The Effects of Restricting Coal Consumption

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Abstract

Reducing coal consumption is a goal of many countries' energy and environmental policies. However, policies that restrict domestic coal consumption also incentivize the export of coal to non-abating foreign countries and encourage coal consuming industries to move their production to these countries. This paper uses a modified version of the GTAP-E model to quantify these effects for a US restriction on coal consumption. I find that the coal restriction's impact on foreign greenhouse emissions is negligible, but domestic fuel-switching offsets 15 to 28 percent of the drop in domestic coal emissions. But trade is more important for welfare analysis, as the economic costs of the restriction are concentrated in the US, while the rest of the world's welfare increases by 15 to 19 percent of the US losses.

JEL: Q54; F17; Q48; C68

Keywords: Coal, Carbon Leakage, International Trade, GTAP

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1 Introduction

In 2015, 33 percent of US electricity generation came from coal.[2] However, coal generation is substantially more carbon intensive than alternatives. Coal produces 2.1 to 2.2 pounds of carbon dioxide per kilowatt-hour of electricity generated, compared with 1.2 for natural gas, the other main source of US electricity.[3] These coal emissions are also large in absolute magnitude. In 2014, electricity generation from coal produced 76 percent of the power sector's greenhouse gas emissions, or 23 percent of all U.S. emissions.[4]

In order to combat coal emissions, some national and local governments have enacted policies to eliminate the use of coal for electricity generation. Ontario closed its last coal power plant in 2014 and has banned the construction of any new ones.[5] The United Kingdom has committed to phase out coal power plants by 2025 and Oregon has passed a law to do the same by 2035.[6] And politicians in other regions have also expressed support for phasing out coal.[7]

However, policies that restrict coal in a particular region create unintended incentives since they do not apply to other regions. For example, reduced energy demand by the United States depresses international energy prices, increasing consumption in other countries.[8] Moreover, such policies put energy-intensive sectors in the United States at a cost disadvantage compared to competitors abroad.[9] If these sectors are also sufficiently trade exposed, production and exports of domestic industry would decline while imports from non-regulated foreign countries would increase,[10] incentivizing the relocation of these industries abroad.[11] As a result, although the policy may decrease domestic emissions, it could decrease or even increase world emissions, depending on if foreign production is more or less emission intensive than the US industries were.[12] But in any case, these effects promote the export of coal to non-abating foreign countries and encourage coal consuming industries to move their production to these countries. This increases the domestic welfare cost of the policy and reduces its impact on global greenhouse gas emissions.

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[2] Energy Information Administration, "What Is U.S. Electricity Generation by Energy Source?"

[3] Energy Information Administration, "How Much Carbon Dioxide Is Produced per Kilowatthour When Generating Electricity with Fossil Fuels?"

[4] Total US greenhouse gas emissions in 2014 were 6,872.6 million metric tons (MT) of CO2 equivalent of which 2,059.4 million was from electricity generation in general and 1,570.4 million was from coal generation in particular. Environmental Protection Agency, *Draft U.S. Greenhouse Gas Inventory Report: 1990-2014*, ES–7, 3–6, 3–10.

[5] Ontario Ministry of the Environment and Climate Change, "Ontario Permanently Bans Coal-Fired Electricity Generation."

[6] BBC News, "UK's Coal Plants to Be Phased out within 10 Years"; The Guardian, "Oregon Becomes First State to Pass Law to Completely Eliminate Coal-Fired Power."

[7] Cuomo, *2016 State of the State*; Kerry, "Remarks at UN's Earth to Paris Event with Mashable's Andrew Freedman."

[8] Böhringer, Lange, and Rutherford, "Optimal Emission Pricing in the Presence of International Spillovers: Decomposing Leakage and Terms-of-Trade Motives."

[9] Fischer and Fox, "Climate Policy and Fiscal Constraints: Do Tax Interactions Outweigh Carbon Leakage?"

[10] Böhringer, Lange, and Rutherford, "Optimal Emission Pricing in the Presence of International Spillovers: Decomposing Leakage and Terms-of-Trade Motives."

[11] Böhringer, Carbone, and Rutherford, "Unilateral Climate Policy Design: Efficiency and Equity Implications of Alternative Instruments to Reduce Carbon Leakage."

[12] Fell and Maniloff, *Beneficial Leakage : The Effect of the Regional Greenhouse Gas Initiative on Aggregate Emissions*.

Researchers are well aware of these spillovers and there has been extensive research on their magnitude for comprehensive carbon policies, such as cap and trade or carbon taxes. This literature has typically found that these comprehensive policies increase foreign emissions by about 5–20 percent of the domestic emissions reduction.[13] And a review of the literature by Zhang and Baranzini concludes that the competitive losses and distributive impacts are generally not significant for cap and trade or carbon taxes.[14] [15]

However, compared to comprehensive policies, there is less research on these spillover effects for policies that focus on any particular fuel, such as coal. The most extensive work has been done on the impact of biofuel mandates and how these policies may increase, not decrease, global emissions, by changing foreign land-use.[16] Literature on the carbon leakage of other types of policies is more limited. For example, Goulder, Jacobsen, and Benthem examine how one US state's automobile fuel efficiency standard can cause emissions to spillover to other states, but did not look at international effects.[17] However, authors of such papers have noted how these policies are likely to have international spillover effects.[18] [19]

These spillover effects may be much larger for coal-specific policies than for comprehensive policies. In particular, by ignoring natural gas emissions, coal-focused policies incentivize domestic fuel switching to natural gas more than comprehensive carbon policies do. And while coal can be traded globally, gas is difficult to transport.

These trade effects can be substantial. Riker estimates that an exogenous reduction in domestic coal consumption could substantially impact coal exports to foreign countries.[20] The change in exports ranged from 47 percent to –64 percent of the domestic coal demand reduction. Richter, Mendelevitch, and Jotzo look at implications of an Australian coal export tax on both international trade and world emissions.[21] They find that such a policy could both reduce Australian welfare and increase world emissions. As a result, we should not be surprised if restrictions on domestic coal consumption induce very different amounts of carbon leakage or domestic welfare costs than comprehensive policies do.

The key questions are thus: how substantial are these effects? And what is the impact of coal restrictions, once these effects are taken into account? In order to answer these questions, I simulate the impact of US coal consumption restrictions using the GTAP-E model. I utilize this model because of its

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[13] Paltsev, "The Kyoto Protocol: Regional and Sectoral Contributions to the Carbon Leakage"; Barker et al., "Carbon Leakage from Unilateral Environmental Tax Reforms in Europe, 1995-2005"; Böhringer, Balistreri, and Rutherford, "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29)."

[14] Zhang and Baranzini, "What Do We Know about Carbon Taxes?"

[15] See also Arlinghaus, "Impacts of Carbon Prices on Indicators of Competitiveness: Review of Empirical Findings."

[16] Searchinger et al., "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change."

[17] Goulder, Jacobsen, and van Benthem, "Unintended Consequences from Nested State and Federal Regulations: The Case of the Pavley Greenhouse-Gas-per-Mile Limits."

[18] Yeh and Sperling, "Low Carbon Fuel Standards: Implementation Scenarios and Challenges"; Goulder and Stavins, "Challenges from State-Federal Interactions in US Climate Change Policy."

[19] Riker, "International Coal Trade and Restrictions on Coal Consumption."

[20] Ibid.

[21] Richter, Mendelevitch, and Jotzo, "Market Power Rents and Climate Change Mitigation : A Rationale for Coal Taxes ?"

detailed treatment of the two areas most relevant for this policy: electricity generation and international trade. These features allow the model to accurately capture these carbon leakage and welfare effects.

2 Methodology

To simulate the effects of reducing coal consumption, I utilize version 6-pre2 of the GTAP-E model and version 8.0 of the GTAP database. The GTAP model is a multi-region multi-sector comparative static computable general equilibrium model of the world economy. Its database describes the world economy in 2007. GTAP-E is a modification of the main GTAP model that adds additional detail to the energy sector of the economy. For example, it allows for inter-fuel substitution and adds changes in carbon emissions as an outcome variable.[22] GTAP-E was run using RunGTAP 3.61 and GEMPACK 11.4.003.

I calculate the impact of restricting coal consumption by comparing a baseline scenario to one where coal consumption is restricted. The baseline is the business-as-usual scenario of the world economy in 2007 as described in the GTAP database. In the coal restriction scenario, the US government implements a policy that requires the US electricity generation sector to decrease its ratio of the quantity of coal inputs used to quantity of electricity generated by 10 percent below the baseline level. As the power sector generated 95 percent of all emissions from coal combustion in the US in 2014, restricting this sector is very similar to an economy-wide restriction on coal combustion.[23] The effects of the coal restriction are expressed as the change of various economic outcomes under the restricted coal scenario relative to the baseline scenario.

I also examine alternative versions of the coal restriction with a 20, 30, 40, or 50 percent decrease in the coal input ratio (instead of 10 percent). To give a sense of the scale of these numbers, the Clean Power Plan in the US would reduce emissions by 870 million MT (metric tons), which is an emission reduction between the 40 and 50 percent simulations.[24] [25]

2.1 Constrained Optimization in GTAP-E

Modeling this policy experiment in GTAP-E presents a number of practical challenges that must be overcome. The main issue is the firm cost function in the standard GTAP-E model. When coal consumption is restricted, a binding constraint is added to the firm's cost minimization problem. As a result, the representative firm will no longer be using the input mix that unconditionally minimizes costs. However, this is not possible to implement in the standard GTAP-E model: the form of the GTAP-E equation that relates input prices to output costs implicitly assumes that the firm's cost minimization problem is an unconstrained optimization.

I resolve this issue by revising the GTAP-E firm cost equation to allow for constrained optimization. This necessitates changes in a number of related equations. I insert slack variables into the firm demand for each input, which will represent the additional shadow price of that input when quantity

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[22] GTAP-POWER is an alternative model to GTAP-E that I looked into using. However, it did not have the necessary details on emissions. See Peters, *The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base*.

[23] Environmental Protection Agency, *Draft U.S. Greenhouse Gas Inventory Report: 1990-2014*, 3–5.

[24] Environmental Protection Agency, "FACT SHEET: Clean Power Plan By The Numbers."

[25] I reference the Clean Power Plan only to give an idea of the scale of these restrictions. The Clean Power Plan is not purely a mandate to decrease the coal intensity of electricity generation, as the simulations in this paper are.

restraints for that input are binding. I also modify the firm cost function so that costs depend on these shadow prices as well as nominal prices. However, other than allowing constrained optimization, I do not change the properties of the GTAP-E cost function: the nesting structure of inputs remains the same and the modified nests remain constant elasticity of substitution with the same elasticity values.

In order to better understand my implementation of constrained optimization, I will walk through the original and revised equations related to one commodify, "ncoal".[26] Ncoal is the aggregate commodity containing crude oil, gas, and petroleum products. Analogous changes are made to the equations of other commodities.

In the original GTAP-E model, the cost of producing non-coal energy to industry j in region r is calculated using the following code:

```
Equation NCOALFPRICE # price of non-coal energy #
(all,j,PROD_COMM)(all,r,REG)
   pf("ncoal",j,r) = sum(k,NCOAL_FCOMM, FSHNCOAL(k,j,r) * [pf(k,j,r) - af(k,j,r)]);
```

where k indexes the inputs into producing non-coal energy, FSHNCOAL(k,j,r) share of input k in total costs of producing ncoal, pf is the firm's price of that input and af is input k augmenting technological change. However, note that this formulation does not allow for binding quantity constraints. To see this, compare the left and right hand sides of the equation. Imposing a binding quantity constraint on its inputs should increase the cost of producing ncoal, the left hand side variable, even if there was no change in technology or the price of inputs, and thus the right hand side was unchanged.

In order to allow for unconstrained optimization, I amended this equation to instead be:

```
pf("ncoal",j,r) = sum(k,NCOAL_FCOMM, FSHNCOAL(k,j,r) * [qf(k,j,r) + pf(k,j,r)]) -
         qf("ncoal",j,r);
```

where qf is the quantity of input k used by industry j.

Analogous changes need to be made to the equation defining the input quantity. The original demand for inputs to make non-coal energy is calculated by:

```
Equation NCOALFDEMAND
# demand for inputs into non-coal energy subproduction #
(all,i,NCOAL_FCOMM)(all,j,PROD_COMM)(all,r,REG)
   qf(i,j,r) = -af(i,j,r) + qf("ncoal",j,r) - ELFNCOAL(j,r) * [pf(i,j,r) - af(i,j,r) - pf("ncoal",j,r)];
```

where ELFNCOAL(j,r) is the elasticity of substitution between the inputs used to produce ncoal for industry j in region r. Note that in this formulation, quantity demanded depends only on nominal prices, not shadow prices.

I modify the input demand equation to be:

[26] This is not an exhaustive list of the changes to the model. A number of other equations need to be altered in order to calculate pf_so or to get RunGTAP to report additional variables in the simulation results.

```
qf(i,j,r) = -af(i,j,r) + qf("ncoal",j,r) - ELFNCOAL(j,r) * [pf_s(i,j,r) - af(i,j,r) - pf_so("ncoal",j,r)];
```

where pf_s(i,j,r) is the shadow price of input i and pf_so("ncoal",j,r) is the price of ncoal calculated using the shadow prices of inputs, instead of their nominal prices.

Now that the existing GTAP-E equations have been revised to allow for binding constraints, the last step is introducing the new equations. These equations involve the consumption intensity variable to be shocked and the shadow price of inputs. The shadow price of an input is defined as

```
Equation pf_sBINDING
# relates the shadow and real price of commodities i for use by j in r #
(all,i,FIRM_COMM)(all,j,PROD_COMM)(all,r,REG)
   pf_s(i,j,r) = pf(i,j,r) + pf_slack(i,j,r);
```

where pf_slack(i,j,r) is a slack variable that describes whether there is a binding constraint on the use of input i by industry j in region r. Finally, the input to output ratio (which is shocked by –10 to –50 percent in the scenarios) is defined as

```
Equation NCOALFINTENS
# demand for inputs into non-coal energy subproduction divided by output#
(all,i,NCOAL_FCOMM)(all,j,PROD_COMM)(all,r,REG)
   intf(i,j,r) = qf(i,j,r) - qf("ncoal",j,r);
```

In the initial state, pf_slack(i,j,r) is exogenous and intf(i,j,r) is endogenous. A binding constraint can be imposed on the firm cost function by swapping the slack variable pf_slack(i,j,r) with intf(i,j,r) and then shocking intf(i,j,r) in order to achieve the desired change in the ratio.

With these modifications, special care must be taken in the model's welfare calculation. GTAP-E calculates welfare using two different variables, EV(r) and EV_ALT(r). These variables are normally equivalent but are calculated using two different methods. In particular, EV_ALT(r) is calculated directly from the prices of goods, while EV(r) is calculated from consumption expenditures. Unfortunately, the modifications I made to input prices and quantities in order to allow binding constraints also break the EV_ALT(r) calculation. As a result, all welfare calculations discussed in this paper are calculated using EV(r) instead.

2.2 Calculating the Marginal Welfare Cost of Abatement

The marginal welfare cost of abatement is a standard summary statistic used for analyzing the cost of emission abatement.[27] However, it is not normally calculated by GTAP-E. Calculating the marginal US welfare cost of abatement requires calculating two things: the marginal change in welfare and the marginal change in world emissions, and then dividing the former by the latter. This is accomplished by running additional simulations where the coal input ratio is reduced by 1 additional percent, for a total reduction of 11, 21, 31, 41, or 51 percent. So, for example, the marginal US welfare cost of abatement in

[27] For a discussion of why welfare costs should not be measured indirectly through carbon prices, see Morris, Paltsev, and Reilly, "Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model."

the 20 percent simulation is 35 dollars per metric ton. This is equal to the change in US welfare between the 20 and 21 percent simulation divided by the change in world emissions between the 20 and 21 percent simulation.

3 Results

The coal restriction decreases US consumption of coal for electricity generation, but increases US consumption of alternative fossil fuel inputs such as oil and gas (see Table 1). However, there is a net reduction in emissions. Emissions from coal in the US decrease by 204 to 1,294 million MT of CO2 equivalent per year while US emissions from oil and gas increase by 31 to 368 million MT. This interfuel substitution increases in importance for more stringent coal reductions, as it offsets 15 percent of the reduction in coal emissions when coal intensity falls by 10 percent, but offsets 28 percent of the coal reduction when coal intensity falls by 50 percent.

Table 1: Change in Carbon Emissions

	Coal Reduction (percent)				
Variable	**10**	**20**	**30**	**40**	**50**
Change in Emissions (million MT per year)					
US Coal	-204	-427	-676	-958	-1,294
US Oil and Gas	31	72	127	212	368
Rest of the World	-1	-2	-2	-3	-4
Total World	-173	-357	-551	-750	-930
Ratios of Changes in Emissions (percent)					
US Oil and Gas / US Coal	-15	-17	-19	-22	-28
Rest of the World / US Coal	0.4	0.4	0.4	0.4	0.5
Total World / US Coal	85	84	81	78	72
Change in Total US Emissions (percent)	-3	-7	-11	-15	-20

The coal restriction also reduces worldwide emissions. The direct effect of the policy, the reduction in US coal emissions, is partially offset by domestic fuel switching, as US firms and consumers use more oil and gas. However, surprisingly, emissions in the rest of the world go down. This is because although foreign coal emissions increase, increased US demand for oil and gas reduce foreign emissions from those sources (foreign fuel switching). However, the magnitude of this reverse leakage is extremely small, less than 0.5 percent of the change in US coal emissions.

The welfare costs of the coal restriction are concentrated in the United States, but not to the same extent as the emissions changes. The equivalent variation of the coal restriction is the reduction in baseline household income under the original prices that would give them the same utility as under the coal restriction. It increases with the stringency of the coal restriction, ranging from 1.3 to 89.9 billion dollars per year (see Table 2). Expressed in terms of the change in world emissions, the US welfare cost ranges from \$15 to \$678 per MT CO2 equivalent, also increasing with the magnitude of the coal restriction.

Table 2: Change in Welfare

	Coal Reduction (percent)				
Variable	**10**	**20**	**30**	**40**	**50**
Change in Welfare (billion USD per year)					
United States	-1.3	-5.6	-15.3	-36.6	-89.9
Rest of the World	0.2	0.9	2.4	5.7	13.8
Total World	-1.1	-4.7	-12.9	-30.9	-76.1
Ratio of Changes in Welfare (percent)					
Rest of World / United States	-19	-17	-16	-16	-15
Marginal US Welfare Cost (USD per MT CO2)	15	35	73	166	678

The US restriction causes changes in trade that benefit foreign households. Aggregate foreign welfare increases and the largest foreign beneficiaries are Eastern European countries, energy exporting countries, and some small developed countries. Foreign welfare increases range from 15 to 19 percent of the US domestic reduction. As the coal reduction becomes more stringent, the dollar value of the foreign welfare gain increases, but its share of the total welfare change falls. This means that as the restriction increases in strength, the welfare cost to the US increases faster than the gains to foreign countries do.

4 Conclusions

A restriction on coal consumption in the US has a negligible effect on foreign emissions but a substantial effect on foreign welfare. The coal restriction causes changes in trade that benefit foreign countries, so that foreign welfare increases by 15 to 19 percent of the US welfare loss. Although foreign carbon leakage is minimal, domestic fuel switching is not: it reduces the total domestic emission reduction by 15 to 28 percent.

This research has several areas for improvement that provide a natural opportunity for future work. First would be increasing the level of detail in the results section in order to trace the mechanism for the emissions and welfare changes farther back into the model. Additionally, the database used for this simulation is from 2007. Since then, the energy sector has changed substantially due to increased energy demand by developing countries, the adoption of hydraulic fracturing, and falling renewable costs. As a result, updating the database could have a substantial impact. Improvements could also be made to the GTAP-E model itself, as Beckman, Hertel, and Tyner have critiqued the default GTAP-E parameters.[28]

[28] Beckman, Hertel, and Tyner, "Validating Energy-Oriented CGE Models."

5 References

Arlinghaus, Johanna. “Impacts of Carbon Prices on Indicators of Competitiveness: Review of Empirical Findings.” *OECD Environmental Working Papers*, no. 87 (2015).

Barker, Terry, Sudhir Junankar, Hector Pollitt, and Philip Summerton. “Carbon Leakage from Unilateral Environmental Tax Reforms in Europe, 1995-2005.” *Energy Policy* 35 (2007): 6281–92. doi:10.1016/j.enpol.2007.06.021.

BBC News. “UK’s Coal Plants to Be Phased out within 10 Years,” 2015. http://www.bbc.com/news/business-34851718.

Beckman, Jayson, Thomas Hertel, and Wallace Tyner. “Validating Energy-Oriented CGE Models.” *Energy Economics* 33, no. 5 (September 2011): 799–806. doi:10.1016/j.eneco.2011.01.005.

Böhringer, Christoph, Edward J. Balistreri, and Thomas F. Rutherford. “The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29).” *Energy Economics* 34 (December 2012): S97–110. doi:10.1016/j.eneco.2012.10.003.

Böhringer, Christoph, Jared C. Carbone, and Thomas F. Rutherford. “Unilateral Climate Policy Design: Efficiency and Equity Implications of Alternative Instruments to Reduce Carbon Leakage.” *Energy Economics* 34 (December 2012): S208–17. doi:10.1016/j.eneco.2012.09.011.

Böhringer, Christoph, Andreas Lange, and Thomas F. Rutherford. “Optimal Emission Pricing in the Presence of International Spillovers: Decomposing Leakage and Terms-of-Trade Motives.” *Journal of Public Economics* 110 (February 2014): 101–11. doi:10.1016/j.jpubeco.2013.11.011.

Cuomo, Andrew M. *2016 State of the State*, 2016. https://www.governor.ny.gov/2016SOSbook.

Energy Information Administration. “How Much Carbon Dioxide Is Produced per Kilowatthour When Generating Electricity with Fossil Fuels?,” 2016. https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.

———. “What Is U.S. Electricity Generation by Energy Source?,” 2016. https://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3.

Environmental Protection Agency. *Draft U.S. Greenhouse Gas Inventory Report: 1990-2014*, 2016. https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.

———. “FACT SHEET: Clean Power Plan By The Numbers.” Accessed April 7, 2016. https://www.epa.gov/cleanpowerplan/fact-sheet-clean-power-plan-numbers.

Fell, Harrison, and Peter Maniloff. *Beneficial Leakage : The Effect of the Regional Greenhouse Gas Initiative on Aggregate Emissions*. Division of Economics and Business Working Paper Series, 2015. http://econbus.mines.edu/working-papers/wp201506.pdf.

Fischer, Carolyn, and Alan K. Fox. “Climate Policy and Fiscal Constraints: Do Tax Interactions Outweigh Carbon Leakage?” *Energy Economics* 34 (2012): S218–27. doi:10.1016/j.eneco.2012.09.004.

Goulder, Lawrence H., Mark R. Jacobsen, and Arthur A. van Benthem. “Unintended Consequences from Nested State and Federal Regulations: The Case of the Pavley Greenhouse-Gas-per-Mile Limits.” *Journal of Environmental Economics and Management* 63, no. 2 (March 2012): 187–207. doi:10.1016/j.jeem.2011.07.003.

Goulder, Lawrence H., and Robert N. Stavins. "Challenges from State-Federal Interactions in US Climate Change Policy." *The American Economic Review* 101, no. 3 (2011): pp. 253–57. http://www.jstor.org/stable/29783749.

Kerry, John. "Remarks at UN's Earth to Paris Event with Mashable's Andrew Freedman," 2016. http://www.state.gov/secretary/remarks/2015/12/250423.htm.

Morris, Jennifer, Sergey Paltsev, and John Reilly. "Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model." *Environmental Modeling & Assessment* 17, no. 4 (2012): 325–36. doi:10.1007/s10666-011-9298-7.

Ontario Ministry of the Environment and Climate Change. "Ontario Permanently Bans Coal-Fired Electricity Generation," 2015. https://news.ontario.ca/ene/en/2015/11/ontario-permanently-bans-coal-fired-electricity-generation.html.

Paltsev, Sergey V. "The Kyoto Protocol: Regional and Sectoral Contributions to the Carbon Leakage." *The Energy Journal*, 2001. http://www.jstor.org/stable/41322930.

Peters, Jeffrey C. *The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base*. GTAP Resource #4619, 2015.

Richter, Philipp M., Roman Mendelevitch, and Frank Jotzo. "Market Power Rents and Climate Change Mitigation : A Rationale for Coal Taxes ?," 2015. https://ccep.crawford.anu.edu.au/sites/default/files/publication/ccep_crawford_anu_edu_au/2015-08/ccep1507.pdf.

Riker, David A. "International Coal Trade and Restrictions on Coal Consumption." *Energy Economics* 34, no. 4 (2012): 1244–49. doi:http://dx.doi.org/10.1016/j.eneco.2011.11.007.

Searchinger, Timothy, Ralph Heimlich, R a Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change." *Science* 319, no. February (2008): 1238–40. doi:10.1126/science.1151861.

The Guardian. "Oregon Becomes First State to Pass Law to Completely Eliminate Coal-Fired Power," 2016. http://www.theguardian.com/environment/2016/mar/03/oregon-coal-climate-law-kate-brown.

Yeh, Sonia, and Daniel Sperling. "Low Carbon Fuel Standards: Implementation Scenarios and Challenges." *Energy Policy* 38, no. 11 (2010): 6955–65. doi:10.1016/j.enpol.2010.07.012.

Zhang, ZhongXiang, and Andrea Baranzini. "What Do We Know about Carbon Taxes? An Inquiry into Their Impacts on Competitiveness and Distribution of Income." *Energy Policy* 32, no. 4 (March 2004): 507–18. doi:10.1016/S0301-4215(03)00152-6.