The Effect of Carbon Taxation on Cross Border Competition and Energy Efficiency Investments

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Abstract

Carbon taxes increase costs for energy-consuming firms and can impact firms' ability to compete with other firms located in regions without that tax. This paper considers the effect of asymmetric carbon taxation when firms are able to adjust their energy efficiency investment levels. Using a dynamic model of firm competition, we find that endogeneity in energy efficiency levels could allow firms facing a carbon tax to significantly mitigate competition effects. In our baseline parameterization, additional energy efficiency investments non-trivially mitigates profit loss for the firm facing the carbon tax as well as spurring adding energy efficiency investments in the non-taxing jurisdiction, thus reducing carbon leakage. Strikingly, this increase in energy efficiency can reduce total energy usage by the firm in the taxing jurisdiction by more than the carbon tax alone. While the quantitative impact of energy efficiency investments on firm competitiveness depends on the nature of the industry, from a policy standpoint, the ability of energy efficiency investments to mitigate cross-border emissions leakage and negative competition effects without policy interventions such as a carbon border tax softens these two common criticisms of unilateral carbon taxes.

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1 Introduction

Carbon emissions, largely stemming from energy use, are a point of concern for policymakers and environmentalists. As such, a carbon tax, or other carbon pricing scheme, is frequently cited as plausible policy tool. However, the unilateral implementation of a carbon tax can be problematic. First, policy asymmetry when some areas impose a carbon tax and others do not, generates competition issues for local firms. If local firms compete with firms operating in carbon-tax free jurisdictions, the carbon tax would place them at a competitive disadvantage by raising their energy costs but not the costs of their competitors. Beyond just competition effects on firms, the effectiveness of a carbon tax at reducing carbon emissions can also be affected by cross-border considerations when one jurisdiction implements a carbon tax and the other does not. Carbon emissions could increase in the other jurisdiction as production shifts to the location without the carbon tax, causing "leakage" of carbon savings in the taxing jurisdiction.

These competition effects of a carbon tax have resulted in proposed policies to address this concern, such as carbon border taxes (CBTs) which apply to products imported from carbon-tax-free regions or adjusting the amount of the carbon tax based on the sector (for example, Hoel (1996): "Should A Carbon Tax be Differentiated Across Sectors?"). Furthermore, the unsuccessful 2016 Washington State initiative to implement a carbon tax included a cut to business taxes for manufacturing firms to address this concern.

Firms within the same industry can differ in their level of energy efficiency (Boyd (2017), Lyubich et al. (2018)) and these varying levels will impact how much a carbon tax would cost those firms. The profit maximizing level of energy efficiency for a firm changes with market conditions and firms could increase their investments in energy efficiency in response to a carbon tax or other carbon pricing scheme. A wide variety of investment possibilities range from simple items such as low wattage LEDs, to more complex items such as systems that capture and recycle waste heat. Futhermore, Anderson and Newell (2004) find that the probability of firms implementing recommended energy efficiency upgrades is higher as the payback period for the upgrade is shortened and as energy costs rise, which would occur under a carbon tax. If this is the case, then the competition effects of a carbon tax could be mitigated as improved energy efficiency lowers the marginal cost of production. This positive effect could be especially beneficial in situations where carbon border taxes are not possible, such as between states in the United States.

This paper analyzes the cross-border effects of a carbon tax using a stylized dynamic model of firm competition. The industry consists of two competing firms that are located in neighboring states playing an infinitely-repeated, price-setting game with differentiated products and endogenous energy efficiency levels. When one of the states decides to impose a carbon tax, the firm in that location faces higher energy costs. A carbon tax that increases the price of energy would therefore incentivize firms to become more energy efficient to offset some of the negative competition effects of the tax. This model allows us to analyze competition effect and carbon leakage issues by mapping out the long-run effects of a unilateral (one-state) carbon tax on profits, price, and energy usage. By comparing the results when energy efficiency investments are allowed to change in response to the carbon tax, we can tease out this impact of altered efficiency investments and analyze its effects.

While there are a large number of papers that address the competition effects of a carbon tax, to our knowledge, this is the first paper that studies the role of energy efficiency investment in a dynamic cross-border setting where not all competing firms face the carbon tax. Baker and Shitto (2006) model energy efficiency investment in a static, non-competitive setting, focusing on the role of uncertainty, i.e. R&D does not guarantee success. In the presence of a future carbon tax, firms can choose between investing in safer but more carbon intensive conventional energy, or riskier but cleaner alternative energies. They find that input substitutability as well as the magnitude of the future tax determines the mix of investments. Green (2008) considers a similar risk tradeoff but in the context of gas-fuel generators versus nuclear generators. There are also a number of models that analyze the strategic, cross-border impact of asymmetric carbon policies. Antimiani et al. (2013), for example, models a two region scenario. However, they and other papers (e.g. Dissou and Eyland (2011); Elliott et al. (2010); Qiao-Mei Liang (2016)) tend to focus more on reducing leakage using carbon border taxes. While these carbon border taxes may be appropriate at the international country-country level, they are not applicable at the state-state level because of federal restrictions. Our paper therefore contributes to the literature by focusing on the role of energy efficiency on cross-border competition considerations.

Overall, our model indicates that the negative cross-border effects of carbon taxation can potentially be significantly reduced when firms can adjust their energy efficiency. Under our baseline parameterization, the firm in the carbon tax state is able to reduce its decrease in profits by 22.2% and while its counterpart in the tax-free state still generates higher profit as a result of the carbon tax, changes in energy efficiency investments reduces this increase by 57.3%. Additionally, energy efficiency mitigates the price increase resulting from the carbon tax by 58.9% and 62.87% in the tax and no-tax states, respectively, benefiting consumers. From an environmental perspective, energy efficiency changes can have a large impact on the reduction in carbon emissions as a result of the tax. Under our baseline parameters, the increase in energy efficiency reduces energy usage by several times more than the reduction in energy use in a counterfactual situation where the carbon tax is imposed but firms do not change their energy efficiency levels. Energy efficiency is also slightly improved by the firm in the non-taxing venue, mitigating carbon leakage. The specific numerical results do depend on the value of the parameters used and the ability of energy efficiency changes to mitigate cross-border effects of a carbon tax would vary by industry, as we further discuss below.

The remainder of the paper proceeds as follows. Section 2 presents the model and the structure of the analysis. Section 3 discusses the simulation results. Finally, Section 4 concludes.

2 Model and Analysis

2.1 Description of Model

We model the industry as having two competing firms. Firm A is in a location that will impose a carbon tax on firms located in its territory while Firm B is in a location that does not impose a carbon tax.[1] In addition to Firm A being subjected to a carbon tax, the firms also can differ by their level of energy efficiency. Each period, both firms make two choices: the price at which they sell their product and how much they spend on investing in energy efficiency. Firms compete for an infinite number of discrete periods and both firms share the same discount rate, δ.

The price firms choose to sell their product at each turn affects the quantity sold, which is the result of differentiated-good Bertrand competition. For firm i, the quantity sold in period t is

$$Q_{it} = a - b_1 p_{it} + b_2 p_{-it}$$

where p_{it} is the price firm i charges and p_{-it} is the price charged by the other firm in that period. The inputs to production are energy efficiency and energy:

$$Q_{it} = F_{it} E_{it}$$

where F_{it} is the energy efficiency of firm i in period t and E_{it} is for amount of energy consumed by firm i in period t. The cost of producing each unit is then $\frac{p^{Energy}}{F_{it}}$, where p^{Energy} is the constant price per unit of energy.[2] Increased energy efficiency lowers the marginal cost of production, with decreasing returns to additional energy efficiency. The profit that firm i

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[1] The location that Firm A is in is assumed to not impose any policies to mitigate the competition effects of the carbon tax, such as carbon border taxes.

[2] We assume that the imposition of the carbon tax does not affect energy prices as the region imposing the carbon tax is sufficiently small.

receives in period t from producing and selling their good is then

$$\pi_{it} = p_{it}Q_{it} - \left(\frac{p^{Energy}}{F_{it}}\right)(1+\tau_{it})\,Q_{it}$$

where τ_{it} is the percentage increase in energy costs firm will incur due to the carbon tax. We assume that the revenue from the tax is not used an any manner that would affect this industry apart from changed incentives due to its collection.

Each firm also chooses how much to invest in energy efficiency during each period. These energy efficiency investments determine firms' energy efficiency in the following period; in period *t+1*, the energy efficiency of firm i will be a function of their current energy efficiency F_{it} , the amount of energy efficiency purchased I_{it} and

$$F_{i,t+1} = (1-\kappa)F_{it} + I_{it}$$

κ, the depreciation of prior energy efficiency investments.

The total profit earned by firm i in period t is then equal to π_{it} less their expenditure on energy efficiency investments, $(\theta_1 I_{it})^{\theta_2}$. Thus, the problem facing the firms is a dynamic programming problem, where the amount of energy efficiency of each firm at the start of the period determines the current state and the amount each firm invests in energy efficiency is the action variable. The value of being any any state $V(F_i, F_{-i})$ is

$$V(F_i, F_{-i}) = max_I\left[\pi(F_i, F_{-i}) - (\theta_1 I)^{\theta_2} + \delta V(F_i', F_{-i}'|I)\right]$$

Note that this value function, $V(F_i, F_{-i})$, will be different for firm A and firm B since firm A faces the carbon tax and firm B does not. This setup is related to Ericson and Pakes (1995) with energy efficiency being the state variable that affects profitability.

2.2 Use of Model For Analysis

We use this model to analyze how the ability of firms to change their investments in energy efficiency can affect the impact of carbon taxation on an industry. Initially, we find the long-run equilibrium of the market without any carbon tax by finding the profit maximizing policy functions (and the associated value functions) for the firms and simulating the market for 250 periods. Because the firms at this point are symmetric, outcomes such as energy efficiency level, energy use, prices charged, and profits will symmetric as well.

A carbon tax is then assumed to be unexpectedly imposed on Firm A, so that Firm A's price of energy increases by 20% ($\tau = 0.2$). The profit maximizing policy functions and their associated value functions are recalculated.[3]. The evolution of the industry after the tax is in place is then simulated for 50 more periods in two ways starting at the long-run "no-tax" outcome obtained before. In one case, firms use the original "no-tax" policy function when determining energy efficiency investments in each periods, which leaves their energy efficiency level unchanged. In the other case, firms use the updated policy functions where their energy efficiency investment decisions take the presence of the carbon tax into account. The differences in outcomes between these two situations will indicate the role of adjusting energy efficiency levels as a response to a carbon tax.

3 Results

3.1 Baseline Results

Figure 1 shows the average energy efficiency level, price charged, quantity sold, energy use by firms, and profits for 50 periods for Firms A and B after an unexpected permanent carbon tax raises the energy cost for Firm A by 20%. The initial levels for all variables are the long-run outcomes with no carbon tax and are identical for the two firms as the initial environment is

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[3] The presence of the tax also affects the profit maximizing prices charged for the product by the two firms.

symmetric. After the tax is imposed, as indicated by the vertical dotted lines, the evolution of the variables are shown for both firms, both allowing and not allowing for the energy efficiency investment decisions to be updated to reflect the existence of the carbon tax. The final panel in the figure shows the difference between the tax revenue raised by the carbon tax and the loss in profits for Firm A.

The industry is simulated using the baseline parameters from Table 1. The non-linear cost of energy efficiency investments are parameterized so that a 1% increase in energy efficiency investment will increase the marginal cost of additional energy efficiency investments by 1%. The energy efficiency retention rate, $(1-\kappa)$, is 0.9, based on an approximate 10% annual depreciation rate for capital goods for the U.S. and Canada from Albonico et al. (2014). The discount factor δ is assumed to be 0.95.

Table 1: **Baseline Parameterization**

Description	Parameter	Baseline Parameterization
Cost of Energy Efficiency Investment	θ_1	5.0
Energy Efficiency Investment Cost Exponent	θ_2	2.0
Energy Efficiency Retention Rate	$1-\kappa$	0.90
Size of Market	a	40.0
Own-Price Demand Sensitivity	b_1	2.0
Cross-Price Demand Sensitivity	b_2	1.0
Energy Cost	p^{Energy}	15.0
Discount Factor	δ	0.95

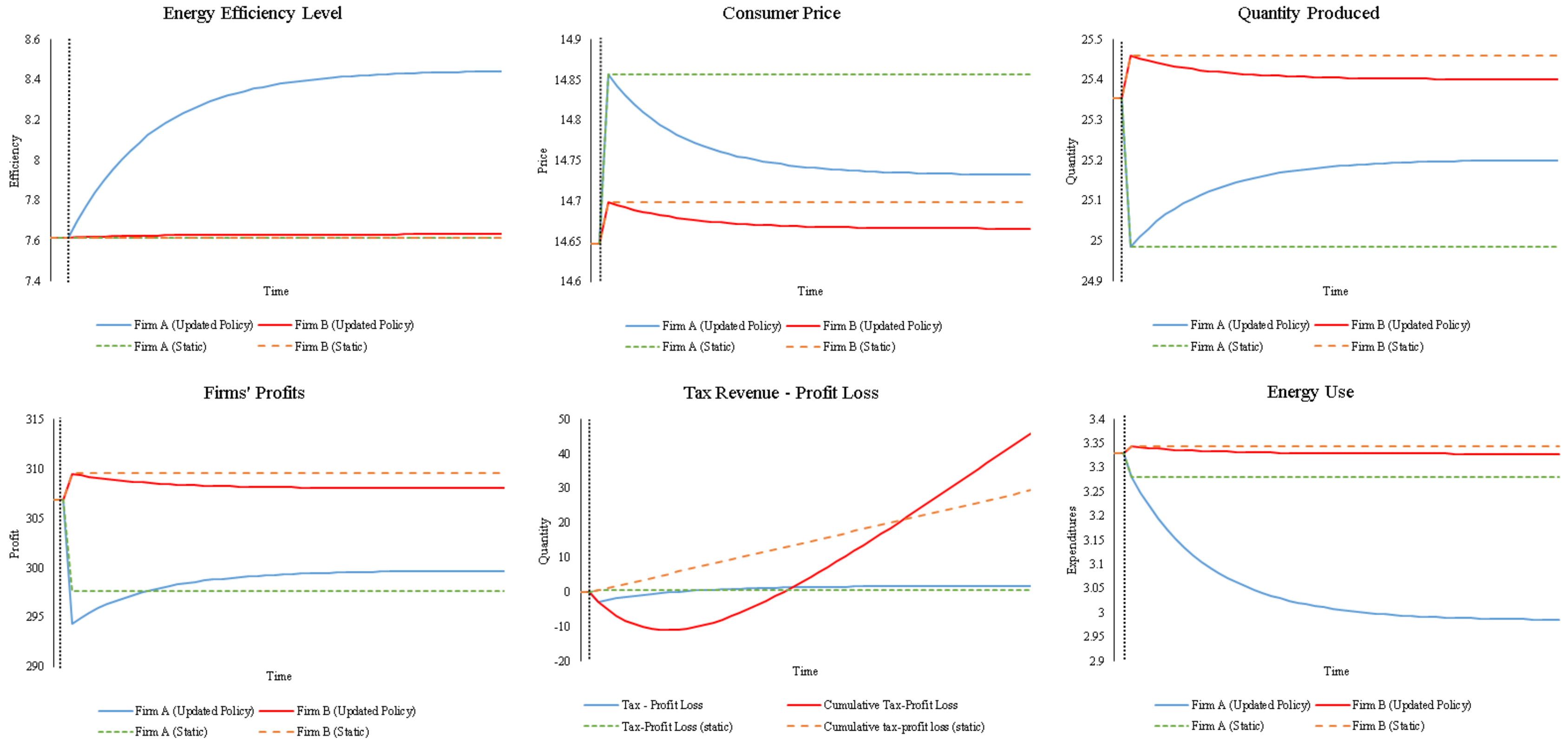
The demand and relative cost of energy parameters from Table 1 are not chosen to be representative of any specific industry, though at the original no-tax long-run equilibrium, for both firms the own-price elasticity of demand is -1.16 and the cross-price elasticity of demand is 0.58. How these results could change for industries with more price-sensitive customers or where energy has a relatively lower cost as compared to demand are discussed in 3.2.

As seen in the top left of Figure 1, initially both firms are at the same energy efficiency level. By assumption, when firms do not update their energy efficiency decisions based on the existence of the carbon tax, they remain at the same energy efficiency level forever. When they do update their energy efficiency investment decisions after the carbon tax is imposed, Firm A, which was the only firm subject to that tax, increases their energy efficiency level, with the most rapid growth in the first few periods . Firm B also increases its energy efficiency level as Firm A increases its energy efficiency (and obtains a lower marginal cost of production than would otherwise be the case), though to a much smaller degree.

As seen in the upper center of Figure 1, when the carbon tax is imposed, both firms raise the price they charge for their products, though Firm A raises their price substantially more. If the model incorporates changing energy efficiency investments in response to the carbon tax, then as Firm A's energy efficiency increases and its per-unit energy costs fall, the price it charges falls, though it always remains above the initial no-tax level. Firm B's price falls as well with its price also remaining above the initial no-tax level. As seen in Table 2, the increase in Firm A's price due to the tax is mitigated by 58.90% and the increase in Firm B's price is mitigated by 62.87% by the energy efficiency improvements. Thus, profit maximizing energy efficiency improvements could potentially mitigate a non-trivial amount of a price increase that consumers face due to the imposition of a carbon tax.

The upper right of Figure 1 shows quantity produced by Firm A falling after the imposition of the carbon tax and the quantity produced by Firm B increasing, as a result of the larger increase in price for Firm A. When energy efficiency investments are allowed to change, then as Firm A increases its energy efficiency and lowers its prices by more than Firm B, the quantity produced and sold by Firm A substantially recovers and Firm B's quantity falls back towards the original level, although in the long-run, Firm A and B's sales remain below and above their original no-tax level, respectively.

Figure 1: **Evolution of Key Outputs By Firm (Baseline Parameterization)**



Figures indicate the value in each period for the variable described for firms A and B when an unexpected permanent carbon tax raises the energy cost for Firm A by 20% in the third period, indicated by the horizontal dotted line. The industry is simulated both allowing and not allowing for the energy efficiency investment decisions (via the policy function) to incorporate the existence of the carbon tax. Industry simulations use the baseline parameter values found in Table 1. The 'Tax Revenue - Profit Loss' figure indicates the per-period and cumulative difference between tax revenue raised by the carbon tax for Firm A's government and the loss of profit for Firm A, with and without the firms updating their energy efficiency investment policy in response to the tax.

Table 2: **Baseline Impact of Energy Efficiency on Effect of Carbon Tax**

	Baseline Parameterization	
	Firm A	Firm B
Initial energy cost per unit	1.969	1.969
Long-run energy cost per unit after tax (updated EE investments)	1.777	1.965
Initial profits	306.903	306.903
Long-run profits after tax (original EE investments)	297.650	309.572
Long-run profits after tax (updated EE investment)	299.699	308.042
Mitigation of impact of carbon tax on long-run profits from updating energy efficiency investments	22.15%	57.31%
Initial price charged	14.646	14.646
Long-run price charged after tax (original EE investments)	14.856	14.699
Long-run price charged after tax (updated EE investment)	14.733	14.666
Mitigation of impact of carbon tax on long-run price from updating energy efficiency investments	58.90%	62.87%
Initial energy use	3.329	3.329
Long-run energy use after tax (original EE investments)	3.281	3.343
Long-run energy use after tax (updated EE investment)	2.985	3.328
Size of decrease of long-run energy use from updating EE investments as compared to change in energy use when EE investments do not update	611.59%	-106.11%

Displayed results include the initial long-run value of per-unit energy cost, firm profits, price charged and energy use before a carbon tax is imposed, the value after 50 periods when a carbon tax is imposed on only Firm A that increases their energy costs by 20% but firms do not adjust their energy efficiency investment decisions in response to the tax, and the value after 50 periods when a carbon tax is imposed on only Firm A that increases their energy costs by 20% but firms do adjust their energy efficiency investment decisions in response to the tax.

Combining these results, profits are initially lower for Firm A and higher for Firm B as a result of the carbon tax on Firm A, as seen in the lower left of Figure 1. When firms adjust their energy efficiency investments, Firm A's profits are even worse for the first several periods after the carbon tax is in place than if they had not adjusted their energy efficiency investments, as they spend additional funds on improving their energy efficiency. After several periods as Firm A's energy efficiency improves, its profit becomes higher than it would have been without the energy efficiency adjustments, though still lower than they were without the carbon tax, mitigating the per-period fall in profits in the long-run by 22.15%.[4] Thus, ignoring the ability of firms to adjust energy efficiency levels as a result of a carbon tax could lead to an overstatement of profits for the taxed firm initially, while understating their profits in the long-run. Even after firms update their energy efficiency, Firm B continues to make more per-period profit when Firm A faces the carbon tax than in the original no-tax equilibrium, though the gain in Firm B's profits is decreased by 57.31% through the increases in energy efficiency.

Without any changes to energy efficiency, under the baseline specification, the per-period tax revenue obtained through the carbon tax slightly exceeds the profits lost by the firm subject to the tax. The lower middle of Figure 1 shows that if energy efficiency investments are allowed to change in response to the tax, initially the profit losses exceed the tax revenue (as Firm A spends additional money on energy efficiency investments). In the long-run, however both the per-period and cumulative values for the difference between carbon tax revenue and Firm A's profit loss are larger when energy efficiency levels can change, indicating that the new tax revenue ultimately exceeds the loss in profits for the firm in the taxing location.[5]

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[4] Note that potentially moving locations is not incorporated into the model; for example, Firm A is not modeled to have the ability to incur a moving cost in order to move to the region without the carbon tax. Not explicitly modeling this possibility will not affect the results as long as the moving costs are larger than the present discounted value of the higher profits from that potential move (which would restore the pre-carbon tax competitive outcome).

[5] Note that changes in consumer surplus for residents of the taxing country cannot be calculated under the demand specification. However, prices of both goods increased and overall quantity consumed of both goods has fallen, so consumer surplus would be expected to fall. Additionally the social discount rate is likely

Under the baseline parameterization, when the carbon tax is imposed, the resulting change in energy efficiency has a strong impact on the reduction in energy use. Allowing energy efficiency investment to adjust due to the carbon tax decreases the energy use of Firm A by over six times the initial amount of reduction without energy efficiency changes.[6] Changing energy efficiency as a result of the carbon tax also affects energy use in the non-taxed region. Without energy efficiency adjustments, energy use in the non-taxing region increases 0.4% due to increased production by the firm in that area (while energy use in the taxing region fell 1.4% from the same initial level), illustrating carbon leakage. Incorporating energy efficiency investments that adjust to the presence of the carbon tax under the baseline parameterization reduces the energy use in the non-taxing region and mitigates carbon leakage; in this specific parameterization the energy use from Firm B falls in the long-run slightly below the initial "no-tax" level. Increased energy efficiency (and the resulting lowered prices) in the taxing region, as well as increased energy efficiency for the firm in the non-taxing region both contribute to this effect.

3.2 Alternative Parameterizations

As noted earlier, the baseline parameterization of the model is not intended to represent any specific industry. The results of the analysis in section 3.1 does demonstrate how one particular industry specification would react to a carbon tax and how taking profit maximizing energy efficiency investments into account can affect the long-run outcome. Table 3 shows how outcomes can differ from this baseline scenario as energy efficiency becomes more expensive, as energy costs are reduced or as demand parameters change.

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not zero so timing, as well as the value placed on energy use reduction, will also affect the social desirability of the tax.

[6] Note that when Firm A increases its energy efficiency and then lowers its price, they also increase the quantity produced and sold. The 611.59% increase in energy use savings incorporates these additional sales.

Table 3: **Energy Efficiency Mitigation of Carbon Tax Effects Across Parameterizations**

	Baseline		EE Investment More Expensive		Reduced Energy Cost		Less Own-Price Demand Sensitivity		Less Cross-Price Demand Sensitivity	
			$\theta_1 = 6.0$		$p^{Energy} = 10.0$		$b_1 = 1.95$		$b_2 = 0.95$	
	Firm A	Firm B	Firm A	Firm B	Firm A	Firm B	Firm A	Firm B	Firm A	Firm B
Mitigation of impact of carbon tax on long-run profits from updating energy efficiency investments	22.15% (-)	57.31% (-)	22.43% (↑)	56.45% (↓)	23.99% (↑)	58.57% (↑)	21.95% (↓)	57.39% (↑)	22.56% (↑)	57.34% (↑)
Mitigation of impact of carbon tax on long-run price from updating energy efficiency investments	58.90% (-)	62.87% (-)	58.31% (↓)	62.84% (↓)	59.83% (↓)	62.79% (↓)	58.92% (↑)	62.73% (↓)	58.99% (↑)	63.05% (↑)
Size of decrease of long-run energy use from updating EE investments as compared to change in energy use when EE investments do not update	611.59% (-)	-106.11% (-)	519.98% (↓)	-104.74% (↓)	837.40% (↑)	-107.10% (↑)	642.93% (↑)	-106.34% (↑)	589.90% (↓)	-105.94% (↓)

Baseline parameters are from Table 1. Other columns change one parameter from baseline to the value shown. Arrows indicate how magnitude compares to baseline.

When the cost of energy efficiency investment becomes more expensive or the price of energy is reduced, allowing firms to change their energy efficiency mitigates the profit loss of Firm A to a greater degree. For these situations, before the tax was imposed there was less incentive to invest in a high level of energy efficiency than in the baseline specification. When changing demand parameters, less price-sensitive consumers (lowering b_1) are associated with less mitigation of profit loss for Firm A from increasing energy efficiency levels in response to a carbon tax, while the opposite is true for an industry with more differentiated products (lowering b_2)

Additionally, specifications where allowing energy efficiency improvements results in a larger mitigation of lost profits for Firm A are usually also associated with less mitigation of price increases (for both firms) as well as a lower share of the overall energy use savings from Firm A resulting from energy efficiency improvements. Reduction in energy use from Firm B as a result of energy efficiency improvements also tends to be lower in these situations as well.

4 Conclusion

In this paper, we have examined how profit-maximizing adjustments in energy efficiency can mitigate cross-border concerns when one region implements a carbon tax. We analyzed this potential impact by comparing the results of a dynamic model of firm competition when energy efficiency investments are allowed to change in response to imposition of a carbon tax to the results of a model when they are not. In our baseline parameterization, while adjusting energy efficiency investments lowers profit for the firm facing the carbon tax in the short run, in the long-run, per-period profit loss for the firm facing the carbon tax due to that tax is non-trivially reduced by 22.15%. Furthermore, total energy usage from the firm that faces the carbon tax is reduced by over six times the initial energy use reduction when energy efficiency investments were not allowed to change and with reduced emissions leakage to the non-tax jurisdiction as well as the price increase of the taxed firm due to the tax is significantly mitigated and the non-taxed firm implements (limited) energy efficency improvements.

While the values for the baseline parameterization were not connected to an actual industry, comparing the baseline results to alternative specifications suggests that energy efficiency could play a larger role in mitigating competition impacts of a carbon tax for industries that initially had reduced incentives to invest in high levels of energy efficiency via more expensive energy efficiency investment costs or lower energy costs, as well as industries with more differentiated products and more price-sensitive consumers. Future research could estimate for specific industries the effect of accounting for changes in energy efficiency on cross-border carbon tax issues.

From a policy standpoint, the ability of energy efficiency investments to mitigate negative cross-border effects soften two common criticisms of unilateral carbon taxes: negative competition impacts on local firms that compete with out-of-state firms and “carbon leakage” that reduces the environmental benefits of the tax. An improved understanding of this relationship and the circumstances in which it could play a larger role contributes to our academic understanding of carbon pricing, as well as being informative for policymakers and voters who are concerned about the competitive impacts of imposing a carbon tax or other carbon pricing scheme.

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