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# Climate Change Policy in the International Context: Solving the Carbon Leakage Problem

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Abstract

*Under the Paris Agreement, nations set their own emissions goals and policies. As a result, climate policies vary widely across countries, with some countries imposing stringent emissions policies and others doing very little. A key problem when carbon policies vary across countries is that energy-intensive industries can relocate to places with few or no emissions restriction. Relocated industries would continue to pollute but would be operating in a less desirable location. Moreover, the countries that imposed strict emissions reductions lose the benefit of having those industries located domestically. This problem, known as leakage, is one of the key reasons the United States has failed to enact substantial climate change policies. Without a solution to leakage, it may be much more difficult to prevent catastrophic climate change.*

*The most commonly proposed response to leakage is to impose border adjustments—tariffs on imports based on the emissions from the production of the imported good, and rebates for exports of prior taxes or other prices imposed on emissions. Border adjustments ensure that the same price is paid regardless of the location of production. Border adjustments, however, are complex to impose and potentially incompatible with the WTO. Moreover, numerous studies show that border adjustments do not significantly improve the effectiveness of regional carbon policies.*

*We propose a better solution to the leakage problem. Our solution, the extraction/production tax or the EPT, combines a tax on domestic extraction with a conventional tax on emissions from domestic production. The core intuition behind this hybrid tax is that shifts in location due to carbon prices arise because of their effects on the price of energy seen by foreign actors. By reducing demand for fossil fuels, taxes on emissions from domestic production lower the global price of energy. In response, foreign actors increase their energy use, generating leakage. Border adjustments do not change this*

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*effect: carbon taxes on production with border adjustments also reduce the price of energy and increase energy use abroad. A tax on domestic extraction, however, raises the global price of energy because it reduces supply. A higher price of energy causes foreign users of energy to reduce their energy use, reducing leakage. Foreign extractors of energy, however, increase their supply. By combining a tax on the supply of energy and a tax on the demand for energy, the EPT sets these two forces against each other. A tax on the supply side of the market allows a lower tax on the demand side, with the two taxes set to minimize distortions in non-taxing regions.*

*The EPT not only better solves the economic problem of leakage than conventional approaches; it is also much simpler to implement. The EPT can be implemented by imposing a nominal tax on domestic extraction and border adjustments only on energy (but not goods in general) at a lower rate than the nominal extraction tax. Both an extraction tax and border adjustments on energy are easy to impose, which means that the EPT can greatly simplify the administration of carbon taxes. Finally, the EPT reduces concerns with WTO legality raised by traditional approaches. The EPT is a practical solution to the leakage problem and, therefore, can be a key piece to solving the global climate change problem.*

A central fact about climate change is that emissions of carbon dioxide ($CO_2$) cause the same harm regardless of where they originate.[1] Climate change is a global problem. We can only address climate change by reducing emissions everywhere. The least cost method of doing so would be to have a globally harmonized policy so that polluters in all locations face the same incentives to reduce emissions.

Nations, however, are differently affected by climate change, have different histories, are at different levels of development, have different sources and uses of energy, and are subject to widely different political pressures. Moreover, because climate change is a global problem, nations have an incentive to let others bear the cost of emissions reductions, that is to free ride on the efforts of others. As a result, rather than seeking a uniform approach to the problem, the current approach in global climate negotiations, most notably in the Paris Agreement, emphasizes universal participation, with each country choosing on its own how it wants to participate and its level of ambition.[2] The result is widely different climate change policies in different parts of the world, with some regions imposing relatively strict controls on emissions and others, including many of the worlds' largest emitters, doing very little.

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[1] For basic background on climate science see KERRY EMANUEL, WHAT WE KNOW ABOUT CLIMATE CHANGE, UPDATED EDITION (2018); DAVID ARCHER, THE LONG THAW: HOW HUMANS ARE CHANGING THE NEXT 100,000 YEARS OF EARTH'S CLIMATE (2008).

[2] Each nation's proposed level of ambition is determined by its "nationally determined contribution" or NDC. The NDCs are publicly announced and registered with the UN Framework Convention. For a list of NDCs, see https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs. Before Paris, climate negotiations emphasized an even stronger differentiation between countries, seeking obligations to reduce emissions only on developed countries, with developing countries allowed to have no restrictions whatsoever. For a discussion of this approach, see, Joseph E. Aldy & Robert N. Stavins, *Climate Negotiators Create an Opportunity for Scholars*, 337 SCIENCE 1043–1044 (2012).

The problem with this approach is that industries in nations that impose strict controls may simply relocate to countries with fewer or no restrictions on emissions. Relocated industries would continue to pollute, and the nations that attempted to address the problem of climate change would be effectively punished by losing those industries. This problem, known as leakage, is one of the central reasons that the United States has, so far, failed to act on climate change at a level anywhere near what is needed.[3] Leakage has been rightly called the defining issue in the design of regional climate policies.[4] If leakage is not solved, climate change may not be solved.

The most commonly proposed policy to address leakage is to impose what are known as "border adjustments." Border adjustments are combinations of import tariffs and export rebates. The import tariff is a tax on the emissions that arise from the production of imported goods, known as "embodied emissions." The tariff ensures that imports face the same carbon price as goods produced domestically. The export rebate gives back

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[3] For example, the 1997 Kyoto Protocol would have imposed obligations to reduce emissions on most developed countries without imposing similar obligations on developing countries, including China and India. In response, the United States Senate unanimously passed what is known as the Byrd-Hagel Resolution. The Byrd-Hagel Resolution's key operative provision stated that the United States should not sign a climate agreement that included mandatory emissions reductions for developed countries (known as the Annex I parties) without also imposing limits on developing country parties. See Byrd-Hagel Resolution (S. Res. 98) at https://www.congress.gov/bill/105th-congress/senate-resolution/98/text In announcing that he opposed the Kyoto Protocol, President Bush expressly invoked the Byrd-Hagel Resolution. For a history, see Susan Biniaz, *What Happened to Byrd-Hagel? Its Curious Absence from Evaluations of the Paris Agreement?*, Sabin Center for Climate Change Law, working paper, January 2018.

[4] Meredith L. Fowlie, *Incomplete Environmental Regulation, Imperfect Competition, and Emissions Leakage*, 1 AMERICAN ECONOMIC JOURNAL: ECONOMIC POLICY 72, 73 (2009). As discussed below, there are several hundred published estimates of leakage, an indication of its importance to climate policy.

any taxes or other prices (such as the cost of permits in a cap and trade system) on emissions paid domestically when a good is exported. By removing taxes on export, the rebate ensures that goods sold abroad face the same price as other goods sold in the foreign country. Every carbon-pricing proposal introduced in the United States Congress in recent years has included border adjustments.[5] The European Union has proposed a version of border adjustments known as the Carbon Border Adjustment Mechanism or CBAM to prevent leakage caused by its Emissions Trading System.[6] Recently, 3,623 economists, including 28 Nobel Laureates, signed a statement on carbon taxes that, among other things, stated that carbon taxes should include border adjustments.[7]

Border adjustments, however, pose serious legal and administrative problems. Measuring embodied emissions is difficult and expensive, and in

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[5] For a summary of carbon tax bills, see https://www.rff.org/publications/data-tools/carbon-pricing-bill-tracker/ (last visited July 11, 2021).

[6] See European Parliament, P9_TA(2021)0071, A WTO-compatible EU carbon border adjustment mechanism (March 10, 2021). CBAM would impose an import tariff on carbon-intensive goods but would not offer an export rebate.

[7] See "Economists' Statement on Carbon Dividends," available at https://www.econstatement.org/ (last visited June 8, 2022). The literature on border adjustments is vast. Citations to papers on the economic effects of border adjustments are found in note 30, on the implementation problems with border adjustments, in note 43, and on legal issues, in note 49. For recent surveys, see Aaron Cosbey et al., *Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature*, 13 REVIEW OF ENVIRONMENTAL ECONOMICS AND POLICY 3–22 (2019); Michael A. Mehling et al., *Designing Border Carbon Adjustments for Enhanced Climate Action*, 113 AMERICAN JOURNAL OF INTERNATIONAL LAW 433–481 (2019).

many cases, embodied emissions will be unknowable.[8] Moreover, the import tariff may be an illegal barrier to trade under the WTO and the export rebate may be an illegal subsidy, adding further uncertainty to the use of border adjustments.[9] On top of the implementation and legal challenges, border adjustments do not seem to help very much. A large literature analyzing border adjustments suggests that they reduce leakage only by about one-third,[10] and the resulting tax is still not very effective at reducing emissions because of its regional nature.

We propose a new approach to climate change policy and leakage. Our approach, which we call the Extraction-Production Tax or the EPT, reduces emissions more effectively and at a lower cost than conventional approaches. It is simple to implement and enforce. And it better complies with international trade law than standard border adjustments. It largely solves the leakage problem, removing one of the major barriers to adopting an aggressive carbon policy in the United States or other countries.

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[8] See Part I.C.4. For an analysis of the administrative problems with imposing border adjustments, see Samuel Kortum & David Weisbach, *The Design of Border Adjustments for Carbon Prices*, 70 NATIONAL TAX JOURNAL 421–446 (2017).

[9]  See Part I.C.5 See, also Joel P. Trachtman, *WTO Law Constraints on Border Tax Adjustment and Tax Credit Mechanisms to Reduce the Competitive Effects of Carbon Taxes*, 70 NATIONAL TAX JOURNAL 469 (2017); KATERYNA HOLZER, CARBON-RELATED BORDER ADJUSTMENT AND WTO LAW (2014). Note that border adjustments under broad-based VATs (as opposed to on carbon taxes) are almost universal, and are clearly legal under the WTO. A VAT with a border adjustment is known as a destination-based VAT, which is the form used in most of the world. Border adjustments under a carbon tax rate issues that are, for the most part, distinct from the issues they raise under VAT. Border adjustments under a carbon tax are sometimes referred to as carbon border adjustments to avoid confusion with border adjustments under a VAT. Because our usage is clear here, we use the shorter terminology, border adjustments.

[10] See Part I.C.3.

The EPT, as its name suggests, combines a tax on domestic extraction of fossil fuels with a tax on emissions of $CO_2$ during domestic production.[11] For example, if the desired price on emissions is \$100/ton of $CO_2$, the EPT combines an extraction tax and a tax on emissions from production such that the two rates add up to \$100. The rates might be, for example, a \$40 tax on extraction and a \$60 tax on production.

The EPT works by targeting the core channel for leakage: the effect of domestic climate policies on the price of energy in foreign countries. If the United States were to tax emissions from domestic production, domestic producers of goods and services would substitute away from energy, and domestic consumers would purchase fewer energy-intensive goods, in both cases reducing the demand for energy. A reduction in demand lowers the price and this lower price gets transmitted, via trade, to foreign countries. Foreign producers, seeing a lower price, have an incentive to increase their energy use (and domestic producers have an incentive to relocate).

Border adjustments do not change this dynamic. Adding border adjustments to a conventional carbon tax on production, we will show, shifts the tax to domestic consumption. A tax on domestic consumption still reduces the price of energy seen by foreign actors. As a result, a conventional carbon tax with border adjustments still increases energy use abroad and, therefore, fails to address the core problem.

Suppose instead that the United State taxed the domestic extraction of fossil fuels rather than the emissions that result from their use. A tax on domestic extraction *increases* the global price of energy rather than reduces it. The reason is that domestic extractors of fossil fuel, who must now pay a

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[11] The term "production" is sometimes used in the fossil fuel industry to refer to what we call extraction. We use the term production to mean the manufacturing of goods and services. The tax would fall on emissions from the combustion of fossil fuels during manufacturing.

tax, reduce unprofitable extraction, reducing supply. The price of energy goes up. This higher price gets transmitted via trade to foreign markets. Because they raise the global price of energy, extraction taxes do not create an incentive to expand production abroad, so they do not cause conventional leakage. Instead, because foreign extractors can sell their output at a higher price, extraction taxes induce an increase in extraction outside of the taxing region. This expansion in foreign extraction partially offsets the reduction in domestic extraction in what we might call "extraction leakage."

Neither tax alone—a tax on emissions from use in production or a tax on extraction—can solve the leakage problem. They both induce changes in foreign activity that partially offset their effects. Combining a tax on domestic extraction and a tax on emissions from domestic production, however, largely does. The combination would allow the United States or a larger taxing coalition to control the net effects on the price of energy seen in foreign countries because the two taxes act on the price of energy in opposite directions. The mix of the two should be set based on how foreign actors respond to changes in the price of energy, the foreign supply and demand elasticities and the size of those markets. Set correctly, the combination of taxes, we will show, reduces emissions much more effectively than standard approaches at a lower cost.

The other key to the EPT is that it can be implemented simply and accurately, unlike carbon taxes with conventional border adjustments. To do so, the taxing region imposes a nominal tax on domestic extraction and a limited and narrow kind of border adjustment: a border adjustment only on the imports and exports of fossil fuels, but not other imports or exports (that is, not on goods and services more generally). As we explain below, border adjustments on energy shift an extraction tax downstream to production.

Rather than being imposed at the same rate as the underlying extraction tax, however, these border adjustments would be at the desired tax rate on emissions from domestic production. Using the numbers above,

the nominal extraction tax would be at $100/ton and the border adjustments on fossil fuels would be at only $60/ton. The border adjustments on energy at $60/ton shift only that portion of the tax downstream from extraction to production, and leave the remaining $40 on extraction. The net effect is a combination of a tax on extraction at $40/ton and a tax on emissions from production at $60/ton.

Implemented this way, the EPT is simple to impose. The base of the tax is an extraction tax, which, as prior work has shown, can be easily imposed by taxing only large sophisticated entities who already carefully track fossil fuels.[12] These entities are already highly regulated and must keep careful books and records, which means that auditing and enforcement would also be simple. The border adjustments in the EPT are on energy, not on goods in general. Unlike border adjustments on goods, border adjustments on energy imports and exports would be easy to impose because we know with great precision the volume of imports and exports of each type of fossil fuel, and its carbon content.[13] This contrasts with border adjustments on goods more generally, where we have little way of knowing the carbon emitted from production in foreign countries.

Finally, the EPT has fewer legal problems than conventional approaches. The problem with border adjustments imposed on goods generally is that the carbon itself does not cross the border. Instead, border adjustments are on the emissions from production in the foreign country. Taxes based on the process of production or the method of production, however, raise WTO problems because they have the potential to impose

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[12] See Gilbert E. Metcalf & David Weisbach, *The Design of a Carbon Tax*, 33 HARVARD ENVIRONMENTAL LAW REVIEW 499–556 (2009).

[13] The U.S. Energy Information Administration carefully tracks trade in energy. See, e.g., https://www.eia.gov/energyexplained/us-energy-facts/imports-and-exports.php

different taxes on like goods.[14] This is not true for border adjustments on energy. The tax would be on the carbon molecules that cross the border, substantially reducing concerns about WTO compatibility.

In short, the EPT works substantially better than conventional carbon taxes, or conventional carbon taxes with border adjustments. It is easier to implement. And it is much more likely to be consistent with the WTO. It solves (or at least greatly reduces) the leakage problem and, therefore, removes one of the major barriers to the enactment of a carbon tax in the United States.

The remainder of this paper explores the arguments made above in detail. Part I provides background on carbon pricing, leakage, and border adjustments. Part II describes the EPT, starting with an explanation of why it performs better than conventional carbon taxes in an international setting and then turns to implementation and legal issues. It also includes results from a calibrated simulation of the global economy and trade, allowing us to compare the EPT to other approaches. Part III considers extensions of the analysis as well as limitations. Part IV concludes.

## I. Background

### A. Carbon pricing basics

Climate change can be thought of as a global externality. People emit greenhouse gases, which cause, or will cause, grievous harm to other people and other living things around the world, now and in the future.[15] Without

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[14] See Trachtman, *supra* note 11.

[15] There are two key features of greenhouse gases that make climate change different than a conventional pollution problem. The first is that greenhouse gases mix evenly in the atmosphere, which means that the harms are the same regardless of where the greenhouse gas was emitted. As a result, climate change is a global problem. Most other pollutants are local. Second, some greenhouse gases, notably $CO_2$, have very long

a carbon price or some other policy, people will not fully consider the harms they cause to others when they pollute. In addition, they lack incentives to develop cleaner technologies.

While there are a number of greenhouse gases,[16] most carbon taxes focus on, and are limited to, emissions of $CO_2$ from fossil fuel combustion. There are two reasons. The first reason is that in developed countries, $CO_2$ emissions from the use of fossil fuels make up the overwhelming majority of emissions.[17] For example, in the United States, about 85% of net emissions are from fossil fuel combustion.[18] As a result, solutions to climate change

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atmospheric lives, which means that emission today will continue to cause harm long in the future. See ARCHER, *supra* note 3. These two features of greenhouse gases mean that emissions affect people in other countries and in the distant future, making conventional approaches to pollution, such as bargaining between injurers and victims or legal rules imposed from above, unworkable for climate change.

[16] The major greenhouse gases are carbon dioxide ($CO_2$), methane, nitrous oxide, and a number of highly-potent gases used for refrigeration and related uses, such as hydrofluorocarbons. See https://www.eia.gov/energyexplained/energy-and-the-environment/greenhouse-gases.php (last visited July 11, 2021).

[17] In some developing countries, the most important source of emissions is deforestation. Forests take up and store carbon dioxide through photosynthesis. Deforestation reduces this carbon sink, and is categorized as an emission in most accounting methodologies. For comprehensive emissions data, by country, sector, and year, see https://www.climatewatchdata.org/

[18] See Table ES2 in United State Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2018, EPA 420-R-20-002, https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf (last visited July 11, 2021). The other major source of emissions are methane emissions and nitrous oxide emissions from agriculture and hydrofluorocarbons from refrigeration. Land use change in the United States is a net sink (e.g., an increase in forested areas increased carbon sequestration in forests). Gross greenhouse gas emissions were 6,677 million metric of carbon dioxide equivalents

necessarily, and primarily, involve transforming the fossil fuel sector of the economy.

The second reason is that emissions from fossil fuels are easier to tax than other emissions. Many non-fossil fuel emissions are from small, dispersed sources that are hard to measure and track, such as methane from enteric fermentation in livestock and nitrous oxide released from the soil by farmers when they till, plant, and harvest.[19] While we can estimate these in the aggregate, there is no available method of accurately tracing them to individual sources to be taxed. Emissions from fossil fuels, in contrast, can be taxed by imposing the tax on a relatively small number of large sources such as refineries, coal mines, and natural gas processors.[20] These sources already track inputs and outputs of fossil fuels and must keep careful records.

We will follow that approach here, addressing only prices on emissions of $CO_2$ from the combustion of fossil fuels. We will occasionally refer to these carbon prices as prices on energy, with the understanding that carbon-free energy is exempt. Moreover, the three different fossil fuels, oil, gas, and coal, have different carbon content per unit of energy, and the carbon price has to be adjusted to account for this. When we refer to a price on energy, we assume that it is adjusted appropriately to account for the actual carbon content of different types of energy.

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(CO2e) in 2018, 5032 of which were from fossil fuel combustion. Net emissions were 5,903 million metric tons of $CO_2$e.

[19] In 2018, methane from livestock in the United States resulted in 178 million metric tons of $CO_2$ equivalents, and nitrous oxide from agricultural soil management in the United States resulted in 338 million metric tons of $CO_2$ equivalents (out of a total of 5,903 million metric tons). See *id.*

[20] See Metcalf and Weisbach, *supra* note 14.

We will generally refer to carbon prices as carbon taxes. Carbon prices can also be imposed through a cap and trade system, a liability system, subsidies, or implicitly through regulation. While there are differences in all of these approaches, and a debate about which approach is preferable, to simplify the analysis, we consider taxes. Our approach implicitly includes the possibility of subsidies (which are just negative taxes) and applies equally to cap and trade systems. Tort liability and regulatory approaches may raise distinct issues not considered here.

Because each ton of $CO_2$ causes the same harm regardless of who emits it, a carbon tax should be uniform, across industries and locations. A uniform carbon tax ensures that emissions reductions occur where they are cheapest. A non-uniform tax, by contrast, would induce reductions where the tax is highest even if those reductions are more difficult or more expensive than reductions elsewhere.

To implement a carbon tax, it is useful to think of fossil fuels as moving through the economy in three steps.[21] Fossil fuels enter the economy when they are extracted from underground deposits. After processing and distribution, users of fossil fuels burn them to produce energy and use the energy to create goods or services. In the process, producers emit $CO_2$.

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[21] To see a visualization of energy flows in the U.S. see https://us-sankey.rcc.uchicago.edu/ According to the Energy Information Agency, about 19% of energy in the United States is carbon free. https://www.eia.gov/energyexplained/us-energy-facts/ (last visited July 11, 2021). Just under half of that amount (8% of total energy) is from nuclear power, with renewable energy making up the rest (11%). Biomass, wind and hydroelectric power are the dominant source of renewable energy (43%, 24%, and 22% of renewable power, respectively). Fossil fuel energy is made up of petroleum (37% of total energy), natural gas (32% of total energy) and coal (11% of total energy). Id.

Finally, people consume the goods or services created with that energy. We will refer to these three stages as extraction, production, and consumption.[22]

In a closed economy, that is, an economy without trade, all fossil fuels that are extracted in a country are used to produce goods or services in that country, and all the resulting goods and services are consumed in that country. As a result, we can tax fossil fuels at any of the three stages, with the same result.[23]

There are, however, many fewer entities that extract fossil fuels than entities that use them in production or individuals who consume the resulting goods and services. According to one estimate, the United States can tax all emissions from fossil fuels by imposing the tax upstream on extraction (or nearly so, such as on refining) on only about 2,500 large, sophisticated entities.[24] As a result, in a closed economy, a domestic carbon tax can be imposed simply and effectively.

To our knowledge, however, all existing carbon prices are imposed on emissions from production. They are imposed where the smokestack or

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[22] In some cases, these stages are closely tied together. For example, if you use gasoline to power your vehicle, you are producing transportation services using a fossil fuel and also consuming those services as you are whisked to your destination. In other cases, production can be split between market production and home production: power plants burn coal and natural gas to produce electricity and individuals use that electricity to produce light and heat, which they consume. There may also be links in the chain of production that fall between these stages. For example, refining may be thought of as part of extraction (preparing deposits for use in the market) or as part of production (making an intermediate good). As we will discuss, what matters for tax system design is the effects of a tax at that step on the price of energy.

[23] A tax on extraction can also work in reverse, as a subsidy to sequestered carbon. See Metcalf and Weisbach, *supra* note 14.

[24] *Id.*

tailpipe is located, that is, where the emissions actually take place. For example, the cap and trade system in the European Union is imposed on industrial use of fossil fuels.[25] Only industries operating in the EU are required to have a permit. Industries located outside the EU are not subject to their permit system even if their products are ultimately imported into the EU and consumed there. And if an industry in the EU exports its products, it still must pay a carbon price because the emissions occurred in the EU. The same is true of California's cap and trade system and the northeast's Regional Greenhouse Gas Initiative.

Existing systems impose a tax directly on production, in the sense that producers must remit the tax. Recent carbon tax bills in the United States Congress would impose a tax on emissions from domestic production but get there in a different way. They would start by imposing a tax on domestic extraction. They would then impose a tax on all imported fossil fuels and rebate taxes on all exported fossil fuels.[26] The net result is a tax on emissions from domestic production. To see why, consider a unit of fossil fuel extracted domestically. A tax is imposed on its extraction. If the unit of fuel is used domestically, the tax remains. If it is exported, the tax is rebated. Suppose instead that the unit of fossil fuel is extracted abroad. If it is imported and used here, a tax is imposed, while if it remains abroad and is used there, no tax is imposed. The net result is to tax emissions from fossil fuel use in domestic production. The advantage of this newer approach is that it requires large domestic extractors to remit the tax, along with any importers, while exporters get a rebate. This simplifies the operation of the

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[25] See European Commission, EU ETS Handbook, (2015) p. 20.

[26] See for example, S. 685, 117th Cong. 2021-2022 (America's Clean Future Fund Act), introduced by Majority Whip, Richard Durbin. This bill also imposes border adjustments on goods, which as discussed below, shifts the tax to domestic consumption.

tax. As we will discuss in Part II, the EPT takes advantage of this same mechanism, but with a different goal.

In Part II, we will turn back to how to use the location of the tax—on extraction, production, or consumption—to design carbon taxes in an open-economy setting. For now, we follow the conventional approach and assume the tax is on emissions during production.

## B. Leakage

In an open economy, one where there is trade, domestic carbon taxes on production can be avoided by moving production to a country without a carbon tax. For example, a U.S. steel producer who sells the steel domestically can avoid a carbon tax imposed by the United States by moving abroad, to a jurisdiction without a carbon tax, and exporting the steel to the United States. As long as any increase in production costs plus the cost of shipping is less than the tax, the formerly-domestic and now foreign producer of steel selling in the United States can do so at a lower cost than a domestic producer who must pay the tax. The same holds for sales in foreign markets: domestic producers facing a carbon tax are at a disadvantage relative to foreign producers selling in foreign markets. They can eliminate that disadvantage by moving abroad. As a result, a carbon tax on production creates an incentive to shift production abroad.

This shifting of domestic activities to low-tax regions is known as leakage. Leakage is usually defined as the increase in emissions outside of the taxing region, measured as a fraction of the emissions reductions in the taxing region.[27] For example, if the United States imposed a carbon price that reduced domestic emissions by 100 units, and as a result, foreign

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[27] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007 -- MITIGATION OF CLIMATE CHANGE, CONTRIBUTION OF WORKING GROUP III TO THE FOURTH ASSESSMENT REPORT OF THE IPCC (2007) (section 11.7.2).

emissions went up by 20 units, leakage would be 20%. The net emissions reduction from the tax would be 80 units.

Leakage threatens to make domestic carbon pricing futile because emissions reductions at home are replaced by emissions increases abroad. If leakage were 100%, a domestic carbon price would achieve nothing other than causing producers to operate in a less-preferred location. And whatever benefits there were to the United States of having production occur domestically, such as supply chain security, would be lost. For this reason, leakage has been called the defining problem in the design of regional climate policies.[28]

To understand the size of the problem, researchers use large-scale, computable general equilibrium (CGE) models. These models include detailed representations of the economy, most often with a high level of detail in the energy sector.[29] They calibrate the models to the inputs and outputs of each sector, and how those inputs and outputs feed into other sectors. Sectors in the models adjust their behavior in response to prices based on calibrated response functions. For example, a sector may reduce its energy use when energy prices go up, with the extent of its response depending on available technology. The models attempt to represent the response elasticities for different sectors, enabling them to simulate how each sector, and the economy as a whole, would respond to a carbon tax.

By our count, since the turn of the century, there have been over 50 CGE studies of the general problem of differential carbon prices published in the peer-reviewed literature, many more in the gray literature, and yet

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[28] Fowlie, *supra* note 6.

[29] For an overview of the use of CGE modeling for environmental problems, see Lars Bergman, *Chapter 24 CGE Modeling of Environmental Policy and Resource Management*, 3 *in* HANDBOOK OF ENVIRONMENTAL ECONOMICS 1273–1306 (Karl-Göran Mäler & Jeffrey R. Vincent eds., 2005).

still more of specific industries or countries. Each study considers multiple different scenarios. Combined, there are hundreds of simulations of the effects of a carbon price on leakage.[30]

The majority of studies find leakage to be within a broad but relatively consistent range: carbon prices in the developed world[31] that produce global emissions reductions in the range of 10% have leakage rates between 5% and

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[30] For example, a 2014 meta-study of carbon leakage papers examined 25 studies (20 of which were CGE studies, 5 of which were partial equilibrium studies). Frédéric Branger & Philippe Quirion, *Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies*, 99 ECOLOGICAL ECONOMICS 29 (2014). These 25 studies, which make up only a portion of the literature, had 310 different modeled scenarios. Since that meta-study in 2014, there have been a number of additional studies of the issue. See, e.g., Christoph Böhringer, Knut Einar Rosendahl & Halvor Briseid Storrøsten, *Robust policies to mitigate carbon leakage*, 149 JOURNAL OF PUBLIC ECONOMICS 35–46 (2017); Warwick J. Mckibbin et al., *The role of border carbon adjustments in a u.s. carbon tax*, 09 CLIM. CHANGE ECON. 1840011 (2018); Xiujie Tan et al., *Assessment of carbon leakage by channels: An approach combining CGE model and decomposition analysis*, 74 ENERGY ECONOMICS 535–545 (2018). For surveys of this literature, see SUSANNE DROGE, *Tackling Leakage in a World of Unequal Carbon Prices* (2009), http://www.centre-cired.fr/IMG/pdf/cs_tackling_leakage_report_final.pdf; ZhongXiang Zhang, *Competitiveness and Leakage Concerns and Border Carbon Adjustments*, 6 INTERNATIONAL REVIEW OF ENVIRONMENTAL AND RESOURCE ECONOMICS 225 (2012). An important series of studies on carbon leakage and border adjustments was undertaken by Stanford's Energy Modeling Forum. For a summary of these studies, see Christoph Böhringer et al., *Introduction to the EMF 29 special issue on the role of border carbon adjustment in unilateral climate policy*, 34, Supplement 2 ENERGY ECONOMICS S95–S96 (2012).

[31] Most models use the set of countries that had, or would have had, obligations to reduce emissions under the Kyoto Protocol as their taxing region. These countries are referred to as the Kyoto Protocol Annex B countries. The countries listed in Annex B do not correspond precisely to today's definition of developed countries. For example, South Korea is not an Annex B country but many countries that were formally part of the Soviet Union but that are today quite poor, are.

25%.[32] That means that for every hundred tons of emissions reductions from a carbon price in the developed world, there is an increase of between 5 and 25 tons in other parts of the world, such as in China or India.

Whether this is large or small depends on one's point of view. On the one hand, it is not so large as to make a carbon tax futile. On the other hand, 25% is hardly insignificant. Moreover, leakage is likely to be concentrated in a small set of industries, those that are energy intensive and exposed to trade. A leakage rate of 20% nationally may mean that for some industries, leakage is quite high. The effects in those industries could be substantial. Moreover, CGE models tend to use short-run or medium-run response elasticities, and if a unilateral carbon tax were to persist in the long run, leakage could be much higher (because long run responses will be larger than short run responses). Furthermore, leakage would likely be higher when policies aim to achieve greater emissions reduction than just the 10% mentioned above. In any event, these numbers are large enough, or are concentrated enough, that leakage is viewed as the central problem in the design of carbon taxes in an international setting.

C. Border adjustments

Border adjustments, also called carbon border adjustments or border adjustment taxes, are the most prominently proposed solution to leakage, by a substantial margin.[33] As noted, every carbon tax bill introduced in the

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[32] See Branger and Quirion, *supra* note 32; Joshua Elliott et al., *Unilateral Carbon Taxes, Border Tax Adjustments and Carbon Leakage*, 14 THEORETICAL INQUIRIES IN LAW 207–244 (2013); Böhringer et al., *supra* note 32.

[33] The EU cap and trade system, the Emissions Trading System, currently uses a free allocation of permits to vulnerable industries to address leakage. As part of the EU Green Deal the EU, however, has, recently proposed shifting to border adjustments, in a system known as the Carbon Border Adjustment Mechanism: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12227

current and the last Congress, includes border adjustments.[34] As part of the EU Green Deal, the EU is expected to implement a version of border adjustments, the Carbon Border Adjustment Mechanism, for its emissions trading system in the near future.[35] Over 3,600 economists, including 28 Nobel Prize winners and the current Secretary of the Treasury, signed a statement endorsing border adjustments.[36] Major environmental groups have devoted substantial resources to their design and implementation.[37] Border adjustments are a central element of climate change policy in an international setting.

Unfortunately, as we document below, they only modestly improve the effectiveness of carbon prices, they are nearly impossible to implement accurately, they would be costly to impose and easy to avoid, and they raise significant problems under international trade law.

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[34] For a list of carbon pricing bills, see https://www.rff.org/publications/data-tools/carbon-pricing-bill-tracker/

[35] Proposal for a Regulation of the European Parliament and of the Council, establishing a carbon border adjustment mechanism, Com (2021) 564 final, Brussels July 14, 2021. For a summary, see https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_en

[36] https://www.econstatement.org/ (last visited July 11, 2021).

[37] For example, Resources for the Future has devoted significant resources to a project on the design of border adjustments. See, Brian Flannery, Jennifer Hillman, Jan Mares, and Matthew Porterfield, Framework Proposal for a US Upstream GHG Tax with WTO-Compliance Border Adjustments: 2020 Update, Report 20-14, Resources for the Future.

As an illustration of the prominence of the issue, a Google Scholar search (on July 9, 2021) for "carbon border adjustment" turned up 19,100 articles mentioning the term since 2010.

*1. Terminology*

Border adjustments are taxes on imports and rebates of prior taxes paid for exports. We will differentiate between border adjustments on energy and border adjustments on goods. For energy, the border adjustment on imports is based on the carbon content of the energy (plus any emissions from extraction of the energy). For example, if the United States imported a barrel of oil, the border tax would be on the carbon content—the number of carbon molecules—in the oil. If the United States exported a barrel of oil, the rebate would be of the taxes paid during extraction, if any.

For goods (other than energy), the tax on imports is based on the emissions from the production of the good, known as embodied emissions. Consider, for example, a piece of steel imported into the United States from South Korea. When the steel was produced in South Korea, the producer emitted $CO_2$ because of the energy required during manufacturing. When the steel crosses the border, a tax would be imposed on those emissions as if the emissions arose in the United States. For example, if production of the unit of steel produced one ton of $CO_2$ in South Korea, when the steel is imported into the United States a tax on one ton of $CO_2$ (e.g., \$100/ton) would be imposed. The rebate on exports of goods is of carbon taxes paid during the production of a good. For example, if the United States produced the steel domestically and exported it, the rebate would be of any taxes paid domestically from the production of that steel.

If the United States were to impose a tax on extraction, border adjustments on energy would shift the tax downstream to production. To illustrate, consider a tax on domestic extraction with a border adjustment on imports and exports of energy (but not goods). Any energy that is extracted here and used in production here bears a tax. Any energy that is extracted domestically and exported for use in production abroad does not bear a tax because of the rebate of the extraction tax on export. And any energy that is imported and used here in production is taxed on import.

Therefore, an extraction tax plus border adjustments on energy is just a tax on emissions from domestic production, or what we call a production tax.[38]

Border adjustments on goods shifts the tax further downstream, to consumption. Any goods produced here and consumed here bear a tax because the border adjustment does not apply to purely domestic items. Exported goods do not bear a tax because the production tax is rebated at the border. And goods that are imported and consumed here have a tax imposed at the border. Therefore, adding border adjustments on goods to a tax on domestic production shifts it to a tax on domestic consumption. And combining these steps, an extraction tax with a border adjustment on both energy and goods is a consumption tax.

We will use the terms "extraction tax," "production tax," and "consumption tax" to refer to, respectively, a tax on the carbon content of fossil fuels when extracted, a tax on emissions from the use of fossil fuels in production, and a tax on the emissions associated with, or the emissions "embodied in" goods when consumed. We will refer below to both the effective taxes (e.g., extraction tax, production tax, and consumption tax) and nominal taxes (e.g., an extraction tax plus border adjustments on energy), depending on the context. For example, in Part II.A, we will use effective taxes because we focus there on the effects of these taxes, not on how they are implemented. In Part II.B, we consider implementation and there, discuss how the effective taxes can be implemented via simple nominal taxes. The context should make our reference clear.

### 2. The Argument for Border Adjustments under a Production Tax

As noted, conventional carbon taxes are imposed on production. Production taxes creates an incentive to shift production abroad, creating

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[38] As noted, recent carbon tax proposals in the United State often use this structure to impose a tax on domestic production while requiring fewer entities to remit taxes.

leakage. The argument for imposing border adjustments on a production tax is that border adjustments eliminate the incentive to relocate production, reducing leakage.

To illustrate, consider a country with a tax on emissions from domestic production that is trading with a country that does not impose a carbon tax. Compared to the situation with no tax, producers in the taxing country have higher costs than producers in the rest of the world. Consider, for example, domestic producers exporting to the rest of the world that had about equal costs to producers elsewhere before a carbon tax is imposed. After the carbon tax, their costs will be higher than their competitors, reducing exports. Similarly, if without tax, domestic producers selling domestically had equal costs to importers, with tax their costs will be higher, increasing imports. Stated in terms of comparative advantage, a domestic carbon tax on production reduces the comparative advantage of domestic producers, shifting trade shares in favor of foreign producers.

Border adjustments (on goods) eliminate this distortion. Because they shift the tax to domestic consumption, the tax does not depend on where a good is produced. Domestic producers exporting to foreign markets have the tax removed, so their comparative advantage in those markets is the same as it was without the tax. Similarly, foreign producers selling to the domestic market have a tax imposed on import, which means all producers (domestic and foreign) selling domestically see their costs increase equally. Comparative advantage is once again maintained. Because it eliminates distortions in trade patterns, a consumption tax, or equivalently, a production tax with border adjustments, is more efficient than a production tax.

### 3. The Size of the Effects

While border adjustments improve the efficiency of a domestic production tax, to decide whether they are desirable, we need to compare the benefits of improving the operation of the tax to their costs. To do this, we need to estimate the size of the effects. Most studies of leakage also

estimate the effects of adding border adjustments, so we can look at the results from those studies to get a sense of the likely magnitude.

The consensus from these studies is that border adjustments offer some, but modest, gains. They reduce leakage by about a third, and they result in modestly greater emissions reductions for any given tax rate.[39]

Figure 1 illustrates. It is a simulation of leakage and border adjustments from a typical CGE modeling effort.[40] The x-axis is the carbon tax in dollars per ton of $CO_2$ and the y-axis is the percent reduction in global emissions relative to the business as usual estimate (i.e., the emissions expected under current policies, without a new tax). The simulation considers taxes in what are known as Annex B countries, effectively most of the developed countries.[41] The top three lines are the relevant ones for understanding leakage and border adjustments. The bottom line shows the simulated reductions that would arise with a global tax. It is included to get a sense of scale.

The top line shows the global emissions reductions from a standard production tax in Annex B. The line labeled "Annex B reductions—Annex B tax" shows the emissions reductions in just the Annex B countries from that tax. Note that the global emissions reductions from a tax in Annex B are less than the Annex B emissions reductions (that is, the global line is above

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[39] See Joseph E. Aldy, *Frameworks for Evaluating Policy Approaches to Address the Competitiveness Concerns of Mitigating Greenhouse Gas Emissions*, 70 NTJ 395, 402 (2017).

[40] For a description of the model and results, see Elliott et al., *supra* note 34; Joshua Elliott et al., *Trade and Carbon Taxes*, 100 AMERICAN ECONOMIC REVIEW 465–469 (2010); Joshua Elliott et al., *CIM-EARTH: Framework and Case Study*, 10 THE B.E. JOURNAL OF ECONOMIC ANALYSIS & POLICY Article 11 (2010).

[41] For a discussion of Annex B countries, see note 31

the Annex B line). The reason is that emissions increase outside of Annex B because industries relocate offshore. This increase—the vertical distance between the two lines—is leakage. As can be seen, leakage goes up with the tax rate. The higher the tax, the greater the incentive to shift production offshore. Leakage in this simulation is less than 20%, which is consistent with much of the literature.

The effects of adding border adjustments is illustrated with the line labeled "Global Reductions-BA's." This shows global emissions reductions when the Annex B countries add border adjustments to the tax, converting the tax to a consumption tax. Global emissions go down when Annex B countries add border adjustments. Border adjustments help.[42] The effects however are modest, at best. Emissions are lower when we add border adjustments by only a small amount. They are not a panacea.

## Figure 1: Effects of Border Adjustments



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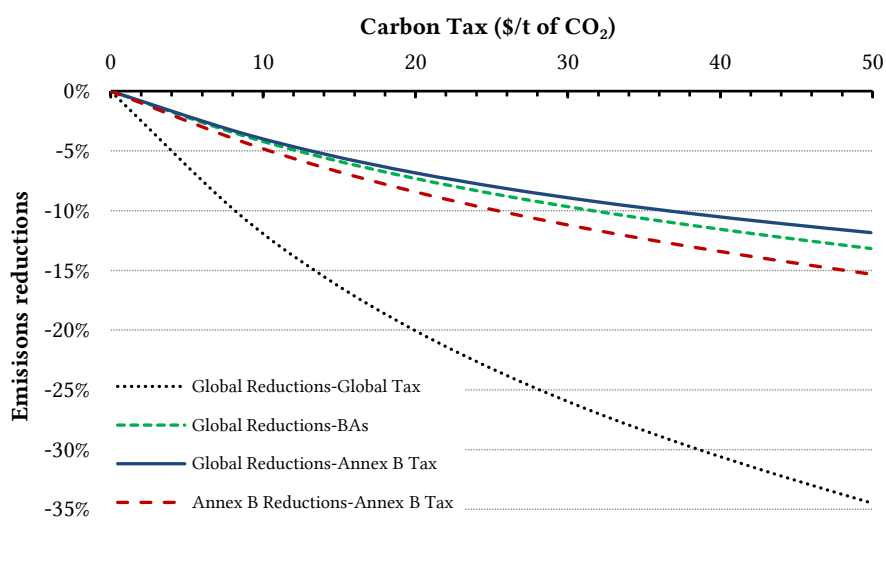
[42] Although we do not show the relevant line, the Annex B reductions, with an Annex B consumption tax, leakage goes down too.

*4. Implementation Problems*

If border adjustments on goods were simple to impose (and raised no legal problems), the modest gains that they generate might be worth it. But, in fact, they are a nightmare to impose. We have previously explored the implementation problems with border adjustments at length.[43] Rather than repeat this analysis, we provide a brief overview.

The key problem with imposing border adjustments is that there is no straightforward way to determine the emissions associated with an imported good. Consider a shipload of automobiles arriving in Los Angeles. Each automobile will have parts from many different countries with the parts assembled in yet another set of countries. Those parts may have been produced using various technologies and fuel sources under a number of environmental regimes. The mix of parts, countries, and fuel sources will be different for each type of vehicle and different for different model years of

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[43] Kortum and Weisbach, *supra* note 10. For other analyses of the implementation issues, see Branger and Quirion, *supra* note 32; Jr. McLure Charles E., *Selected International Aspects of Carbon Taxation*, 104 THE AMERICAN ECONOMIC REVIEW 552–556 (2014); Aaron Cosbey, *Border carbon adjustment*, *in* IISD BACKGROUND PAPER FOR THE TRADE AND CLIMATE CHANGE SEMINAR, JUNE 18–20 (2008), http://www.iisd.org/pdf/2008/cph_trade_climate_border_carbon.pdf (last visited Sep 22, 2015); AARON COSBEY ET AL., *A Guide for the Concerned: Guidance on the Elaboration and Implementation of Border Carbon Adjustment*, (2012), http://papers.ssrn.com/abstract=2178312 (last visited Jul 15, 2015); TREVOR HOUSER ET AL., LEVELING THE CARBON PLAYING FIELD (2008); Roland Ismer & Karsten Neuhoff, *Border tax adjustment: a feasible way to support stringent emission trading*, 24 EUROPEAN JOURNAL OF LAW AND ECONOMICS 137–164 (2007); Catherine F. Izard, Christopher L. Weber & H. Scott Matthews, *Primary and Embedded Steel Imports to the U.S.: Implications for the Design of Border Tax Adjustments*, 44 ENVIRON. SCI. TECHNOL. 6563–6569 (2010); Stéphanie Monjon & Philippe Quirion, *How to design a border adjustment for the European Union Emissions Trading System?*, 38 ENERGY POLICY 5199–5207 (2010); T. Persson, *Linking the Northeast states of the US mitigation program to the EU Emission Trading Scheme—Implications and costs*, 14 MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE 399–408 (2009).

the same vehicle. Customs agents would be at a complete loss if they were required to impose a tax on each automobile based on its emissions during production, let alone impose a similar charge in each and every other good passing through the border. In 2019, the United States, for example, imported about $2.8 trillion dollars of goods, including $357 billion in transportation equipment such as automobiles and trucks.[44] Imposing accurate border adjustments at this scale is infeasible.

Because of this problem, border adjustment proposals, including the border adjustments proposed in every carbon tax bills in the current and last U.S. Congress, are limited to a narrow set of goods, most often raw materials such as steel and chemicals.[45] They exclude complex final goods such as automobiles. Moreover, even within this narrow set of goods, they aggregate goods into broad categories and assume, counterfactually, that all goods in each category generate the same emissions when produced.

This approach is both narrow and inaccurate. Different types of raw materials in the same category can have widely different emissions profiles.[46] Even raw materials of the same type are produced using a variety of production methods and fuel sources, resulting in different emissions profiles.[47] As a result, the border adjustment on any given raw material may bear little relationship to the emissions associated with its production.

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[44] See The Observatory of Economic Complexity, at www.oec.world (last visited July 11, 2021).

[45] For example, the border adjustments proposed in a major study by Resources for the Future, a prominent environmental think tank, are limited in this way. See Flannery et al, *supra* note 40.

[46] See Kortum and Weisbach, *supra* note 10.

[47] See HOUSER ET AL., *supra* note 45.

On top of these problems, most border adjustment proposals also would not apply to countries with comparable carbon prices. The reason is that if emissions are already taxed during production in its country of origin, there is no need to impose a second tax when the resulting good is imported to the United States. While this idea makes sense, it would be hard to implement because there is no easy way to determine which countries have comparable carbon prices. Climate policies in any single country are likely to be complex, combining regulations, subsidies, pricing, and other mechanisms, imposed differentially on different parts of the economy. There is no straightforward way to translate these complex mixes of policies to a comparable carbon price to determine if imports from that country should be subject to a border tax. Any determination of which goods from which countries are exempt would end up being political.

Even if we managed to determine an appropriate import charge, these narrow border adjustments would be easy to avoid. Rather than selling raw materials, exporters could shift to selling final goods or partially finished goods which would not be subject to the border tax. The result is perverse. Border adjustments would end up encouraging the very thing that they seek to avoid, which is shifting production abroad.

If exporters from low tax countries wish to continue exporting raw materials rather than finished goods, they could switch fuel sources, using clean sources of fuel for exports to the United States and dirty sources to produce goods for their own consumption. They could also transship goods through countries with high carbon taxes (but no border adjustments), making the goods appear as if they were from the high-tax country rather than the low-tax country. The opportunities for mischief would be legion.[48]

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[48] None of these effects are captured in CGE modeling efforts which means that the models may substantially over-estimate the effectiveness of border adjustments.

To implement this regime, the United States would need a vast new bureaucracy. The bureaucracy would have to classify goods, determine their carbon content, police avoidance schemes, and resolve disputes. For example, setting the import taxes and adjusting them regularly, would require a large amount of data on how goods are produced in foreign countries and the relevant fuel source. Actors would argue about the classification of goods or the method of attributing emissions to their production technology and fuel source. Someone would have to adjudicate those disputes. Detecting illegal transshipping would require policing and investigative work. Imposing even a narrow, inaccurate, and easily avoidable set of border adjustments would not be a casual undertaking. In short, implementing border adjustments on goods would require engaging in a costly and mostly hopeless task to achieve modest gains.

### 5. Legality: The WTO

A final problem with border adjustments is that they may not comply with international trade law. The World Trade Organization has never considered a close analogy to border adjustments under a carbon tax, so there is considerable uncertainty about whether they are allowed. There are a number of thorough analyses of the legal issues, so we provide only a brief overview.[49] WTO law is archaic and legalistic. Many of its terms often do

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[49] For a more complete analysis, see Trachtman, *supra* note 11. See also, Ismer and Neuhoff, *supra* note 47; Javier de Cendra, *Can Emissions Trading Schemes be Coupled with Border Tax Adjustments? An Analysis vis-a-vis WTO Law*, 15 RECIEL 131 (2006); HOLZER, *supra* note 10; Stéphanie Monjon & Philippe Quirion, *A border adjustment for the EU ETS: Reconciling WTO rules and capacity to tackle carbon leakage*, 11 CLIMATE POLICY 1212 (2011); WORLD TRADE ORGANIZATION & UNITED NATIONS ENVIRONMENT PROGRAMME, *Trade and Climate Change* (2009); Jagdish Bhagwati & EPTros C. Mavroidis, *Is action against US exports for failure to sign Kyoto Protocol WTO-legal?*, 6 WORLD TRADE REVIEW 299 (2007); Robyn Eckersley, *The Big Chill: The WTO and Multilateral Environmental Agreements*, 4 GLOBAL ENVIRONMENTAL POLITICS 24 (2004); Jeffrey Frankel, *Climate and Trade: Links Between the Kyoto Protocol and WTO*, 47 ENVIRONMENT: SCIENCE AND POLICY FOR SUSTAINABLE DEVELOPMENT 8 (2005); Jacob Werksman, *Greenhouse Gas Emissions*

not comport with their economic or commonsense meanings. Therefore, what makes sense from a policy perspective may not be consistent with the WTO and straightforward intuitions about results may be wrong.

The WTO rules apply separately to duties on imports and to rebates on exports. Duties on imports cannot discriminate between goods that are produced domestically and goods that are imported, or exceed the tariff bindings agreed to by a nation. Rebates for exports cannot be an illegal subsidy. We limit our discussion to selected issues regarding imports charges.

Under GATT Article III, foreign producers must be treated with no less advantageous terms than domestic producers (national treatment clause). To determine this, the WTO will look at the treatment of "like" products (Article III.:2 first sentence) and to "directly competitive and substitutable products" (Article III:2 second sentence).

There is no clear definition of what it means for products to be "like." It seems most likely, however, that the method of production is irrelevant. For example, steel produced using one method of production, such as a blast furnace, may be functionally the same as steel using a different method, such as an electric arc furnace. The two types of steel are "like" one another and, therefore, must be treated the same way. The emissions from these two methods are quite different, however. Accurate border adjustments would treat the two types of steel differently. If the "likeness" rule prevents them from being treated differently, it would effectively prohibit accurate border adjustments.

Once we have identified "like" products, we have to determine what its domestic treatment is and whether a border adjustment is allowed to match

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*Trading and the WTO*, 8 REVIEW OF EUROPEAN COMMUNITY & INTERNATIONAL ENVIRONMENTAL LAW 251 (1999).

that treatment. GATT Article II.2(a) allows countries to impose "at any time on the importation of any product a charge equivalent to an internal tax . . . in respect of the like domestic product." This means that if a carbon tax is an internal tax on a product, nations can impose an equivalent import charge—that is, a border adjustment.

Unfortunately, there is no clear definition of an internal tax on a product. The WTO distinguishes between direct and indirect taxes, and only indirect taxes count as a tax on a product. For example, VATs count as internal taxes on products and taxes on profits do not. There is, however, no guidance on how to characterize a carbon tax. Because we do not know what it means for a product to be "like" another and do not know when a product is subject to an internal tax, there is considerable uncertainty on whether the import charge component of border adjustments are WTO compliant.

Commentators typically suggest, therefore, that nations seeking to impose border adjustments rely on two exceptions found in Article XX. Article XX(b) allows measures necessary to protect human animal, or plant life or health. Arguably a border adjustment meets this requirement. A key issue, which we return to below, is whether an import charge is "necessary." A charge is necessary only if there are no less restrictive alternatives. If one views border adjustments as the best means of controlling leakage, and, therefore, of implementing a carbon tax and reducing the harms from climate change, they may be necessary. But if other means are available, they are not.

Article XX(g) creates an exception for measures that relate to the conservation of exhaustible natural resources made effective in conjunction with domestic restrictions. The ability of the atmosphere to absorb $CO_2$ is most likely an exhaustible natural resource. There is no "necessity" provision in Article XX(g), so on its own terms, Article XX(g) seems more promising than XX(b).

Measures that satisfy Articles XX(b) and XX(g), however, must also satisfy the "chapeau" of Article XX. This requires that there be no arbitrary or unjustifiable discrimination between countries where the same conditions prevail and no disguised restrictions on international trade. These requirements have been interpreted to require meeting a "least trade restrictive alternative" test. As we will discuss below, because there are alternatives that are less trade restrictive than border adjustments on goods, notably the EPT, there is some issue whether border adjustments can survive either Article XX(b) or Article XX(g).

There is a large amount of additional detail. The majority view seems to be that the WTO would not hold border adjustments under a carbon tax to be illegal. The WTO would, it is hoped, be hesitant to interfere with policies designed to address climate change. There are enough exceptions and nuances in WTO law that there is room to uphold border adjustments if the WTO so desired. Nevertheless, there is considerable uncertainty.

*6. Summary*

Border adjustments to conventional carbon taxes on production are designed to reduce or eliminate the trade distortions introduced by those taxes. They only modestly improve the performance of a production tax, however, reducing leakage by about a third. With or without border adjustments, the emissions reductions from conventional approaches are modest. Border adjustments are also difficult to administer, will be inaccurate, and will be avoidable. Moreover, although most likely consistent with the WTO, they raise considerable legal uncertainty. There are good reasons that they are controversial.

Below, we explore a better way to impose a regional carbon price.

## II. A better alternative

We show here how to design a better regional carbon price. Our approach reduces global emissions more effectively and at a lower cost than

traditional approaches. It is also simpler to implement and it raises fewer legal problems.

Our reasoning is based on a formal model of the problem, and we show some results here from a calibrated version of the model. Rather than presenting the model here, we describe the underlying reasoning that comes out of the model. We describe the basic structure of the model in the Appendix. The full model, its solution, and the details of our calibration, are available elsewhere.[50] Our code is freely available and can be run using open source software.[51]

A. The root of the leakage problem

To understand how to design a better regional carbon tax, we start by clarifying why carbon taxes generate leakage. Carbon taxes affect the price of energy in other parts of the world. Leakage is caused by foreign actors responding to that changed price. The key idea is that different methods of imposing a carbon tax, all of which would be equivalent in a world without trade, have different effects on the price of energy in other parts of the world when there is trade, and, therefore, different leakage effects.

To understand this, start with the standard explanation of how taxes affect prices and quantities.[52] The analysis applies to an arbitrary good, service, or type of fuel but, because we are focused on energy, we will apply it to the market for oil.

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[50] Samuel Kortum and David Weisbach, *Optimal Unilateral Carbon Policy*, CESifo Working Paper No. 9409 (2021), available at https://ssrn.com/abstract=3906912

[51] https://github.com/dweisbach/Optimal-Unilateral-Carbon-Policy.

[52] This analysis mirrors that found in in basic public finance textbooks. See, e.g., JONATHAN GRUBER, PUBLIC FINANCE AND PUBLIC POLICY (Sixth ed. 2019).

Figure 2 is a supply/demand diagram for oil. The dark lines represent the pre-tax supply and demand curves. Without taxes, the market clearing quantity of oil would be $Q_o$ and it would sell at price $p_o$.

Suppose that we want to impose a tax of $t$ per unit on oil. We can alternatively require sellers or buyers to remit the tax. The sellers, we will assume, are the extractors of the oil. The buyers are either producers who use oil to make things, or consumers of oil, who buy products made with oil. In Part II.B, we will more carefully differentiate between these different types of buyers. For now, we treat them the same.

As noted in Part I, current carbon taxes (or equivalently, cap and trade systems) require users or buyers of energy to remit the tax. The tax is on the demand side. If the buyers must pay a tax on oil, their demand will go down because they must now pay the tax on top of what they pay the seller. The demand curve shifts downward and inward, as reflected in the dashed, downward-sloping line in Figure 2. The after-tax equilibrium is where the new demand curve intersects the supply curve. The market price goes down to $p_t$, but, including the taxes, buyers pay $p_t+t$. With a tax on demand, $p_t$ is *lower* than the pre-tax price and the equilibrium quantity goes down to $Q_t$.
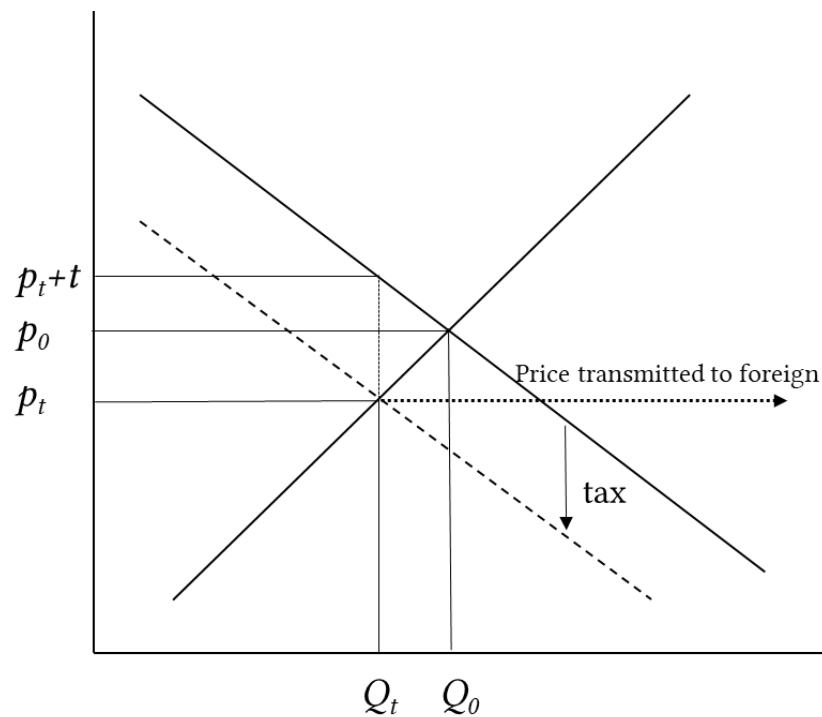
**Figure 2: Tax on Demand**



Figure 3 shows the same tax, but now with the tax remitted by extractors. If extractors remit the tax, their costs go up. They must charge more per unit to cover their costs, which now includes taxes. As a result, the supply curve shifts upward and inward, as reflected in the dashed, upward-sloping line in Figure 3. The market clearing quantity that is sold goes down to $Q_t$, where the new supply curve and the original demand curve intersect. The market price of oil will go up to $p_t$. Extractors will receive $p_t$, pay a tax of $t$, leaving them with $p_t$-$t$. Relative to when there is no tax, buyers pay more and sellers receive less.

**Figure 3: Tax on Supply**
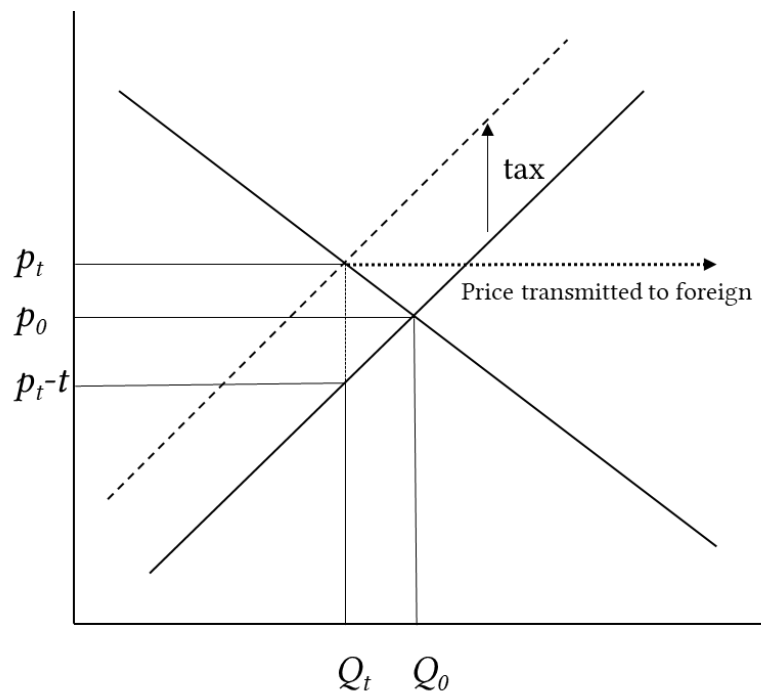


With no trade, it makes no difference whether the tax is remitted by buyers of oil or sellers (extractors) of oil. In both cases, the market-clearing quantity is the same, $Q_t$, and the difference between what buyers pay and sellers receive is the tax, $t$. That is, regardless of who remits the tax, there is a wedge between what buyers pay and sellers receive of $t$. As a result, the standard view in tax policy is that it does not matter whether the government imposes a tax on sellers or buyers.[53] A consequence of this conclusion is that in a world without trade, we can impose remittance

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[53] *Id.* This view is reflected in the incidence of social security taxes. They are remitted half by workers and half by employers, but the incidence is thought to fall entirely on workers. It would not matter if they were remitted entirely by employers or by employees.

obligations where it is most convenient, such as on larger, more sophisticated entities.[54]

With trade, this equivalence no longer holds. The reason is that taxes on demand and taxes on supply have different effects in foreign markets (in which carbon taxes are absent). To see this, return to Figure 2, showing a tax on demand. In this case, buyers pay $p_t+t$ for oil and sellers receive $p_t$. The after-tax price, $p_t$, goes down. With trade in oil, this is the price that is seen in international markets (indicated by the dashed arrow). A tax on domestic demand for oil suppresses the global price of oil. A lower price of oil in foreign markets generates an increase in the demand for oil in those markets, which is what causes leakage. Note, however, that there is a second effect of a tax on the demand side: a lower global price of oil will cause a reduction in extraction in foreign markets because extractors will receive less for the oil that they extract. Marginal oil fields will go offline. This effect partially offsets demand-side leakage. That is, a tax on domestic demand increases foreign demand but reduces foreign supply.[55]

The reverse holds for a tax on domestic supply. As Figure 3 illustrates, a tax on domestic supply makes the after-tax global price, $p_t$, go *up* rather than down. Foreign users of oil will reduce their demand because they face a higher price. Foreign suppliers of oil, however, will extract more because the price they can sell it at has gone up. Previously marginal oil fields will

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[54] See Metcalf and Weisbach, *supra* note 14. The standard conclusion does not hold if one side of the market is more likely to evade taxes than the other. If, for example, sellers are more likely to evade taxes than buyers, taxing sellers is not the same as taxing buyers.

[55] In addition, the equilibrium supply and demand shown in Figure 2 (as well as in Figure 3) cannot be the equilibrium with trade. The reason is that at the price shown, there is excess demand in foreign countries, which means that global supply does not equal global demand. In equilibrium, the price would go down less than is shown, generating excess supply in the taxing regime sufficient to meet the excess demand elsewhere.

now be profitable. Taxes on supply generates what we might call "extraction leakage," which is an increase in the supply of energy in other parts of the world in response to a domestic tax (as opposed to conventional leakage, which is an increase in the demand for or use of energy in other part of the world). That is, a tax on the supply of oil causes foreign demand to go down and foreign supply to go up.

Neither tax on its own is able to control the responses in other parts of the world. They both transmit price changes to foreign markets, which respond by offsetting the tax at least in part.[56] With a tax on demand, foreign users of oil increase their use, offsetting domestic reductions. With a tax on supply, foreign suppliers of oil increase their extraction, offsetting domestic reductions.

B. Designing a better alternative

The key idea behind designing a better regional carbon policy is to exploit this difference between taxes on supply and taxes on demand. Exploiting this difference allows the taxing region to better control the effects of its policy elsewhere in the world and, by doing so, control leakage. It also turns out that the same strategy ends up making the tax easier to implement and more likely compatible with the WTO, making it a win-win-win approach. We start by showing how to combine taxes on supply and demand to control leakage. We then consider how to impose a tax on the

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[56] A second reason the equivalence no longer holds when there is trade is that the tax base of a tax on extraction need not be the same as the tax based on energy used production or the energy embodied in goods that are consumed. The reason is that with trade, domestic extraction may be larger or smaller than energy use in production if energy is exported or imported, respectively. The same holds for energy used in production compared to the energy embodied in goods that are consumed domestically. Changing who remits the tax changes the tax base.

demand side, either on emissions from production, emissions embodied in consumption, or some combination.

### 1. Hybrid Taxes: Combining Taxes on Supply and Demand

Recall that taxes on the demand side of the market lower the price (of oil, here) seen in foreign markets, and taxes on the supply side of the market increase the price seen in foreign markets. The key insight is that by imposing part of the tax on both sides of the market, the taxing region can choose how its taxes affect foreign prices.[57] If, for example, half the tax were imposed on the demand side and half the tax were imposed on the supply side, the two would push in opposite directions, the demand side tax pushing the foreign price down and the supply side tax pushing it up. By choosing the right mix, the taxing region can choose the effects of its tax abroad.

Figure 4 illustrates. To be concrete, suppose that the desired tax is $10 per unit of oil. Rather than a $10 tax on buyers or a $10 tax on sellers, Figure 4 shows a combination of a $3 on the supply side and $7 on the demand side. There is still a $10 difference between what buyers pay and sellers receive in the taxing jurisdiction, so the effective tax is the same. This combination lowers the price seen in foreign markets relative to the price before the taxing region imposes the tax, but does so less than a tax entirely on the demand side.[58]

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[57] This insight dates back to a paper published in 1975. See James R. Markusen, *International externalities and optimal tax structures*, 5 JOURNAL OF INTERNATIONAL ECONOMICS 15–29 (1975). Nevertheless, it does not seem to have been appreciated in the literature on the design of carbon taxes.

[58] In Figure 4 the after-tax amount supplied, $Q_t$, in the taxing region and the after-tax amount demanded in the taxing region, denoted by $C_t$, are not equal. This is because if the price is lower in foreign countries, their extraction will go down but demand will go up, generating a net demand for exports from the taxing region, similar to the effect

**Figure 4: Combining taxes on supply and demand**
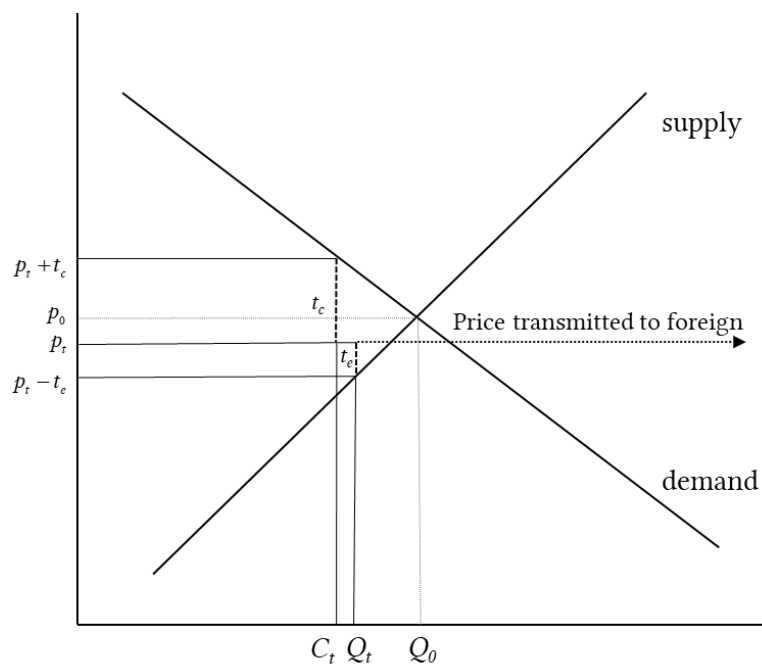


The choice of a demand side tax of $7 and a supply side tax of $3 was just illustrative. The taxing region can choose any combination of the two that add up to the total tax that it seeks to impose. By choosing the mix, it chooses the price, and, therefore, the effects seen in foreign markets.

The optimal mix minimizes market distortions, which means that the optimal mix depends on how foreign markets respond to price changes. If foreign supply is highly responsive to price changes, the taxing region will not want to impose taxes on the supply side because doing so induces large

discussed in note 55. Figure 4 is drawn to show an excess of supply in the taxing region to meet that demand for exports. The equilibrium price of oil sets the demand for exports in foreign countries equal to the excess supply in the taxing region. Note that this would also be true in Figures 2 and 3, but we have omitted this feature for simplicity.

responses. Similarly, if foreign demand is highly responsive to price changes, the taxing region will want to avoid demand side taxes. The optimal mix balances these effects.[59]

To illustrate the logic, suppose that the taxing regime begins with a tax only on supply, which in the case of oil, is an extraction tax. Ideally, the rate would be set equal to the marginal harm from emissions. This tax increases the global price of oil, resulting in an increase in foreign extraction. Increases in foreign extraction cause harm because that extracted energy ultimately produces atmospheric $CO_2$, causing an increase in climate change. The size of this effect, what we called extraction leakage, is determined by the elasticity of energy supply in foreign markets multiplied by the size of those markets.

To offset this effect, the taxing region can lower the extraction tax and impose an offsetting tax on the demand for energy, leaving the sum of the two taxes the same as the original extraction tax, equal to the marginal harm from emissions. For example, if the original extraction tax were $10/ton, the taxing region can lower it to $9/ton and impose a $1/ton tax on demand, leaving the sum of the two taxes the same. This change reduces extraction leakage by lowering the price of energy. A lower price of energy, however, increases foreign demand (relative to what it would be with the pure extraction tax), resulting in more energy use and, therefore, once again

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[59] In fact, the taxes are set so that the two tax rates multiplied by the relevant change in foreign markets are equal, or in notation:

$$t_e \varepsilon_e Q_e^* = t_d \varepsilon_d C_e^*,$$

where $t_e$ is the tax on extraction, $\varepsilon_e$ is the foreign elasticity of extraction, and $Q_e^*$ is the amount of foreign extraction, and $t_{d,}$ is the tax on consumption, $\varepsilon_d$ is the foreign elasticity of demand, and $C_e^*$ is the amount of (demand for) foreign consumption. In addition, the two taxes sum to the marginal harm from emissions, thereby giving us two equations for two unknowns.

more harm from climate change. The size of the demand-side effect is determined by the foreign demand elasticity and the size of that market.

The optimal policy trades off these two effects: the harm of an increase in foreign extraction due to an increase in the price of energy and the harm of an increase in foreign demand due to a decrease in the price of energy. The combination of the two smaller distortions, one on the supply side and one on the demand side, will typically be less than one bigger distortion in either supply or demand alone, which means that combining taxes on supply and demand produces superior outcomes compared to taxing only one side of the market.[60] Because these two effects may not be equal—the supply and demand elasticities and the size of the markets may be different—the optimal policy may not leave energy prices fixed at their pre-tax price level. The taxing region may be more concerned about conventional leakage than extraction leakage, or vice versa.

### 2. Choosing the Demand-Side Tax

We have, so far elided the difference between different taxes on demand, namely taxes on production and taxes on consumption. As discussed, we can think of the demand side as two distinct steps: the use of fossil fuels in production and the consumption of goods produced using fossil fuels. The question is where to place the demand side tax, on emissions from production or emissions associated with consumption. Border adjustments on goods shift the tax from production to consumption, so the question is equivalent to whether, or to what extent, to have border adjustments on goods. We discuss this choice here. We start by discussing

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[60] One intuition for this is that the costs of a tax go up with the square of the tax rate. One $10 tax produces much greater costs than two $5 taxes. GRUBER, *supra* note 54. If either supply or demand were perfectly vertical, then the taxing region would choose to tax only one side of the market, but in all other cases, it should tax both sides.

the effectiveness—how well different choices reduce emissions—and then turn to implementation and WTO compatibility.

Note that while the considerations are similar to those discussed in the literature on border adjustments, we are considering here a demand side tax that is part of a hybrid system that also taxes the supply side or extraction. As a result, the costs and benefits of different choices will not be the same as in the general literature. In fact, we will argue that because of the extraction tax, a simpler demand side tax, the extraction production hybrid, or the EPT, should often be preferred.

*Effectiveness.* There are three salient possibilities for the demand side tax: the two just mentioned—taxing production or taxing consumption—and a combination of the two.[61]

The key problem with taxing emissions from domestic production is that doing creates an incentive to shift production abroad, generating leakage. The incentive to shift production abroad arises both for goods potentially produced abroad but consumed at home (the import margin) and for goods currently produced at home but consumed abroad (the export margin). A tax on production causes shifts along both margins, increasing imports and reducing exports.

As discussed in Part I, shifting the tax downstream to domestic consumption (e.g., by adding border adjustments) eliminates these incentives because the tax is the same regardless of the location of

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[61] In fact, there are a number of other possibilities, including only taxing goods that are both produced and consumed at home, taxing only imports or only exports, and taxing imports and exports but not goods both produced and consumed at home. Our modeling shows that none of these possibilities turns out to be desirable.

production. As a result, a consumption tax is, all else equal, a more effective tax than a production tax.[62]

In the hybrid tax environment we are considering here, however, (i.e., with the addition of a tax on extraction), the advantage of a consumption tax over a production tax is reduced, possibly significantly (as our simulations in Part IIC show). A key reason is that when the taxing region imposes a hybrid tax, the tax rate on the demand side is lower. Part of the tax is on the supply side. A lower tax on the demand side generates less leakage. In addition, if the taxing region chooses to tax production rather than consumption, the taxing region can shift more of the tax to extraction to limit leakage. As a result, the benefits of border adjustments on goods to shift the production portion of the tax to consumption are lower in hybrid systems.

While a consumption tax is more effective than a production tax, the combination of both is more effective than either. This should not be surprising because the combination is less restrictive than a tax that must fall only on one or the other. That is, of the three possibilities, taxing both production and consumption is the most effective.

A tax on both production and consumption can be thought of as falling on (1) all goods consumed at home, regardless of whether they are produced

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[62] If taxing region is constrained to imposing the demand side tax on production (say for political or legal reasons), it can account for leakage by lowering the tax rate. In particular, if leakage is 100%, the optimal production tax would be zero because any positive tax would result in completely offsetting shifts in production, resulting in no emissions reductions but distortions in the location of production. The hybrid tax would fall purely on extraction. If leakage were zero, the optimal production tax would be the same as the optimal consumption tax (e.g., the marginal harm from emissions) because leakage would not be a consideration. For leakage rates between 0% and 100%, the optimal production tax rate scales with the leakage rate. In effect, because of leakage, a production tax cannot be imposed at as high a rate as a consumption tax.

at home or abroad, and (2) goods produced at home and exported. The potential third category—goods produced at home that are consumed at home—does not need a separate tax because those goods are already taxed under the consumption portion of the tax. That is, if the consumption portion of the tax covers all goods consumed at home, then the production portion of the tax need only cover exports. Because the consumption portion of the tax picks up imports, there is no incentive for leakage along that margin. As a result, with a tax on both production and consumption, we only need to worry about leakage on the export margin.

One way to think about the benefit of taxing both production and consumption is that it has a larger base than either production or consumption alone. It taxes all domestic consumption plus exports. A pure consumption tax would remove the tax on exports (via a border adjustment), allowing exports to be produced with greater emissions than if the tax were not removed. The broader base of a tax on both production and consumption helps ensure that exports face a carbon tax and, therefore, exporters take climate change externalities into account.

To account for the possibility of leakage, the tax on exports should be lower than the tax on domestic consumption. If leakage were 100%, it would not make sense to try to tax exports because doing so would result in a shift of that production abroad. The tax on exports in this case should be zero. If leakage is zero, the tax on exports should be the same as the tax on domestic consumption.

*Implementation.* While the production tax hybrid, the EPT, is the least effective tax on the demand side, it has a substantial advantage in its cost of implementation. The reason is that the extraction/consumption hybrid (and similarly, the extraction/production/consumption hybrid) faces all of the implementation problems with border adjustments on goods that were discussed in Part I.C.4, while the EPT can be implemented in a simple and accurate manner.

There are two observations that allow the EPT to be implemented simply and accurately. First, as we observed in our discussion of current production tax proposals in Congress, an extraction tax with border adjustments on energy but not goods is equivalent to a production tax. The border adjustments on energy shift the tax downstream to production. To illustrate, suppose that the taxing region imposes a $40 tax on extraction and imposes a $40 tax on imports of energy and rebates the $40 tax previously paid if energy is exported. Any energy used domestically bears the tax: if it was extracted domestically the tax is imposed on extraction and if it was extracted abroad and imported, the tax is imposed at the border. Any energy used abroad does not bear a tax: if it was extracted domestically, the tax is rebated when the energy is exported and if it was extracted abroad, no tax is imposed. Therefore, border adjustments on energy, but not goods, shift an extraction tax to domestic production.

Second, if the border adjustments on energy are imposed at a lower rate than the underlying extraction tax, only that portion of the extraction tax is shifted to production. For example, suppose that the desired set of taxes is a $60 tax on extraction and a $40 tax on production. To implement this tax, the taxing region would impose a nominal extraction tax at $100/ton of $CO_2$ and a border adjustment on imports and exports of energy (but not goods) at $40/ton. The border adjustment shifts $40 of the tax downstream to production, leaving an effective $60 tax on extraction. Therefore, this combination is equivalent to imposing a $60/ton extraction tax and a $40/ton tax on production.

This combination—an extraction tax and border adjustments on energy—can be implemented easily and accurately. As noted, the United States, for example, can impose a tax on all extraction of fossil fuels by taxing only about 2,500 large, sophisticated entities.[63] Border adjustments on energy are also easy to implement. To implement them, we only need to

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[63] Metcalf and Weisbach, *supra* note 14.

know the carbon content of imported or exported fuels, which are already tracked in great detail.[64] And compared to imports and exports of goods, the volumes are smaller.[65] The EPT, implemented this way, is, therefore, simple to impose and hard to avoid.

The hybrids that involve a consumption tax, by contrast, require border adjustments on goods. For example, to implement the extraction/consumption hybrid, the taxing coalition would start with an extraction tax and then apply the border adjustments (at a lower rate than the nominal extraction tax) to energy and goods. Applying border adjustment to goods shifts the demand-side component of the tax all the way downstream to consumption, generating a hybrid of an extraction tax and a consumption tax.

Applying the border adjustments to goods, however, brings in all of the implementation and legal problems discussed above with traditional border adjustments. Those problems did not depend on starting with a nominal production base and adding border adjustments. They arise if we start with a nominal extraction base as well, in exactly the same fashion. As a result, unless the gains from adding border adjustments on goods are substantial (which they are not in our simulations using our preferred calibration), it is preferable to just impose them on energy, or, said another way, to use the EPT.[66]

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[64] This is done in the United States by the Energy Information Agency. It is done globally by the International Energy Agency.

[65] The Energy Information Agency already carefully tracks energy imports and exports. See https://www.eia.gov/todayinenergy/detail.php?id=43395#:~:text=Energy%20exports%20ofrom%20the%20United,(EIA)%20Monthly%20Energy%20Review.

[66] If the taxing coalition is such that there remains a benefit to the extraction/consumption hybrid, a possible middle ground might impose border adjustments on energy and on a

The same is true for the hybrid of all three taxes, extraction, consumption, and production taxes. This hybrid would be implemented by imposing the same nominal tax on extraction, partial border adjustments on energy, and partial border adjustments on imports of goods. The rebate on exports, however, would be at an even lower rate (possibly zero) to keep some fraction of the tax on exports. As noted, the fraction depend on the leakage rate. If leakage were zero, the tax on exports should be at the same rate as on domestically consumed goods, which means that the rebate should be zero. If leakage were 100%, the tax on exports should be zero, which means that the entire demand-side tax should be rebated on export. For leakage rates between zero and 100%, the border adjustment on exports would scale accordingly.

This system has the same administrative costs as the extraction/consumption hybrid. The taxing region would still need to estimate the emissions associated with imports of goods. As a result, the administrative considerations for this system, as compared to the EPT, are the same. As between the hybrid of all three taxes compared to the extraction/consumption hybrid, there is little reason to prefer the more limited extraction/consumption hybrid. The only implementation difference is that the rebate on exports of goods is lower for the hybrid of all three. While as seen below in our simulations, it generates only modest gains, imposing the hybrid of all three would add no additional implementation costs.

*The WTO.* As discussed above, while it is likely that border adjustments on goods would be held to be consistent with WTO law, uncertainties remain. Shifting to border adjustments on energy but not goods—to the EPT—reduces those uncertainties. The reason is that border adjustments on

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subset of goods that are particularly energy intensive and trade exposed. This approach is the approach taken in most proposed border adjustments in bills introduced in Congress.

energy would not be on the production process or method. They would be on the actual carbon molecules that cross the border. To the extent that the legal determination keys off of problems with taxing production processes or methods, the EPT is more likely to be allowable than the extraction/consumption hybrid or the combination of all three taxes.

A second consideration for the legality of the various taxes is that the EPT would be accurate while the extraction/consumption hybrid and the hybrid of all three would not. An inaccurate tax generates easy opportunities for complaints: litigants would be able to show to the WTO that they are over-taxed relative to their domestic competitors, generating what looks like a trade barrier. The EPT eliminates this concern.

A final note is that the effectiveness of the EPT makes it more difficult for countries to make the "necessity" showing required for the Article XX(b) exception in the GATT. It is not necessary to impose border adjustments on goods for environmental reasons if the EPT is available as an alternative. An implication is that pure consumption taxes, the extraction/consumption hybrid, and the hybrid of all three taxes are more likely to violate the WTO than otherwise. That is, the effectiveness of the EPT makes the legal case for the EPT stronger.

### 3. Summary

Hybrid taxes—combinations of taxes on the supply of energy and the demand for energy—work better than pure taxes on either supply or demand. The reason is that hybrids can be designed to control the price of energy seen in foreign markets, and, therefore, the responses to the tax in those markets. Of the three hybrids, the EPT seems the most promising. Although it may be somewhat less effective, it is much easier to implement and is less likely to raise legal problems.

Ultimately, the trade-off between the two hybrid taxes depends on how much better the extraction/consumption hybrid or the hybrid of all three

perform compared to their higher administrative cost. We explore this issue below using a calibrated simulation of our model.
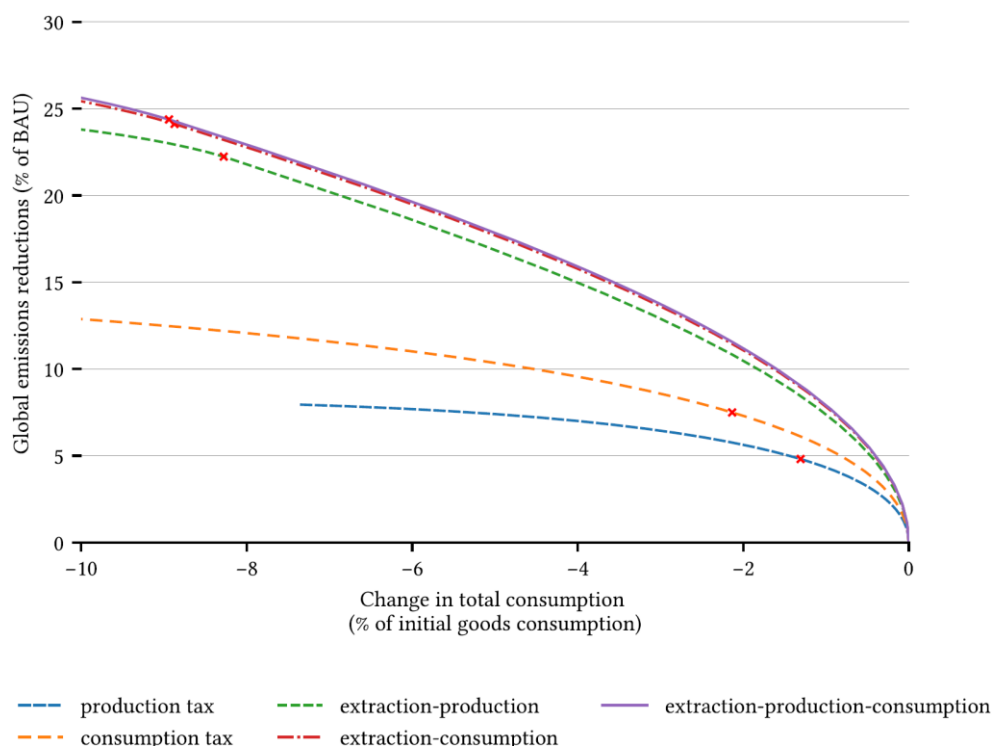
C. Simulations

To get a sense of the quantitative benefits of the various hybrid taxes and to compare them to one another, we present a number of simulations of our formal model of the problem. Details of our calibration are in the Appendix. Briefly, we assume for these simulations that a tax is imposed in the OECD countries and that the rest of the world does not impose any climate policy. (We consider the effects of changing the taxing coalition in Part III.) We assume that the economy has three stages: extraction of energy, which is traded, the use of energy in production to manufacture goods, also traded, and consumption of those goods. We calibrate the model to trade shares in extraction, production, and consumption, and estimate the elasticities based on the relevant data.

We start with a comparison of the EPT to three conventional taxes (a tax on emissions from domestic production, and to the other two hybrid taxes). Figure 5 illustrates. It shows the emissions reductions achievable under each policy (y-axis) for a given cost (x-axis), measured in terms of a reduction in current consumption. It is similar to a standard Pareto Possibilities Frontier graph that shows the tradeoffs available between two goods. Rather than, say, wine and beer, Figure 5 shows the tradeoff between emissions reductions and consumption (measured in terms of costs as a percent of goods consumption). The red dots indicate the emissions reductions that the OECD would choose with each policy, given the same level of marginal harm from climate change.

As can be seen, the EPT vastly outperforms both a conventional tax on emissions from production and a tax on emissions associated with consumption (i.e., a production tax along with border adjustments on goods). At any given cost, the EPT reduces emissions more than conventional approaches, and increasingly so as the OECD spends more to reduce emissions. For example, at a cost of 6 percent of consumption, a

traditional production tax reduces global emissions by about 7.6 percent. Adding border adjustments improves that to 10.9 percent. The EPT reduces emissions by 18.6 percent at the same cost.

**Figure 5: Comparison of the EPT to conventional taxes**



We discussed above the comparison between the EPT and a combination of an extraction tax and a consumption tax. As expected, the extraction-consumption hybrid outperforms the EPT, but in this simulation, the difference is small. The same is true for the hybrid of all three taxes, which in this simulation is almost indistinguishable from the extraction-consumption hybrid. This confirms the argument above that the simplification benefits of the EPT make it the better choice.

In Part IIB we argued that the reason the EPT performs better than conventional approaches is that by combining a tax on the supply of energy

(an extraction tax) with a tax on the demand for energy (a production tax), it allowed the taxing region to control the effects of its policy on the price of energy transmitted to other parts of the world. Figure 6 illustrates this within our simulation.

It shows the change in price of energy in non-taxing regions, that is non-OECD countries, for the same five policies considered in Figure 5. The x-axis is the marginal harm from climate change, set in units relative to the price of the carbon content of energy. A marginal harm of 1 indicates that the marginal harm, and, therefore, the optimal tax rate, is about equal to the price of the carbon content in unit of energy. For example, if a gallon of gas costs \$4, and half of that (\$2) is for the actual carbon molecules in that gallon (the other half being due to the costs of renting the land for the gas station, paying employees, profits to the oil company, and so forth), a value of 1 on the x-axis would mean that the harm from burning a gallon of gas is \$2. The y-axis is the change in the price of energy relative to its no-tax value, which is normalized at 1.

As discussed above, the two demand-side taxes (the production tax and that same tax with border adjustments on goods) decrease the price of energy in the rest of the world, an effect that gives rise to leakage. A pure extraction tax increases the price of energy in the rest of the world. This increase in the price of energy will induce more extraction abroad but will not create conventional leakage.

The EPT moderates these effects. Under the calibration in this scenario, the OECD chooses a mix of extraction and production taxes that still lead to an increase in the price of energy, but a smaller increase than a pure extraction tax. The reason the OECD would want to choose this mix of taxes and this effect is that, as noted, the elasticity of energy supply is relatively low in this calibration. As a result, a large increase in the price of energy abroad does not induce a large increase in extraction. The OECD, therefore, can set the mix of taxes without having to worry too much about an increase in extraction abroad. When we consider robustness checks in Part III, we

will see that with different calibrations, the effects of the EPT on the price of energy look different.

**Figure 6: change in the price of energy**
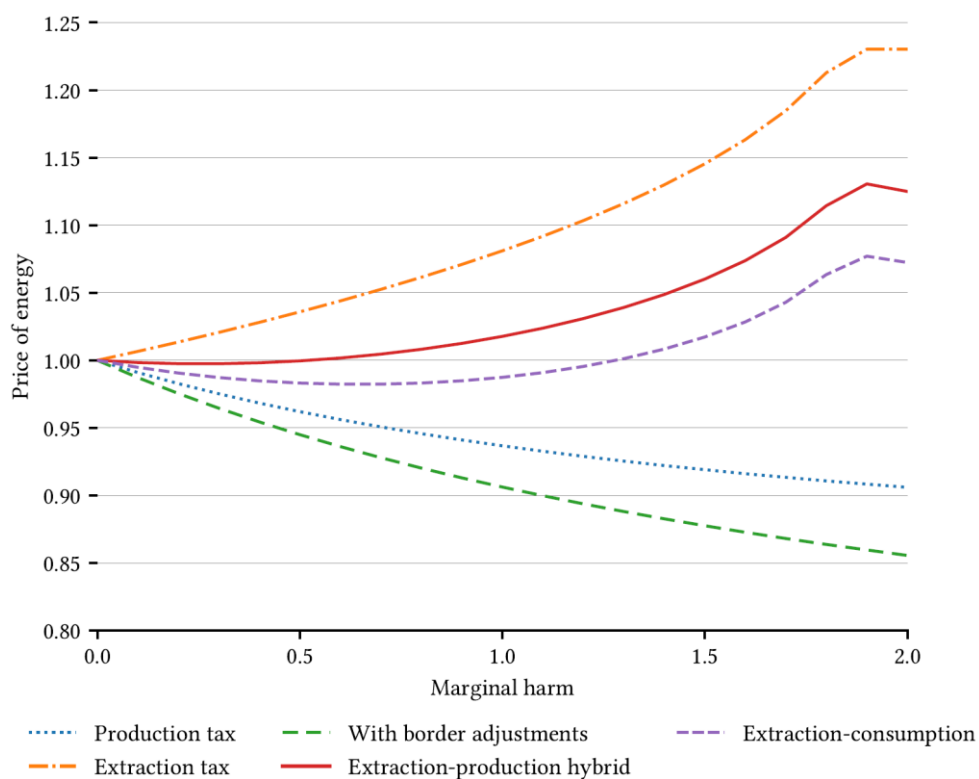


Finally, we simulate the effects of these taxes on foreign activities: how much do the various taxes change foreign extraction, production, and consumption. We can think of location effects as generalized versions of leakage, tracking not just emissions but each individual activity that might shift to or from the non-taxing regions.

Figure 7 illustrates. It shows the change in foreign extraction, production, and consumption for the various taxes. Looking at the three "pure" taxes, the effects are as predicted above. For example, extraction taxes increase foreign extraction but reduce foreign production and

consumption. Production and consumption taxes have the opposite effect. The hybrids moderate these effects, simultaneously reducing the change in all these activities in non-taxing countries. They are the solution to the leakage problem.

**Figure 7: Location effects**
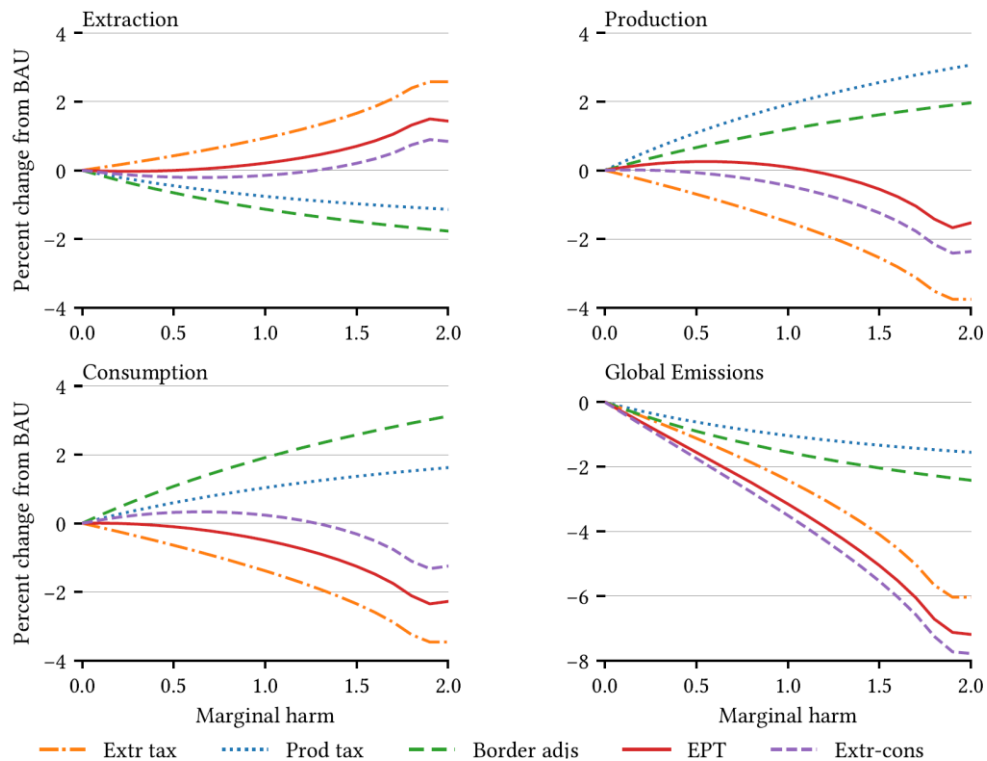


The bottom right hand panel of Figure 7 shows the emissions reductions each tax would achieve, similar to Figure 5. While Figure 5 showed the emissions reductions achievable at any given cost, the bottom right hand panel of Figure 7 shows the emissions reductions that the OECD would choose for any given level of marginal harm from climate change. As can be seen, the hybrid taxes, the EPT, and the extraction-consumption hybrid perform much better than the conventional taxes.

**III. Extensions**

We consider here two additional issues or extensions of the model and then discuss the limitations of our analysis.

A. The taxing coalition

The simulations above held the taxing coalition fixed: all of the simulations assumed that the OECD was the taxing coalition. The OECD, however, produces only about a third of global emissions.[67] No policy implemented only in the OECD can solve climate change. Adding countries to the taxing coalition is of central importance.

There are two benefits to expanding the tax base to include more countries. First, more countries means a broader base. With a broader base, the same tax creates incentives on more actors to reduce emissions and internalize costs. The tax is that much more effective.

Second, with a broader base, there is less room for leakage or other shifts of activities to non-taxing regions. There are fewer actors outside of the system and, therefore, whatever the incentives on actors outside the system, the effects will be smaller. At the limit, where there are no countries outside the taxing coalition, leakage is zero.

Figure 8 is a simulation of the effects of expanding the taxing coalition. It considers five different coalitions, each larger than the prior one: (1) the European Union, (2) the United States and the EU, (3) the OECD, (4) the OECD and China, and (5) a global tax.

As expected, the larger the taxing coalition, the greater the emissions reductions it achieves at a given cost. For example, at a cost of 4% of

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[67] Emissions in the OECD were about 12.2 gigatons of $CO_2$ in 2015 out of global emissions of 32.2 gigatons. See note __ in the Appendix.

consumption (marked by the vertical dotted line), the EU acting alone, can reduce emissions by just under 4%. It has almost no power to act alone. Adding the US to the taxing coalition more than doubles the emissions reductions at that same cost, with emissions now going down by about 10%. We see similar size improvement from expanding the base to all OECD countries. Adding China, the world's large emitter, to the taxing coalition has a large effect, not surprsingly. Getting China to join the taxing coalition is critical. Finally, a globally harmonized tax would reduce emissions by about 41% at a cost of 4% of consumption. Those differences get larger if the taxing coalition is willing to spend more (e.g., the differences between coalitions are greater at a cost of 6% compared to a cost of 4%).

Similarly the black dots on each line in Figure 8 represents the choice each coalition would make at the same social cost of carbon (here set to be twice the cost of the carbon content of energy). As can be seen, the larger the coalition, the more that the coalition would choose to reduce emissions. The EU on its own would only reduce emissions by about 3% while the OECD and China together would choose to reduce emissions 36%.

The key message of Figure 8 is that expanding the taxing coalition is of first order importance.[68] This will be true regardless of which policy among is chosen: as the taxing coalitions get larger, the differences in the policies get smaller, and if the coalition were the entire world, all the policies would produce the same outcome. (The reason is the same as the discussion of the no-trade case above. Once the entire world is in the taxing coalition, there cannot be trade with regions that do not impose a tax.)

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[68] As we discuss in Part III.D, our analysis is static in that we assume that the structure of the tax has no effect on the behavior of the non-taxing region, including its willingness of parties to join the coalition. Nevertheless, there are reasons to believe that hybrid taxes may be better in this regard than pure taxes. For an analysis, see G. B. Asheim et al., *The case for a supply-side climate treaty*, 365 SCIENCE 325–327 (2019).

**Figure 8: Effects of expanding the taxing coalition**
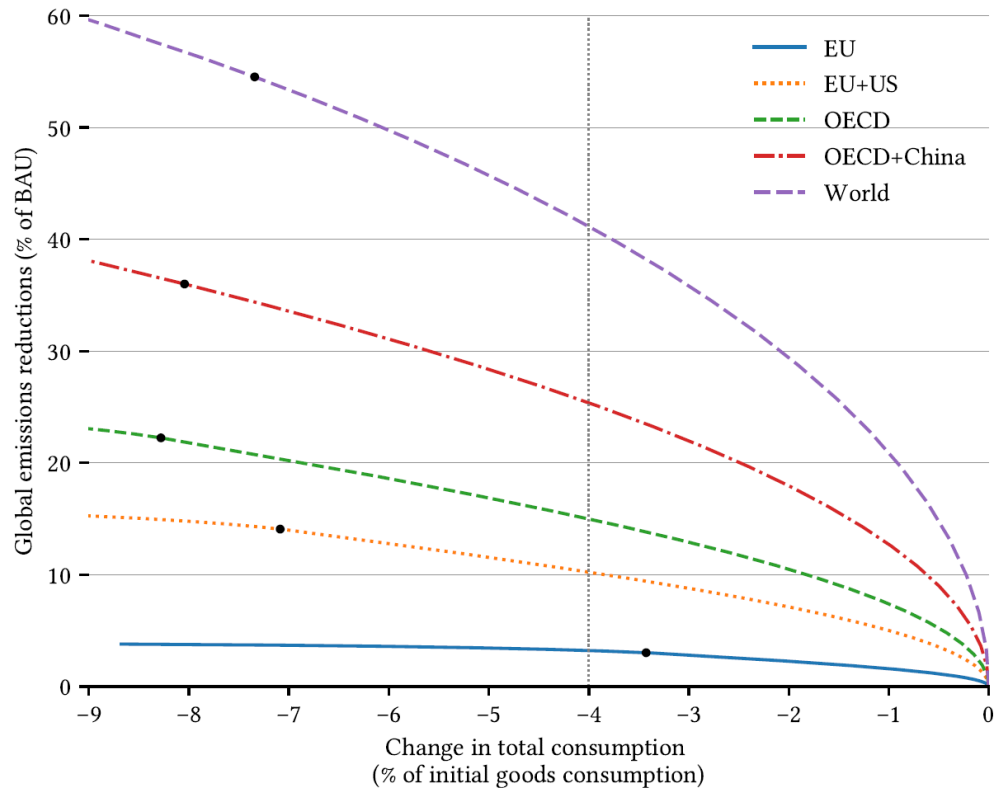


B. The Optimal Policy

While the two hybrids explored so far perform much better than traditional approaches, our model suggests an alternative set of policies is yet more effective. This alternative, however, is more complex than the EPT and raises more significant legal issues even than the extraction/consumption hybrid. Whether these costs are worth bearing depends on how much better it performs. We briefly describe that alternative here. We call it the "optimal" policy because it is the policy that in our model performs the best. Once administrative costs and legal uncertainties are taken into account, it may not be the best policy.

The core idea behind the optimal policy is that the taxing region wants to use all the tools at its disposal to control emissions. It does this by adding two elements to the EPT. The first is that the optimal policy adds a border adjustment on imports (but not exports) of goods, at the same rate as the border adjustment on energy. By doing so, it taxes all domestic production and all domestic consumption, as in our earlier discussion of hybrid demand-side taxes. Here, however, the tax is uniform across both production and consumption.  To illustrate, consider a good produced in the taxing region. It bears the production tax portion of the EPT regardless of where the good is consumed (recall there is no rebate on exports of goods). Consider a good consumed in the taxing region. If it was produced there, it bears a tax because of the production tax component of the EPT. If it was produced abroad and imported, it is taxed at the border. Therefore goods consumed domestically bear a tax regardless of where produced. The demand side of the optimal tax is the union of a production tax and a consumption tax rather than just one or the other, as in our simple hybrids.

Left there, the optimal tax would distort exports. Domestic producers would face the domestic production tax even if they sell in foreign markets, hurting their comparative advantage and reducing their trade shares. To solve this problem, the second addition to the EPT is a per unit export subsidy. The subsidy is not a rebate of prior taxes paid, unlike a border adjustment, so it does not remove the carbon tax. Therefore, it does not reduce the incentives that the carbon tax creates on domestic producers. Instead, it offsets the loss in comparative advantage by giving per unit subsidies.[69] That is, the export policy retains the incentives to produce with

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[69] A similar approach was suggested previously by Carolyn Fischer & Alan K. Fox, *Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates*, 64 JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT 199–216 (2012). See also Alain L. Bernard, Carolyn Fischer & Alan K. Fox, *Is there a rationale for output-based rebating of environmental levies?*, 29 RESOURCE AND ENERGY ECONOMICS 83–101 (2007); Stéphanie Monjon & Philippe Quirion, *Addressing leakage in the EU ETS: Border*

low-carbon technologies but also removes the disadvantage that producing this way might generate.

Under the full optimum, these subsidies don't just offset the loss in comparative advantage. They are large enough to expand the taxing region's trade share. The taxing region does this because production is cleaner at home (there is no carbon tax abroad so production there remains dirty). The cost of the subsidies is worth bearing to get the benefit of this cleaner production.

C. Robustness

While the logic of our argument, discussed in Part IIB, did not depend on empirical parameters, the simulations shown in Part IIC did. One question is whether the results shown above are robust to uncertainty in parameter values.

Our simulations (not presented here) show that the central parameter that affects the robustness of the figures shown above is the elasticity of foreign energy supply.[70] Our simulations assumed that foreign energy supply was not very responsive to changes in the energy price, with an estimated elasticity of 0.5. To test the robustness of our results to alternative values, we replicate Figure 5 but assume that the elasticity of foreign energy supply is 2.0.

Figure 9 presents these results. Because foreign energy supply is now quite sensitive to the price of energy, the extraction tax performs poorly, going from performing almost as well as the best taxes to performing the

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*adjustment or output-based allocation?*, 70 ECOLOGICAL ECONOMICS 1957–1971 (2011); Böhringer, Rosendahl, and Storrøsten, *supra* note 32.

[70] This is consistent with finding in the literature. See Elliott et al., *supra* note 34 at 237–240.

worst. The reason is that an extraction tax pushes up the price of energy, inducing a large response in foreign extraction. This increase in foreign extraction makes a domestic extraction tax ineffective. Because the extraction tax loses much of its power, the ETP is forced to rely on the production tax, which induces leakage. As a result, the tax does not perform well, and in fact does slightly worse than a tax on consumption (i.e., conventional tax on production with border adjustments). The hybrid of an extraction tax with a consumption tax, however, is more robust because, shifting away from the extraction component to the consumption component does not induce leakage. As expected, the hybrid of all three continues to perform the best.

**Figure 9: Alternative calibration for energy supply**
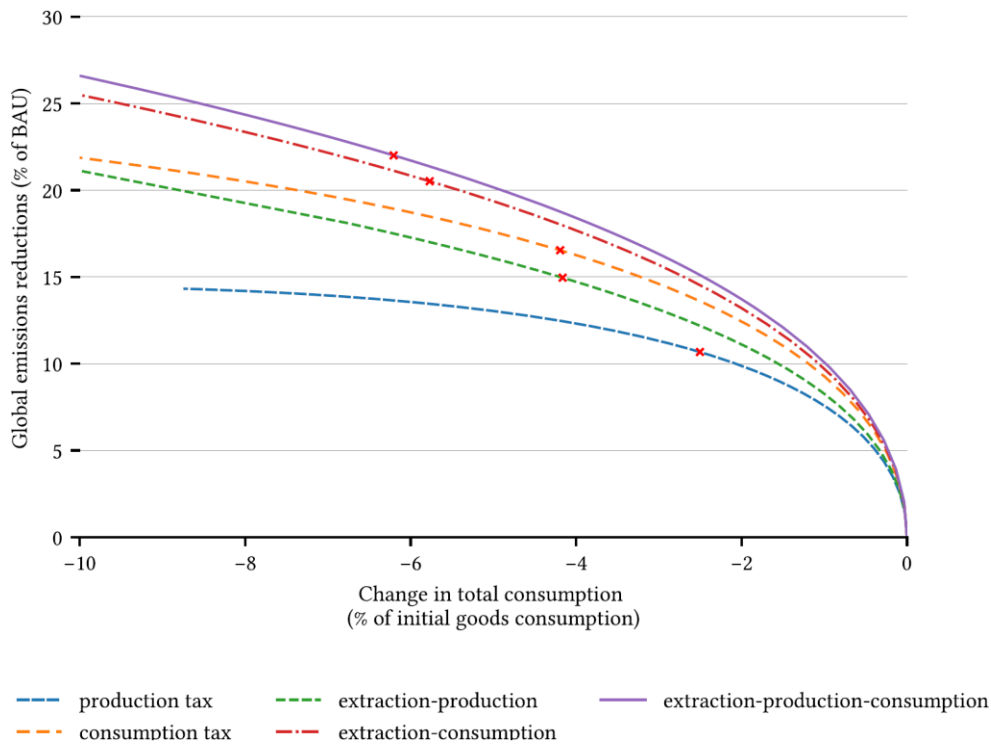


Comparing the EPT to the conventional production tax plus border adjustments in light of Figure 9, we continue to believe that the EPT is superior. In our preferred calibration it easily outperforms conventional approaches, and in our alternative calibration, it performs only slightly worse. Moreover, it is far easier to implement and raises fewer legal problems.

The comparison to the extraction-consumption hybrid is closer. The extraction-consumption hybrid performs better in all of our simulations and is more robust to uncertainty. Nevertheless, it is considerably more difficult to implement and raises WTO-legality issues.

One strategy for ensuring that the EPT is effective is to try to construct a taxing coalition that includes countries with high elasticities of energy supply, thereby ensuring that non-taxing regions have a low elasticity of energy supply. To the extent this is possible, the EPT becomes more effective, which means that the taxing region can take advantage of its simplicity and avoid having to impose border adjustments on goods. That is, when negotiating to construct a coalition of countries that will impose common carbon policies, all else equal, it is important to target countries that have high elasticities of energy supply. These are countries with expensive deposits of fossil fuels, deposits that would go offline if the price of energy goes up (or on line if the price goes down).

D. Limitations

While our model is fully general equilibrium and incorporates many key elements that will affect the design of regional carbon tax systems, it necessarily omits many details. We consider four limitations of our analysis, each of which is an opportunity for further research.

First, our analysis assumes a single global price of energy. In fact, there are three different fossil fuels (and many subtypes, such as grades of oil), each with its own trading characteristics. The model can be extended to consider all three fossil fuels under two alternative conditions: either all three are traded so that there is a global market clearing price (even if that price is different for different types of energy), or that the market clearing price for fuels that are not traded is determined by reference to those that are.

In particular, the market for oil is a single global market. While there are shipping costs and different types of oil, our model is a reasonable description of oil. Coal and natural gas are also traded, but much less so.

According to the World Coal Association, 21% of coal is traded.[71] The rest is consumed in the country where it is produced. About 30% of natural gas that is produced is traded, largely by pipeline but also in the form of liquefied natural gas.[72] (Even so, the volumes are so large that liquefied national gas was the world's 11th most traded product by value in 2019.)[73]

Second, our base model does not include renewable energy or other sources of energy that do not emit $CO_2$. The model can be extended to include renewable energy in the same way it can be extended to include all three fossil fuels. Taxes on fossil fuels in this case stimulate renewables by changing their relative price. We expect that simulations using renewables would show greater emissions reductions at a given cost than those shown in Figures 5 and 7.

A third key limitation is that we assume perfect labor mobility across sectors. For example, when the taxing region imposes a carbon tax, its economy becomes less energy-intensive. Labor reallocates, with more people working in the services sector and fewer in the goods sector. Different tax mixes will cause different labor allocations. The model does not consider the costs of this reallocation.

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[71] https://www.worldcoal.org/coal/coal-market-pricing (last visited July 11, 2021). The International Energy Agency provides additional information on coal trade. See https://www.iea.org/reports/coal-information-overview. (last visited July 11, 2021)Japan, China, India, and South Korea are the largest coal importers. Australia is the dominant exporter. See https://oec.world/en/profile/hs92/bituminous-coal-not-agglomerated (last visited July 11, 2021)

[72] http://www.natgas.info/gas-information/what-is-natural-gas/international-gas-trade (last visited July 11, 2021) The International Energy Agency provides information on natural gas trade here: https://www.iea.org/reports/natural-gas-information-overview

[73] See https://oec.world/en/profile/hs92/natural-gas-liquefied (last visited July 11, 2021)

In reality, shifting where people work may not be easy. We cannot readily turn a coal miner into a coder. The result may be unemployment, at least temporarily. The costs of unemployment and retraining may be significant and need to be carefully considered when designing carbon policies.

More generally, we think of our results as equilibrium results. They do not account for how the economy makes the transition to use fewer fossil fuels. The transition away from fossil fuels may be difficult and expensive, and is important to understand. While it may be desirable to pick the mix of taxes that is best in the long-run, there may be methods of reducing the costs of transition that need to be understood. Similarly, the model does not consider the long run effects of different tax systems, including their effects on growth or innovation.[74]

Finally, we have been considering a world where one region imposes a carbon tax and the rest of the world is passive. The rest of the world, however, is not likely to be passive. It will respond to climate policies enacted elsewhere. Moreover, as we indicated, a key consideration in the design of a carbon policy is to expand the set of countries that impose carbon policies. The mix of taxes may affect the incentives of countries to join the taxing coalition.[75] It may well be worth it for the taxing region to adopt a mix that appears suboptimal from a static perspective if that mix induces more countries to join the taxing coalition.

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[74] See John Hassler & Per Krusell, *Chapter 8 - Environmental macroeconomics: The case of climate change*, 4 *in* HANDBOOK OF ENVIRONMENTAL ECONOMICS 333–394 (Partha Dasgupta, Subhrendu K. Pattanayak, & V. Kerry Smith eds., 2018).

[75] See, e.g., William Nordhaus, *Climate clubs: Overcoming free-riding in international climate policy*, 105 AMERICAN ECONOMIC REVIEW 1339–70 (2015); Scott Barrett, *The theory of international environmental agreements*, *in* HANDBOOK OF ENVIRONMENTAL ECONOMICS 1457–1516 (2005).

## IV. Conclusion

The key to controlling leakage and other location effects of a regional carbon tax is moderating the effects of the tax on the price of energy. From this perspective, the traditional approach of taxing domestic emissions and imposing border adjustments to control leakage suffers from a fundamental flaw. A tax on domestic emissions and that tax combined with border adjustments both push the price of energy in the same direction, down. As a result, these policies do not, and cannot perform well on a global basis. Moreover, border adjustments are complex and legally questionable.

The EPT, which is a combination of an extraction tax and a production tax, performs better because it combines a tax on supply, which pushes the price of energy up, with a tax on demand, which pushes it down. The combination allows the taxing coalition to control the effects in other parts of the world by controlling how the taxes affect prices. The EPT can be implemented easily by imposing a tax on domestic extraction and border adjustments, at a lower rate, on energy (but not goods). The EPT also reduces the legal issues presented by border adjustments. Because the border adjustments would be only on energy, they would not need to be imposed on production processes. Moreover, unlike conventional border adjustments on goods, the border adjustments in the EPT would be accurate. As a result, the EPT is able to solve the carbon leakage problem and removes one of the major obstacles to the enactment of a domestic carbon tax in the United States.

**Appendix: Model description and calibration**

We provide a detailed presentation of the model elsewhere.[76] Here, we briefly describe the structure of the model, the method we use to derive a solution to the model, and the calibration of the model used in our simulations.[77]

Our model of the economy assumes that there are just two countries or regions, which we call Home and Foreign. These are generic placeholders, and we can think of Home as any region, such as the United States, the OECD countries, the Kyoto Protocol Annex B countries, or the entire world. Foreign is whatever set of countries is not Home.

Home imposes a carbon price, while Foreign is passive. As a result, we will sometimes refer to Home as the taxing coalition and Foreign as the non-taxing coalition. The basic structure of their economies is the same, but the size of various sectors and the parameters that affect their interactions can be different. Therefore, their economies can look quite different even though they have the same underlying structure. For example, Foreign might have greater energy resources, be able to extract energy at a lower cost, or be able to do so with less labor. This approach allows us to generate flexibility to study and calibrate the model while at the same time keeping the model as simple as possible.

Each of the countries has the three stages discussed above: extraction, production, and consumption. Energy extractors in each country hire labor to extract fossil fuels from deposits located in that country. They start by extracting the deposits that are easiest to get to, then they move to deposits that are more difficult to extract, continuing until extraction is no longer

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[76] www.kortum@elisites.yale.edu

[77] Our model is a generalization of the canonical model of trade and pollution, by James Markusen. See. Markusen, *supra* note 58.

profitable. The two countries potentially have a different cost structure for their deposits. They each, however, continue extracting energy until the marginal costs of extraction are equal to the price of energy (possibly less any taxes the Home extractor must pay if Home imposes an extraction tax).

Energy is traded globally, establishing a single global price of energy which is seen by extractors in both countries. The price of energy, therefore, is a key parameter in the model because it determines total extraction and, therefore, emissions. A high price of energy induces extractors to extract more, and a low price, less.

Producers in each country buy energy. They use labor and energy to produce goods.[78] When they use energy, they release $CO_2$, which causes climate change. We set units so that energy and $CO_2$ are one-for-one and, because in our base model, all energy is from fossil fuels, we can treat energy and carbon dioxide as interchangeable.

We follow a common method for representing trade in goods, which we assume is due to comparative advantage. In particular, we assume that there is a continuum of goods (indexed from 0 to 1), with each country having a different level of productivity for each of the goods (with goods ranked by Home's comparative advantage).[79] Absent trade costs, each country would specialize in the fraction of the goods where they have a comparative advantage, exporting the goods they produce to the other country, and importing the rest. For example, due to comparative advantage,

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[78] We do not explicitly represent capital in the model. In our simulations, we treat capital as part of the labor sector.

[79] See R. Dornbusch, S. Fischer & P. A. Samuelson, *Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods*, 67 THE AMERICAN ECONOMIC REVIEW 823–839 (1977).

Home might specialize in goods with indices between 0 and 0.6, and Foreign would specialize in goods with indices between 0.6 and 1.

Taxes on the use of energy in production (production taxes) alter Home's comparative advantage by increasing its costs. For example, if Home taxes production, it might instead only specialize in goods with indices 0 to 0.5 rather than from 0 to 0.6. Foreign would likewise expand the set of goods it produces. As a result, taxes alter the pattern of trade in the model, shifting production to Foreign, generating leakage. That is, concerns about carbon taxes hurting "competitiveness" are cashed out in the model as changes to comparative advantage.

These effects are muted somewhat in the model because we assume that trade is costly, as it is in the real world.[80] As a result, both countries will produce the set of goods in which neither has a strong comparative advantage because the gain from specialization among such goods is not large enough to overcome the costs of trade. For example, Home may produce goods with indices 0 to 0.4, Foreign may produce goods with indices 0.7 to 1, and both countries may produce goods in the middle, with indices 0.4 to 0.7. Taxes still change comparative advantage even with trade costs.

Each country also produces a generic good, which we call services, that does not require energy. Increasing the production and consumption of services allows Home and Foreign to become less energy intensive. Furthermore, services are tradable. If, for example, Home produces fewer goods, it can instead produce more services while importing goods from Foreign. We assume that labor can shift freely between the goods sector, the extraction sector, and the services sector. Such a shift is unrealistic in the

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[80] We use a formulation known as iceberg costs. See Paul A. Samuelson, *The Transfer Problem and Transport Costs, II: Analysis of Effects of Trade Impediments*, 64 THE ECONOMIC JOURNAL 264–289 (1954).

short term. We think of the model as producing an equilibrium result, with the understanding that shifting to that equilibrium can take time.

The last stage is consumption: consumers purchase goods and services produced in the two countries. They choose their purchases to maximize their utility. We use a simple utility function that eliminates income effects (which would complicate the model without helping us understand core effects).

Climate change enters the model by reducing utility. That is, utility is a function of the goods and services that individuals are able to consume, less the marginal harm from global emissions. Emissions, as noted, depend on the total amount of energy that is extracted. The harms from climate change depend on global emissions, but individuals in each country only consider their own harm. They are not affected by harm to people in the other country.[81] For simplicity, we assume a constant marginal harm from emissions.

Our solution to the model assumes that Home acts unilaterally to maximize its welfare. Home is subject to two "physical" constraints: its use of labor cannot exceed its supply of labor and the global use of energy cannot exceed the global supply of energy. In addition, we impose a constraint on Home that its policies do not make Foreign worse off. This constraint prevents Home from using climate change as an excuse to manipulate trade policy to its advantage.

We use what is known as the "primal" method to solve the model, in which Home directly picks an allocation of goods and their attributes such as the energy intensity of their production, as if it were an all-knowing social planner. We then show how that allocation can be achieved via taxes

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[81] Even if they are altruistic toward people in the other country, their altruism affects their own utility.

and markets in a decentralized equilibrium. (We could also interpret the social planner's optimal solution more directly, as a set of regulations rather than taxes.) The primal solution method is common in welfare economics (though as far as we known, rarely, if ever, used in the law and economics literature).[82]

A key to solving the model is to note which variables Home can control and which it cannot. It can control anything it touches: anything that is extracted, produced, or consumed domestically. It cannot control anything that is purely foreign. In particular, Home can dictate the amounts and energy intensity of all goods produced domestically (even if exported) and all goods consumed domestically (even if imported). It can also choose its level of energy extraction and how much it is willing to import or export. By doing so, it can determine the global price of energy. In all cases, however, Home has to assume that Foreign extractors, producers, and consumers will alter their behavior in response to Home's policies because Home cannot control those actors. That is, it is always setting policy assuming Foreign markets react to the changing energy price (while Foreign policy makers are passive).

We will discuss the solution to the model—Home's optimal policy—below. We also consider constrained policies. For example, we can use the model to determine how Home would set a production tax conditional on it being constrained to using just that tax. We can do this for extraction and consumption taxes as well, and as we will discuss, combinations of these three taxes. By considering "optimal constrained" policies, we are able to examine the losses from choosing simpler policies and to compare policies that have been proposed to one another. This procedure is how we derive

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[82] See, e.g., Peter A Diamond & James A Mirrlees, *Optimal taxation and public production I: Production efficiency*, 61 THE AMERICAN ECONOMIC REVIEW 8 (1971).

the EPT, which is the policy that is optimal if Home is constrained to using just exaction and production taxes.

Below we present calibrated simulations of the model. For the most part, we assume that the taxing region, Home, is the OECD (although we will examine the effects of changing the taxing coalition). Although some of our motivation was to address concerns in the United States about carbon leakage, we use the OECD for our base calibration because a coalition of OECD countries enacting a carbon price is more likely than the United States acting alone.

We calibrate the model to reflect trade in energy as well as trade in goods between the regions, as measured in units of energy. To provide for common units, all energy is measured in gigatons of $CO_2$. We calibrate the elasticities used in the model to data. For example, we use estimates of oil extraction from a global database of active oil deposits, extraction costs for each, and oil prices to estimate an elasticity of energy supply for Foreign and Home.

Table 2 provides our baseline calibration for the OECD. The columns are where production occurs, while the rows are where consumption occurs. For example, the Home row, Home column (value 11.3) represents the gigatons of $CO_2$ emissions from goods that are produced in the OECD and consumed there. The Home row, Foreign column represents the gigatons of $CO_2$ emissions from goods consumed in the OECD that are produced outside the OECD (i.e., in "Foreign"). A similar interpretation applies to the Foreign row. The Foreign row, Home column is the $CO_2$ emissions from goods produced in Home and consumed in Foreign, and the Foreign row, Foreign column is the $CO_2$ emissions from goods produced and consumed in Foreign. Adding up the rows and columns gives us total consumption and production in Home and Foreign.

Comparing the total $CO_2$ emitted during production in the OECD (12.2 gigatons) to its consumption (13.8 gigatons), we can see that the OECD is a

net importer of carbon embodied in goods. The carbon content of the goods it consumes is greater than of the goods it produces.

The bottom row is extraction. The OECD only extracts energy sufficient to produce 8.6 gigatons of $CO_2$, out of a global extraction of 32.3 gigatons of $CO_2$. It uses 12.2 gigatons of $CO_2$ in production so it imports the difference. It imports yet more for its consumption in the form of goods. Home's overall trade balance is then determined by its exports of services, which are not shown in the calibration (which is just the matrix of $CO_2$ flows).

**Table 2: Calibration matrix for the OECD (Gt $CO_2$)**

|  | **Production** | | |
|---|---|---|---|
| **Consumption** | Home | Foreign | Total consumption |
| Home | 11.3 | 2.5 | 13.8 |
| Foreign | 0.9 | 17.6 | 18.5 |
| **Total production** | 12.2 | 20.1 | 32.3 |
| **Extraction** | 8.6 | 23.7 | 32.3 |

In Part III.A, we consider alternative taxing coalitions. The central values from the calibration matrix used for this simulation are:

| Region | Extraction | Production | Consumption |
|---|---|---|---|
| US | 4.5 | 5.0 | 5.8 |
| US + EU | 5.4 | 8.5 | 9.8 |
| OECD | 8.6 | 12.2 | 13.8 |
| OECD + China | 16.2 | 21.5 | 21.8 |
| Global | 32.2 | 32.2 | 32.3 |