux differently across locations. The question is whether geographic variations in the carbon flux are large enough and measureable enough to usefully employ a spatially varied carbon-pricing scheme. Experience with markets for sulfur-dioxide emissions indicates that pollution-pricing mechanisms can greatly enhance efficiency, even if they do not perfectly account for geographic differences in the marginal costs and benefits of emissions.

Market-Based Regulation

The main appeal of market-based regulations (taxes or permits) is that they minimize abatement cost for a given reduction of pollution. Sulfur-dioxide (SO_2) emissions were subject to a permit trading system in the United States in the 1990s. Stavins (1998) argues that it resulted in annual cost savings of more than $1 billion as firms with the lowest abatement cost reduced SO_2 emissions. It is celebrated as a big success story and has become a benchmark for modern environmental policy.

A tax or permit system can lead to suboptimal outcomes if it interacts with other distortions, or a unit of pollution causes damages depending on where it is emitted. For example, under the NO_x budget program, regulated or publicly owned utilities were more likely to install costly capital equipment (Fowlie 2010). These capital investments generated excess permits that could be sold to firms in deregulated and restructured electricity markets. Since NO_x is a local pollutant, it matters where a unit is emitted. As it turns out, deregulated markets are dirtier to begin with. Permit trading therefore shifted pollution toward areas where a unit of pollution is more damaging.

Market-based regulations have the potential to increase pollution damages if the location of the emission matters (a nonuniformly mixing pollutant). In such a case the tax rate would have to differ between locations, or permits would no longer be traded one-for-one. Instead, differentiated tax and trading ratios incorporate that marginal damages vary between regions.

While CO_2 perfectly mixes in the atmosphere, Borenstein emphasizes that

Wolfram Schlenker is assistant professor of economics at Columbia University and a faculty research fellow of the National Bureau of Economic Research.

For acknowledgments, sources of research support, and disclosure of the author's material financial relationships, if any, please see http://www.nber.org/chapters/c12159.ack.

a policy that reduces greenhouse emissions in one area might increase it in another area.

The Carbon Cycle

Anthropogenic emissions are a small part of the annual carbon cycle. Humans account for carbon emissions of roughly 9 GtC compared to a natural carbon flux of 210 GtC. About half of anthropogenic emissions stay in the atmosphere while the other half gets absorbed by oceans, vegetation, and soils. Each GtC of anthropogenic emissions therefore increases global CO_2 levels by roughly 2.25 ppm (parts per million).

Is this amount of anthropogenic emissions large? The CO_2 levels have fluctuated in the past. Reconstructions for the last 400,000 years by Hansen et al. (2008) show that CO_2 concentrations fluctuated between 200 ppm and 300 ppm, or roughly forty years worth of current emissions (holding current absorption rates constant). Reconstructed temperature records in the Arctic changed in phase by up to 10C. Higher latitudes show larger fluctuations in warming than the global average, and the authors estimate that a doubling of CO_2 concentrations would result in a +3C increase in temperature accounting only for fast feedback processes, and +6C when slow feedback processes are also included. Different models give various estimates of the climate sensitivity as there are large numbers of unresolved uncertainties.

There are at least several layers of uncertainty related to aggregate CO_2 emissions: (a) will sinks continue to absorb CO_2 or will they slow down in the future; (b) how do changes in greenhouse gas concentrations translate into changes in the global temperature; and (c) what are the feedback loops between a warming world and greenhouse gases releases; for example, will there be an extra release of methane when permafrost soils thaw? What is common to all these sources of uncertainty is that they relate to aggregate emissions. If the goal is to minimize compliance cost, a uniform tax rate around the world or a permit system where all countries participate would yield the optimal result. As uncertainty resolves, the regulating agency could adjust the tax rate or number of emissions permits. Several US regulations require periodic reauthorization, at which point these optimal levels could be revised.[1]

Another area with deep uncertainty depends on local anthropogenic interactions with the carbon cycle. Since the natural carbon flux is more than twenty times as large as anthropogenic emissions, even small local feedback loops with the natural carbon flux can in principle be an important component of anthropogenic emissions. Two examples can illustrate this point.

Agricultural policies can both directly impact the carbon flux (tilling

1. Weitzman (1974) demonstrates that the expected deadweight loss can vary under a tax or permit system when there is uncertainty about the marginal abatement cost curve. The optimal choice depends on the slopes of the marginal damage and marginal abatement cost curves.

releases carbon, and the use of fertilizer can release greenhouse gases) and indirectly as supply responses to changing prices occur predominantly on the extensive margin (Roberts and Schlenker 2010). If newly cultivated land comes from deforestation, large amounts of greenhouse gases can be released as 20 percent of carbon emissions are related to land-use change. If, on the other hand, fallow land is brought back into production, the land expansion might be a carbon sink. It crucially depends on where the expansion takes place.

Pollution control policies also affect plant growth and soil practices. Auffhammer, Ramanathan, and Vincent (2006) show that climate change due to brown clouds (air pollution) and greenhouse gases contributed to the slowdown in Indian harvest growth rates. A reduction in harvest growth again impacts world food prices and leads to expansions elsewhere. These local interactions have the potential to impact the carbon flux, and are not incorporated in current policy proposals.

Local feedback effects would require locally differentiated taxes or permit trading ratios. Incorporating local differences would increase economic efficiency. At the same time, the countries of the world have a difficult time agreeing to an overall limit; agreeing on local feedback loops might prove even more daunting: every country will have an incentive to argue that it is subject to a feedback loop that reduces the carbon flux to the atmosphere. In doing so it would obtain a more advantageous trading ratio.

Conclusion

There is considerable uncertainty about all the feedback effects between rising greenhouse gas concentrations in the atmosphere and changes in climate. Uncertainties related to aggregate emissions are easier to incorporate in a market-based system of taxes or permits as regulators only have to adjust the overall tax rate or pollution cap as more information becomes available. On the other hand, local feedback effects would require location-specific taxes or permit trading systems. Once uncertainties are resolved, the entire set of bilateral coefficients would have to be revised, which directly impact the cost of the regulation in each region. Individual countries have a strong incentive to play up feedback loops that reduce the carbon flux into the atmosphere while ignoring feedback loops that reduce the carbon flux. The potential gains from nonuniform regulations should be weighed against the possible implications they have for additional rent seeking and free-riding, which can also cause significant deadweight losses.

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