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Some Basic Ideas

Kala Krishna

3.1 Introduction

On June 26, 2009, the American Clean Energy and Security Act (or the Waxman-Markey Bill after its authors) was approved by the US House of Representatives. It never cleared the Senate, however, and it now seems highly unlikely. Yet this event marked the first time either house approved a law meant to limit emissions to combat climate change and has resulted in a flurry of economics research in the area. The bill would have essentially created cap-and-trade programs for greenhouse gas emissions and specify reductions in total emissions of 17 percent starting from 2012. See Congressional Budget Office (CBO) (2009) for a good summary of the bill and its implications. News at the time indicated that the Senate version of the bill would have been weaker, with utilities being subject to caps by 2012 but with manufacturers being phased in only by 2016. Discussion at the time indicated floor and ceiling prices of ten dollars and thirty dollars per ton that will be adjusted for inflation.[1] It would have had product-specific import taxes based on the cost disadvantage created by such cap-and-trade measures on countries that do not limit their emissions (called border tax adjustments or BTAs for short). Such BTAs would, it was argued, both level the playing field for US firms and prevent leakage, where leakage is the change in foreign

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1. The price ceiling would insure that businesses do not face too high a cost of permits as these are part of their costs. The floor protects them from the risk of investing in technology to reduce emissions only to find that it was not worth their while ex post.

emissions as a share of the domestic emissions reductions. They may also be legal under GATT/WTO; see Frankel (2009).

Existing studies suggest that the size of the BTAs would likely be quite small for most products. This is why, as drafted, US legislation envisioned BTAs mainly for producers in energy-intensive sectors. These include chemicals, paper, ferrous metals, nonferrous metals, and mineral products. However, there is considerable variation in the estimates of the effect of the kinds of emissions limits being discussed. Atkinson et al. (2010), which was a background paper for World Development Report 2010, uses a partial equilibrium model to estimate that if carbon is taxed at fifty dollars per ton of CO_2, Chinese exports to the United States would face an average tariff rate of 10.3 percent. Mattoo et al. (2009) employ a multicountry computable general equilibrium framework (the Environmental Impact and Sustainability Applied General Equilibrium Model, or ENVISAGE model). They compare outcomes under different scenarios for BTAs of a carbon tax that reduces emissions by 17 percent relative to 2005 by all Organization for Economic Cooperation and Development (OECD) countries.[2] Their work suggests some room for leakage, and that BTAs do little to reduce emissions. Most of the action in terms of growth of emissions comes from projected growth in the developing world. They calculate that a 17 percent reduction in emissions in energy-intensive goods only, as proposed by the United States, would lead to total emissions in 2025 relative to 2005 rising by about 54 percent (56.9 percent without BTAs). The 17 percent reduction in emissions by the OECD countries is more than undone by low- and middle-income countries raising their emissions by about 122.5 percent in the absence of BTAs (117.2 percent with BTAs based on foreign emissions).

The effect of BTAs on emissions and exports is also shown to be sensitive to who is reducing emissions. Boehringer, Fischer, and Rosendahl (2010) suggest that reducing emissions is significantly more costly in the European Union (EU) than the United States, mostly because EU emissions are already lower than comparable US ones. Moreover, because the EU is more open than the United States, leakage is greater from EU reductions than US ones. Full border tax adjustment policies, which include a tax on imports and a subsidy to exports, are quite effective in reducing leakage, with the import tariff being more important than the export subsidy.

The computable general equilibrium models used in the literature tend to be a bit of a black box. This chapter provides some intuition behind what goes on in general equilibrium by intuitively explaining what lies behind the demand for emissions. It traces out how a reduction in total emissions allowed in one country affects the general equilibrium and the determinants

2. Mattoo et al. (2009) and McKibbin and Wilcoxen (2009) among others, argue that whether developing country emissions or developed country ones are used as a basis for the BTA makes a substantial difference to developing country exports, leakage, and world emissions.

of the extent of leakage in the model. Finally, it concludes with some implications for policy.

3.2 Emissions in a General Equilibrium Setting

What is the easiest way of modeling emissions in production? A direct way is to treat emissions permits as an input into production. In the absence of emissions controls, this input is in unlimited supply and has a price of zero. One way to think of emissions controls is that they make the supply of this input (emissions permits) finite and binding; that is, their equilibrium price is positive. Let us think of emission permits as being needed whenever carbon-based fuels are used, with the number of permits needed being equal to a constant multiple (e) of the fuel needed for production. Thus, using a unit of fuel results in e units of emissions and so needs e emissions permits. This makes the *effective* price of fuel used in production higher by the emissions permit price times the emissions created by a unit of fuel. Assume that this multiple is fixed for the time being, though of course, this is another margin of adjustment as higher prices of emissions will create incentives to reduce this multiple and economize on emissions permits. This is known in the literature, see Copeland and Taylor (2003), as the technique effect.

Partial equilibrium and general equilibrium can give very different answers when analyzing the effect of emissions controls. In partial equilibrium we would consider the demand and supply of emissions, keeping the prices in other markets for good and factors constant. As the demand for emissions is a derived demand, that is, it is derived from the demand for the goods that use emissions to make them, we could write the demand for emissions as e times the unit input requirement of fuel needed to make a unit of the good in question times the domestic output of the good. If there is substitution between inputs, an increase in the price of emissions will cause substitution away from the use of fuel (and hence emissions) in production so that at a given output of the goods produced, the demand for emissions (and fuel) will fall. This will give a downward sloping demand for emissions permits that comes solely from substitutability between inputs. If the supply of emissions is reduced, the price of emissions permits will rise. This increase in the price of emissions will reduce emissions in partial equilibrium by making firms economize on the use of emissions, which is what moves them up along their demand curve for emissions.

Let us take this one step further. What is the effect on the demand for goods made from using these permits? Well, under competition, an increase in the cost of an input (emissions permits) will raise the marginal (and average) cost of production, shifting the supply curve of these products (recall that supply is just the marginal cost curve) inward and upward so that supply and demand for these goods will intersect at a higher price. In this way, we expect the price of goods that use emissions to rise as well when emissions are targeted. However, this will have two effects: it will reduce our production and consumption of these goods (maybe we will substitute toward cleaner goods whose price has not risen) and this will shift the demand for emissions inward and reduce our emissions as well as our use of fuels (which should also reduce the world price of fuels). Second, to the extent that the higher prices for these pollution-creating final goods make the rest of the world want to produce more of them, and to the extent that lower fuel prices encourage the use of fuels (and hence emissions) in their production, the rest of the world's emissions will rise. To the extent that they use dirtier techniques of production, that is, their *e* is higher, this channel may even raise the total level of emissions in the world. This is the "leakage" that unilateral emissions controls will create. How large is this leakage?

Well, it turns out that the answer depends on the details of the model. It is well understood in trade that in the standard Heckscher-Ohlin model of trade and general equilibrium, where goods made in different countries are perfect substitutes for each other, if factors are reallocated between countries then, under certain conditions, there will be NO effect on world equilibrium prices.[3] All that will happen is that output will move from the country that has lost the input to the country that has gained it. Why? Well, if one country reduces its supply of emissions, say by ten units, and the other has NO emissions limits in place, then the latter can increase its emissions by the same amount (ten units) as the reduction by the former. But this is exactly like reallocating inputs between countries so that this classic trade result has immediate relevance. In this case, the leakage may be 100 percent: we may have no effect of emissions controls in one country on world emissions.[4]

To get around such issues, most computable models use settings where the goods made by different countries are imperfect substitutes for each other. As a result, unilateral emissions controls will, by raising the cost of production, make the emissions-controlling country's goods more expensive relative to those of other countries, causing substitution away from them toward the output of nonemissions controllers and consequent leakage. The extent of such leakage naturally depends on the *substitutability* between these goods in demand. If this substitutability is low, there may be little leakage, but if it is high, there may be a lot. A convenient way of modeling this substitutability between goods is to use the constant elasticity of substitution preference structure where a single parameter (or if a nested setup is used, a few parameters) define this substitutability. This is what makes the elasticity of substitution in the utility function a key parameter.

3. Technically, in the workhorse Heckscher-Ohlin model used in international trade, this is true if the world endowment point is inside what is called the Factor Price Equalization or FPE region. This region is large if there are enough goods relative to factors of production.

4. In the working paper version of this chapter, I lay out a Hecksher-Ohlin type model where this extreme result does not hold, yet remains reasonably tractable. I use the model to formally derive the effects of unilateral emissions controls.

3.3 Policy Implications

A point made in the literature is that unilateral emissions reductions will be at least partly undone by leakage. This leakage is the cause of much concern in the literature. Earlier, I argued that the extent of this leakage predicted by economic models will differ according to the model chosen (for example, goods being perfect substitutes across countries as in the HOS model or not) and the level chosen of certain key parameters (like the extent of substitution between goods made by different countries). The model and parameters used in simulating the effect of various policies will themselves yield the results. The computable general equilibrium literature tends to calibrate the chosen model to the data, and then run counterfactuals to help predict the effects of various policies. But this approach often does not give the reader insight into how alternative modeling assumptions would affect the outcomes of the policy simulations. In addition, the models themselves are often so complex that they are inaccessible to outsiders.

In addition to providing numbers from quantitative theorizing of this kind, general equilibrium models have a great deal of policy content in terms of simple insights. A good example might be the question of whether putting limits on the rest of the world's emissions, at levels that are not binding on them, is worth doing. After all, why bother if the controls are not yet binding, or only barely binding, where the price is very small? That would seem to make the controls on the rest of the world's emissions almost irrelevant. However, it is easy to see that the presence or absence of ANY controls can make a difference. If the rest of the world has caps on their own total emissions, *even if these caps are just binding,* then there will be no such leakage.

Why? Think of the standard Heckscher-Ohlin model of trade and general equilibrium, where goods made in different countries are perfect substitutes for each other. Now, as long as there are caps in all countries on emissions, emissions controls by one country is not equivalent to reallocating factors between countries, but to a reduction in world emissions permits. Thus, there will be an effect on the world equilibrium and the increasing scarcity of emissions permits in one country will result in a reallocation of supply of dirty goods toward the country with less stringent emissions limits until its emissions prices also rise! In this way, unilateral emissions reductions will have multilateral effects. With universal caps on emissions, a reduction in emissions permits in one country will raise the price of emissions everywhere and reduce world emissions one for one with the unilateral reductions undertaken in emissions. This insight has another important implication: the loss in competitiveness engendered by higher emissions prices in the country reducing emissions will be much less of an issue when all countries limit their emissions than when they do not and BTAs will also be less of an issue in terms of maintaining a level playing field.

The main point is that it is not just the level, but the *existence* of emissions controls in the rest of the world (ROW) that matters. Getting the rest of the world to commit to controls on emissions, even if the level of emissions they commit to is high, is a step in the right direction as it affects the nature of international transmission. If the ROW has no controls on emissions, then the price of emissions there is fixed at zero no matter what policy home enacts. Tighter emissions limits at home necessarily tilts the playing field in favor of rest of the world. But if the rest of the world has any limit on emissions, then tightening emissions at home will raise demand for emissions abroad and raise the price of emissions abroad, preventing leakage abroad, limiting the loss of competitiveness at home, and making the home country more willing to reduce its own emissions.

If emissions are controlled only in a subset of countries, there will inevitably be some leakage. How large might this leakage be? Trade theory has some further insights to offer here. First, if some factors are mobile, and in today's world they seem to be increasingly so, factor mobility can make emissions controls much less binding. It is well understood by now, that attempts to tax trade will be undone by the movement of capital (i.e., firm location) in certain situations a la Mundell (1957). In a similar vein, taxing emissions will result in firm relocation if factors are mobile. This relocation could be very large depending on the setting and model used. Babiker (2005) produces estimates for leakage of over 100 percent in an oligopolistic model with increasing returns to scale when relocation is explicitly allowed for.[5]

How large leakage would be is ultimately an empirical matter. Hanna (2010) shows that US multinationals increased their foreign assets by about 5.3 percent and foreign output by about 10 percent in response to the Clean Air Act Amendment, which dramatically strengthened US environmental regulations. Such responses even make things worse in terms of emissions if migrating firms use more polluting technologies abroad than at home.[6]

Recent work in trade, unrelated to the previous model, may also be germane. A concern in, for example, Mattoo et al. (2009) is that BTAs imposed in order to level the playing field may have large effects on the exports of non-emissions-controlling developing countries. While competitive models would suggest that lower exports to the United States when the United States has BTAs could be made up by larger exports elsewhere, in monopolistically competitive settings, the *opposite* prediction exists.

This point is made in Cherkashin et al. (2010). Suppose that the develop-

5. In related work, Cherkashin et al. (2010) show that in heterogeneous firm oligopolistic models, entry/exit by firms in response to trade policies are very large and account for most of the adjustment in output that occurs, suggesting that such settings might give large leakage effects in the emissions control context as well.

6. In contrast, while examining the EU's emissions trading program, Grubb and Neuhoff (2006) argue that the net value at stake is low for most sectors as the cost increases by emissions trading in the ten to thirty euro range are small for all but a few industries. However, if firms are very responsive to such differences, even small changes could have large effects.

ing world has no emissions limits in place and the United States does. Moreover, to prevent leakage, the United States also has BTAs. Cherkashin and colleagues argue that in a monopolistically competitive setting, the lower exports to the United States due to BTAs would be accompanied by *lower* exports to *all* other markets. The argument is elegant. The fall in expected profits from exports to the United States will make the expected profits of all existing firms negative. This will cause an exit of firms from these industries and this exit will raise the expected profits of all remaining firms. However, when firms exit, they exit from all their markets. As a result, developing country exports to *all* markets fall. Therefore the short-run effects of emissions limits, with entry held constant, are likely to be very different from the long-run ones. It would be unfortunate if the adverse effects on developing country exports of BTAs were underestimated.

Ultimately, the effects of unilateral emissions controls and the extent of leakage is an empirical issue. So why don't we ask what the data shows? After all, carbon taxes are levied in the EU.[7] Surprisingly enough, empirical work suggests that there is no effect of carbon taxes on international competitiveness for the EU. In a recently published paper, Kee, Ma, and Mani (2010) run a standard gravity equation for exports from country i to j of product k with the usual variables (exporter and importer fixed effects, product fixed effects, distance, a common border, a common currency, a common free trade area, distance, etc.) augmented by dummies that indicate whether both i and j have a carbon tax in place, only the exporter has a carbon tax in place, and only the importer has a carbon tax in place. They find that carbon taxes by exporting countries do not seem to matter! This is the exact opposite of what people might have expected.

However, the probable reason for this result is an institutional one. As part of the deal in imposing the emissions controls and consequent carbon taxes, firms are allocated emissions permits for free roughly equal to their emissions before the policy is instituted. These allocations are conditional on being in the industry. The allocations should have no real effects, merely being a transfer of rents from the government to the firms in question had the allocations been unconditional. Making them conditional prevents exit of firms due to the greater costs imposed by emissions restrictions, and this may minimize the effects on output and exports. Of course, to the extent that marginal costs are due to the need to have emissions permits, we should see a shift back in the supply curves and a reduction in exports coming from this. That we do not see this suggests that these marginal costs increases are small for most industries. There may be exceptions for the most energy-intensive

7. They may be joined by Australia, a country responsible for a disproportionate extent of GHG emissions and that is extremely vulnerable to climate change However, the proposal is modest: it calls for a low carbon price (of about twenty-three dollars a ton) and a low carbon emission reduction target of 5 percent by 2020.

ones. However, even in these industries the same results are obtained. This suggests that there may have been overcompensation of emissions permits allocated to firms, which raised entry into the industry and undid the expected fall in supply of existing firms. This suggests that incorporating the allocation of free emissions permits as a pure rent transfer as is commonly done may give misleading results.

Emissions permits are likely to be allocated to firms in practice for political economy reasons. Making this allocation conditional gives them a subsidy element that seems to raise exports in the limited evidence available. But then, why have BTAs? After all, if the allocation was fully tied to input use, it would not raise costs at all! In this event, additional border taxes would clearly be tilting the playing field in favor of domestic firms and not leveling it. Clearly, more work on exactly how permit allocation rules affect the behavior of firms in practice is required to better understand the role for BTAs.

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Comment Meredith Fowlie

Policies designed to mitigate climate change are likely to have economy-wide impacts. Consequently, there is a strong case to be made for general equilibrium modeling that seeks to capture interactions between all sectors of the economy. A growing literature uses computable general equilibrium (CGE) models to quantify the economy-wide effects of greenhouse gas emissions regulations.

Kala Krishna begins her chapter with the observation that the CGE models commonly used in the literature tend to be nontransparent "black boxes." She provides a conceptual discussion of how greenhouse gas regulations imposed in one country can affect relative factor prices, trade flows, emissions, and emissions leakage in an open economy. The chapter provides useful insights into the inner workings of CGE models, emphasizing the value added vis-à-vis partial equilibrium approaches.

In this short comment, I first provide some context for Krishna's contribution. I then elaborate upon two of her key points. First, partial and general equilibrium models can yield very different predictions with respect to emissions leakage under incomplete climate change policy. Second, the extent of the emissions leakage predicted by CGE models will depend critically on the assumed structure of the model and the assumed values of some key model parameters.

Modeling Emissions and Emissions Leakage in an Open Economy

In her chapter, Krishna focuses primarily on general equilibrium modeling of emissions leakage. Leakage refers to any increase in emissions in one jurisdiction that occurs as a direct consequence of emissions regulation

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