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Climate policy and competitiveness:
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ABSTRACT

When considering adoption of a domestic climate change policy, politicians and the public frequently refer to concerns about competitiveness. Competitiveness in this context does not have a precise economic definition. In this article, we discuss possible ways to anchor the concept of competitiveness in economic analysis. This framework then serves as the basis of a systematic survey the literature on the quantitative impacts of unilateral climate change policy derived from the results of computable general equilibrium (or CGE) models. We provide empirical estimates of the magnitude of competitiveness effects that might be associated with the adoption of unilateral climate change policies and a meta-analysis of the key sensitivities displayed by the models as a guide to future research.

JEL **classifications: C68, Q52, Q54**

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1 Introduction

Climate change has a number of features that make it a particularly difficult problem for public policy makers to tackle, but perhaps none is more problematic than the global nature of carbon dioxide and other greenhouse gas emissions. This feature of the problem makes unilateral actions to reduce emissions difficult to implement because the costs of abatement are shouldered primarily by the country taking action while the benefits of the policy are shared by all. This environment lends itself to free-riding, resulting in a situation in which countries are reluctant to undertake potentially costly emission reductions because they fear that comparable measures will not be adopted by others. This stalemate is the defining characteristic of the international climate policy process to date (Barrett, 2003).

In this context, policy makers contemplating unilateral emission reductions place a large premium on impacts their domestic economy will experience assuming that other countries will take no comparable action. In policy discussions, these impacts are often referred to as "competitiveness" concerns. In particular, policy makers often cite the fear of a "loss of competitiveness" as a primary factor in avoiding, delaying, or weakening domestic climate change policies.

It is not a large stretch to claim that competitiveness concerns are the primary reason that the public and politicians do not more strongly embrace domestic greenhouse gas mitigation policies. Yet, despite the concept's prominent role in the climate policy debate, it remains poorly defined from the perspective of economic analysis, variously referring to changes in welfare, profitability, output, market share, export volume, terms of trade, or employment levels. In many instances, a precise and commonly-held understanding of the term never appears to be reached in the course of debate.

One of the principal tools employed by economists to understand the impacts of unilateral climate policies is the computable general equilibrium (or CGE) model. These models represent an important complement to standard empirical and theoretical analysis in this area of study because they allow researchers to conduct counterfactual experiments that are grounded in microeconomic theory and have quantitative content. History provides few examples of policies that could serve as the basis of econometric analysis of prospective climate change policies. As a result, calibrated CGE models provide most of the evidence on the quantitative impacts of these policies to date. They are also capable of generating qualitative insights where theoretical models are silent, using the calibration of the model to narrow the range of outcomes to those that are germane to the policy debate.

In this article, we discuss possible ways to link the concept of competitiveness to economic theory and the outcomes of economic models. We then use this discussion to explore what can be learned about the competitiveness effects of unilateral climate policies from CGE models. Thus, we address the follow questions in the paper: How does the concept of competitiveness relate to standard economic treatment of international trade? How should policy makers approach the concept of competitiveness? How can the concept be measured using a CGE model? What do CGE models tell us about the magnitude of competitiveness effects from unilateral carbon abatement policies? How do their conclusions vary systematically with their assumptions? And what opportunities are available for improving their performance?

The paper is divided into two parts. In the first part of the paper, we survey and attempt to reconcile the commonly-used measures of competitiveness with the standard treatment of pollution externalities and international trade in economics. We discuss when competitiveness measures are likely to map into changes in well being or otherwise serve as a useful guide to policy making.

In the second part of the paper, we report on the results of a systematic survey of nearly 300 experiments from 54 articles using CGE models that assess the impact of unilateral climate change policies. We find that there is a relatively strong degree of concordance in the magnitude of competitiveness changes induced by unilateral climate action as well as a few noteworthy outliers. Nevertheless, there is relatively little diversity in the key assumptions employed by analysts in the literature. Moreover, the studies in our sample that relax both assumptions find different impacts.

The use of ex post validation exercises to assess the performance of the models, tighter linkages with empirical work in related fields and the new trade theories currently being advanced, and a more sophisticated treatment of labor market frictions are all areas where deeper analysis could yield important improvements in the quality of the inferences produced by these models. Nevertheless, even vigilance by modelers will leave significant sources of uncertainty in the quantitative predictions the models generate; this is the nature of modeling complex, economy-wide behavior. Better recognition of these limitations and the types of inferences that CGE models are capable of producing is also required of consumers of their outputs.

The paper is structured as follows. In section 2, we provide a definition and discussion of the concept of competitiveness — particularly as it is applied in discussions of unilateral climate change policy — and consider its policy importance viewed through the lens of economic analysis. In section 3, we discuss the use of CGE models in the analysis of unilateral climate policy as well as the measurement of competitiveness in a CGE framework. In section 4 we conduct a review of the literature produced using CGE models focusing on competitiveness issues. In section 5, we describe features that are missing from some or all existing CGE models that hinder the measurement and evaluation of competitiveness. Finally, in section 6 we conclude.

2 Competitiveness

2.1 Defining competitiveness

Competitiveness most commonly refers to the profitability of an individual facility, firm, or sector of the economy.[1] For example, the United States Senate Committee on Finance (1985) defines competitiveness in the following manner:

> A firm is competitive if it can produce products or services of superior quality or lower costs than its domestic and international competitors. Competitiveness is then synonymous with a firm's long-run profit performance ...

Nevertheless, in the public policy debate surrounding climate change, it does not have an unambiguous economic interpretation. Instead, it is used as a catch-all term to reflect an amalgam of concerns related to trade, profitability, employment, and welfare. In many cases, it is not clear how the concept as used relates to fundamental determinants of well-being or how it relates to economists' standard treatment of international trade.

Part of the ambiguity around the term is due to its undifferentiated use at different scales of analysis. Competitiveness is variously used to refer to outcomes at the level of a facility, firm, sector, and country (Jenkins, 1998; Reinaud, 2008; Coseby and Tarasofsky, 2007). Clearly, concepts that make sense at the facility-level may not translate to the country-level and vice versa; Krugman (1994) in particular asserts that the concept of competitiveness is meaningless at the country level.

Ambiguity in the use of the term is also due to its use to refer to both ***determinants*** of competitiveness and competitiveness ***outcomes***. Determinants of competitiveness are the set of factors that drive competitiveness outcomes. Examples of important competitiveness determinants are the endowments and quality of factors of production, the quality of institutions, the level of trust, the characteristics of technology, the policy measures in place, and other factors.[2] The high-profile World Economic Forum annual Global Competitiveness Report and much of the work of Porter (2008, 1990) relates to competitiveness determinants (Schwab, 2013). Competitiveness outcomes refer to the equilibrium resulting from realized levels of success determinants.

In the analysis of the quantitative literature presented in sections 3 and 4, our focus is on competitiveness outcomes at the sector level. We focus on competitiveness outcomes because of their centrality in the public policy debate. We focus on sector-level competitiveness because this is the scale most frequently invoked in public policy debates and is the scale most effectively treated in CGE models.

2.2 Are climate policies likely to influence competitiveness?

A new policy designed to limit emissions can affect the profitability of firms or sectors in the regulating economy. Particular attention has been devoted to emissions-intensive and trade-exposed

[1] The term has also been applied at the country-level, most famously by Porter (1990). However, the analogy of the nation as a firm which underlies the application at this level is contentious (Aiginger, 2006; Krugman, 1994; Warr, 1994).

[2] Aiginger (2006) refers to these as 'drivers of competitiveness,' while Alexeeva-Talebi et al. (2007) refers to them as 'success determinants.'

(EITE) sectors under unilateral carbon regulations. For example, the 2009 proposal to implement a cap and trade system for carbon emissions in the US (H.R. 2454) focused on international competitiveness of EITE sectors. The economic logic for focusing on these sectors is straight forward. Emission-intensive industries will most directly face the costs of complying with the new regulation. Thus, the regulation effectively increases production cost in these sectors. Where industries are producing goods that are highly traded, the price at which firms are able to sell these goods depends on the interaction of world supply and demand. If the domestic industry represents a small share of world supply, then it has limited ability to pass on increased input costs to consumers. Accordingly, under unilateral emission regulations, the competitiveness or profitability of EITE sectors may indeed be worsened. In section 5, we survey the extant CGE literature in an effort to quantify the change in competitiveness associated with introduction of a unilateral environmental regulation.

2.3 How is competitiveness related to well-being?

If competitiveness is to be used as an outcome measure in public policy analysis, one should be able to construct an argument linking competitiveness to standard metrics of well-being used in economics. Here we consider the relationship between competitiveness and different aspects of well-being as it applies to unilateral climate change policy.

Competitiveness and allocative efficiency

The fundamental economic concept underlying our understanding of the determinants and consequences of international trade is comparative advantage. A party holds a comparative advantage in supplying a good to the world economy if it exhibits the lowest opportunity cost to society of producing it. Thus, actors trading to their comparative advantage is synonymous with allocative efficiency in the world economy.

Importantly, if competitiveness is a reliable indicator of comparative advantage, one could justify the focus on this measure in policy on the grounds that increasing competitiveness is likely to increase efficiency. Two key differences in the definitions of these concepts cast doubt on this possibility. First, the theory of comparative advantage, through its connection to opportunity cost, describes an allocation of resources across a range of possible uses (typically within a country). If a country holds a comparative advantage in the production of a particular good, it means that producing it is the most valuable use of the resources employed ***relative*** to the other possibilities. In contrast, assessments of competitiveness typically evaluate the profitability of a sector or firm in isolation from the rest of the economy.

The second (and related) difference is that comparative advantage is assigned based on the opportunity cost of the activity to society. In contrast, measures of competitiveness typically rely on accounting costs to determine profitability. Accounting cost and opportunity cost will coincide when no market failures exist — that is, when market prices of a firm's inputs and outputs reflect the full opportunity cost of an economic activity. Thus, if a firm operating in such an environment is competitive, then it also has the lowest opportunity cost of production. Nevertheless, a number of sources of market failure are relevant in the context of unilateral climate policy:

Pollution externalities — to the extent that firms fail to internalize the effects of their carbon pollution on society, they may appear more competitive than true opportunity cost would imply. Thus, the world economy will engage in too much of the pollution-intensive activity. The purpose of climate-policy interventions is to ensure that these costs are reflected.

Incomplete regulation — the difficulty of addressing global pollution externalities with unilateral policies is that only some sources of the externality will be forced to recognize the social costs imposed by their actions. As a result, too little industry output will be produced by regulated sources and too much by unregulated sources. Said another way, competition from unregulated firms will cause regulated firms to appear less competitive and unregulated firms more competitive than opportunity costs would imply.

Protectionist trade policy — artificial barriers to trade, such as tariffs and subsidies, designed to support domestic industries generally make domestic firms more competitive than the true opportunity costs would imply. Many energy (and carbon) intensive industries are also trade exposed. Thus, there may be important interactions between trade protections and climate policy.

External economies of scale — if firms fail to account for agglomeration effects that lower costs of production then infant industries may fail to grow. Thus firms would register lower competitiveness than the true opportunity cost would imply. Policy makers advocating for the exemption of industries from emission regulations often invoke a version of this argument, suggesting that the burden of compliance with climate policy will prevent the country from exploiting these economies of scale and developing into a worldwide hub for the industry.

To summarize, there is a close connection between global efficiency in trade and firms with the highest degree of competitiveness satisfying world demands in an idealized economy.[3] Yet the environment in which climate policy operates is not ideal. As a result, there are many opportunities for the competitiveness of a country's industry and its comparative advantage to be at variance.

What does this discussion imply for efficiency-based arguments addressing competitiveness in the design of unilateral climate policies?

Climate policies are designed to address a pollution externality. In the absence of the policy intervention, industry fails to account for the social cost of pollution in evaluating its competitiveness. As a result, ***a necessary and desired*** consequence of the new regulation is to lower the

[3] This distinction between comparative advantage and competitiveness has been made numerous times in the applied literature, especially in relation to agriculture. See for example Dunmore (1986), Siggel (2006), Cockburn et al. (1999), and Warr (1994). JunNing et al. (2009) distinguishes slightly differently between comparative and competitive advantage, treating competitive advantage synonymously with economists' concept of absolute advantage.

competitiveness of pollution-intensive activities.[4] Therefore, that firms will experience higher costs under climate regulations is not a sufficient condition for protecting these industries.

The incomplete nature of unilateral regulations provides perhaps the most legitimate efficiency-based argument in favor of differential treatment for regulated EITE industries. Under unilateral emission regulations, the competitiveness of EITE sectors may be worsened because their foreign competitors do not experience the same increase in cost. Comparative advantage, however, is determined by the technology of production, international prices, and availability of factors of production. Most of these characteristics remain unaffected by the application of unilateral emission regulations. Thus, a country’s domestic industry may maintain a comparative advantage but lose its competitiveness because of the incomplete nature of unilateral climate regulation.

This argument was first formalized by Markusen (1975) and elaborated later in a more general model by Hoel (1996). Both authors demonstrate that optimal unilateral regulation of international pollution externalities will involve a domestic Pigouvian tax on the pollutant paired with import tariffs and export subsidies designed to mitigate the effects of unilateral policies on unregulated foreign sources of emissions. More recently, a number of studies employing CGE models have explored the quantitative significance of using instruments of trade policy (or “border tax adjustments” as they are often referred to in this literature) to improve the performance of unilateral carbon regulations.[5]

Protectionist trade policies and external economies of scale suggest policy interventions that work in opposite directions; efficiency will be restored when artificial barriers to trade are removed. The exception to this rule is when external economies of scale are involved, in which case protection may be justified. Note, however, that these sources of market failure are not, in and of themselves, justifications for building competitiveness measures into the design of climate policies. Rather, it must be that there are important *interactions* between the distortions these issue cause and climate policy. Thus one must make the case, for example, that climate policy affects the magnitude of the external economies of scale or reduces the distortionary cost of trade barriers. A priori, there is no obvious reason to think that important interactions of this sort exist.

Competitiveness and regional terms of trade

Even if one cannot make a case for policy intervention based on global efficiency, a nation may find it in its own interest to protect an industry to avoid an unfavorable shift in the terms of trade with other countries. A standard result from international trade economics demonstrates that large countries (or trade blocs) have an incentive to implement policies that raise the price of goods in export industries and lower the price of import industries. This can be accomplished through

[4] We take it as given in this discussion that the benefits of internalizing the climate externality to society exceed to the costs of unilateral action. If one believes the dangers of global warming are very small or that unilateral action is very ineffective at reducing global emissions, then one could argue that no action is warranted. In this case, competitiveness concerns are a moot point.

[5] See Böhringer et al. (2012) for an overview of this literature.

explicit trade policy instruments in the form of tariffs and subsidies. Empirical work suggests that optimal (Nash equilibrium) tariff rates can be quite high (in many cases greater than a 50% ad valorem rate for example) implying that, in practice, these incentives are strong (Limao, 2008; Ossa, 2012).

Indeed, the literature on carbon-based border tax adjustments highlights the possibility that — if the terms-of-trade gains to using these instruments are large — countries may have significant incentives to introduce carbon-based trade policies even when the direct, climate-policy benefits are negligible. Consistent with the literature on optimal tariffs rates, a number of studies find that these gains can be large (Böhringer et al., 2011, 2012,a).

This feature has made the issue of border measures contentious in the international climate policy debate and led to the consideration of two related but less explicit forms of protection. Output-based subsidies combine a carbon tax and an output subsidy. Thus, firms have an incentive to adopt less carbon-intensive production techniques due to the carbon tax, yet competitiveness is maintained by the output subsidy. It is also common to propose explicit exemption of certain EITE sectors from unilateral climate policies.[6]

Other common sources of competitiveness concerns

At least two other arguments for protecting industries from the competitiveness effects of climate policy frequently make their way into the policy debate. Both tend to be more difficult to link directly to the measures of efficiency or regional well-being.

Sector-specific factors in industries expected to be heavily impacted by carbon regulations are often cited as a reason for protection. For example, an aluminum refinery cannot be re-purposed as a chemical plant, so a rapid decline in sector demand may leave stranded capital. Likewise, some of the skills possessed by employees in certain sectors may be specific to that sector, in which case a policy-driven decline in sector output could effectively reduce the value of skills, and reduce output below potential. What is clear is that the owners of these stranded factors may suffer a welfare loss as a result. What is less clear is how policy makers should weigh these losses against the broader gains of the new climate policy in a country's social welfare function. Moreover, protection of the industry is likely to represent an inefficient means of making these stakeholders whole when direct compensation is also possible.

In some cases, policy makers may be concerned about "economic security" associated with domestic production from certain sectors. For example, it may be seen as desirable to maintain domestic energy or food production capacity. In this case, policy makers may be particularly sensitive to policy-induced output reductions in those sectors. However, just as it is challenging to define "competitiveness" in economic terms, terms like "food security" and "energy security" are notoriously difficult to pin down (Metcalf, 2013).

[6] See Böhringer et al. (2012b) for an analysis of the relative performance of these three instruments.

Common proxies used as indicators of competitiveness

At the outset, we noted that policy makers commonly refer to changes in EITE-sector output, export, import and employment levels as indicators of the change in the competitiveness of domestic industry. It is important to emphasize that none of these proxies has a simple relationship to global efficiency or regional well-being. For example, while the most direct consequence of climate policy may be the reduction of output pollution-intensive sectors experience, economic models also predict a corresponding increase in output in clean sectors. Thus one could just as easily emphasize the *increase* in competitiveness in clean sectors caused by climate policy. Similar effects are present for exports and employment across clean and dirty sectors. This loose link between proxies for sector competitiveness and measures of welfare is the root of economists' traditional reluctance to engage on the issue of competitiveness.

3 CGE models and competitiveness

3.1 Why use CGE models?

CGE models supplement existing empirical and theoretical literature focusing on the link between environmental policy and international trade, sector production, and employment — concepts we consider close to the meaning implied by "competitiveness." Theoretical literature provides a useful underpinning for the broader research on the effects of environmental policy, by establishing testable hypotheses about the sign of effects that might result from environmental regulations. However, theoretical models are designed to be parsimonious in order to focus on a particular aspect of the problem being studied. As a consequence, they may not reliably predict quantitative outcomes. In addition, theoretical models often produce ambiguously-signed results. Empirical research tests theoretical hypotheses using real-world data to inform estimates on the link between environmental policies and competitiveness. However, four key problems plague empirical research. First, in many cases there is little difference between the environmental policies of jurisdictions that trade with one another, which makes it difficult to anticipate the effect of a jurisdiction unilaterally adopting a stringent environmental policy. Second, estimating the effect of environmental policies on competitiveness requires that such policies are treated as exogenous. However environmental policies are adopted partly in response to economic conditions. Establishing the causal effect of environmental policies on competitiveness therefore requires the use of clever identifying assumptions. Third, data is often not easily available. In many cases, researchers have limited access to firm-level data, and data on environmental policies and economic performance is often much less available in less developed countries. Fourth, there are few examples of stringent unilateral carbon regulations, and so relatively little evidence can be drawn from past experience.

CGE models provide an alternative method to characterize the link between environmental policies and competitiveness. They have the same foundation as theoretical models, but because they don't require a closed-form solution, they can be significantly more complex than theoretical models. In addition, by calibrating the system of equations to observed economic transaction data and empirically observed elasticities, CGE models can provide a numerical estimate of the magnitude of the effect being considered. Even when magnitudes remain highly uncertain, a CGE model can use the quantitative content of its calibration to sign an effect where theoretical models produce ambiguous results. Additionally, CGE models can be run in a ex ante framework, such that they are not restricted to analysis of past policies, but can consider the application of new policies. Along with readily available data and software, these features of CGE models have led to their wide application in the analysis of the link between climate policy and the broadly defined concept of competitiveness.

3.2 Measurement of competitiveness in CGE analysis

In the context of unilateral climate policy, the concept of competitiveness is particularly related to the ability of particular sectors to maintain market share in international markets. Accordingly, a number of variables have been used as proxies in the applied literature to operationalize the concept. We summarize these in Table 1, and also report instances where these concepts have been used as a measure of competitiveness in recent CGE literature exploring unilateral climate change regulations.

Exports are a proxy measure of sector competitiveness in international markets, while imports relate to sector competitiveness in domestic markets. A worsening of sector competitiveness would be associated with a reduction in exports and increase in imports for that sector. Net exports summarize sector competitiveness in both international and domestic markets. Jaffe et al. (1995) refer to net exports as a theoretically desirable measure of competitiveness.[7] In addition to these measures, many studies report the effect of unilateral environmental regulations on sector output and employment, two variables of particular concern to public policy makers (Fischer and Fox, 2012).

In addition to these main proxies for competitiveness that are used across a number of studies, several others are used less frequently. Böhringer and Alexeeva-Talebi (2012) and Alexeeva-Talebi et al. (2007) report the change in revealed comparative advantage (RCA) as well as the change in relative world trade share (RWS) caused by unilateral climate policy adoption. Rivers (2010) reports the change in the market share of the domestic sector in the domestic market. Babiker (2005) uses a model of imperfect competition and reports the change in the number and size of firms in a sector. Bruvoll and Faehn (2006) and Rivers (2010) report on the change in the cost of domestic output relative to the world price.

4 Quantitative analysis of competitiveness effects

Because competitiveness is not a theme commonly explored by economists, there are few direct

[7] More specifically, Jaffe et al. (1995) suggest that the change in net exports, holding exchange rates and real wages fixed, is a desirable measure of competitiveness. Because of the impossibility of observing this measure, unconditional net exports serves as a proxy measure of competitiveness.

references in the literature to the competitiveness impact of environmental policies. However, by surveying a large literature generated by CGE models on emission pricing, border tax adjustments, unilateral environmental policy, and emission leakage, we are able to find a substantial literature that is closely related to the measures of competitiveness described in this article. Even when we restrict our attention to studies that use CGE models to examine the response of energy-intensive industries to unilateral greenhouse gas reduction policies, we find 54 studies, most conducted in the last decade. These studies report a results on a variety of different indicators of competitiveness. Our attempt here is to synthesize the key results of these studies by focusing on indicators that are reported in multiple studies. Additional detail of how we chose the sample, coded the results, and the sample itself is contained in appendix A.

4.1 Sample characteristics

Our sample consists of experiments with CGE models in which unilateral carbon pricing is applied, either using the mechanism of a carbon tax or a cap and trade system. In some cases, the carbon tax is adopted unilaterally by a coalition of several countries at once, and in some cases by an individual country. Although the papers included in our survey feature a wide range of experiments, we focus on experiments where the carbon policy is applied economy-wide (with no exemptions) and in which revenues from the carbon policy are returned in a non-distorting manner to the consumer (i.e., via lump sum transfers). If there is a government agent specified, we focus on runs in which an equal-yield constraint is applied to maintain government revenue at pre-policy levels. We report impacts on economy-wide indicators as well as on energy-intensive and trade-exposed sectors. Although the precise definition of these sectors may differ from study to study, typically it includes heavy manufacturing (paper, pulp and print, chemical products, mineral products, iron and steel, nonferrous metals), energy-intensive transport (air transport), and oil refining.

We begin with some observations about the characteristics of the dataset. There are 54 published studies in the sample that collectively produce 291 observations, where an observation is defined as a single policy experiment (or simulation). Approximately 90 percent of the experiments were published in the last decade and approximately half of them in the last 5 years.

Naturally, not all studies report all of the outcome measures considered in our analysis, thus in the figures and regression tables that follow the results are based on the subset of observations that report the outcome in question. (See Table 1 for a list of studies reporting each outcome.)

Models based on both partial and general equilibrium concepts are represented in the sample. There are both static and dynamic models and, within the latter category, dynamics based on forward-looking agents as well as myopic agents. There are both deterministic and stochastic models. However, 57 percent of the experiments are based on static, deterministic, general equilibrium models. There are some sub-global (typically national-level) models in the sample, but approximately 85 percent of the experiments are global in scope.

A wide variety of definitions of the coalition of abating countries are employed. However, it is almost exclusively OECD member states that are included in the coalition. Many studies draw on the composition of Annex I or Annex B countries from the Kyoto Protocol. 31 experiments cover the United States, 20 cover Canada and over 100 experiments model the coalition as some subset of Western Europe.

Approximately 70 percent of all experiments are based on models in which the key emission-intensive sectors of the economy are assumed to operate using constant-returns-to-scale technologies in perfectly competitive markets. 95 percent of all experiments are based on the Armington description of international trade, which traded goods are assumed to be imperfect substitutes differentiated by the country in which they were produced. 11 experiments assume that traded goods are perfect substitutes.

Approximately 70 percent of experiments assume that capital is mobile across sectors within a model region while 11 percent assume that it is sector specific. 64 percent of experiments assume that capital is not mobile across regions and 18 percent assume that there is international mobility. The balance do not report what assumption is made with respect to capital mobility.

4.2 Standard model assumptions

In what follows, we look across the studies in our sample to identify broad trends in the competitiveness impacts predicted by CGE models. However, as the preceding description of the sample indicates, there are many models that share many common features. As a result, it is useful to pick out one study that is representative of this group and describe the results of a "standard" CGE model of unilateral carbon policy. We use Böhringer and Rutherford (2010) as our representative of these studies. The paper describes policy options for Canada to comply with its emission reduction tar- gets under the Kyoto Protocol.

The model is a static, multi-regional, multi-sectoral model. There is a single, representative agent in each region which owns three factors of production: capital, labor and fossil-fuel natural resources. Labor is perfectly mobile across sectors but cannot move across regions. Natural resources are sector and region specific. Capital is perfectly mobile across sectors but cannot move across regions. Production in all sectors uses constant return to scale technologies based on nested constant elasticity of substitution production functions. In non-resource sectors, the representative firm combines capital, labor, materials and energy. In resource sectors, the firm combines these inputs plus the specific resource factor. The elasticity of substitution between this factor and all other inputs is chosen to calibrate specific values for the supply elasticity of each fossil fuel in the model (crude oil, coal and natural gas). The representative agent in each region maximizes utility subject to a budget constraint. Income is derived from ownership of the basic factors in the model and government transfers. The agent spends its income on the full roster of produced goods included in the model and saves a fixed, nominal amount. Government policy is exogenous. Bilateral trade is modeled based on the Armington framework. The environmental benefits of emission reductions are not modeled and the authors focus on characterizing the market-based costs associated with different ways of meeting the same emission target.

There are 12 world regions/countries and 23 commodities explicitly modeled. The sectoral detail focuses on the representation of energy and energy-intensive goods and the regional detail focuses on key Annex-B and non-Annex-B players in international climate policy. The model is calibrated using the GTAP 7 database which contains economic accounts and bilateral trade with carbon emissions data for many world regions. Estimates of the key substitution elasticities between capital, labor, energy and materials in production are derived from recent panel data econometric estimates. The international trade elasticities come from recent econometric estimates from a gravity model. The values for the fossil fuel supply elasticities are chosen directly by the authors with the intention of being representative of the empirical literature. The 2004 data from GTAP 7 is projected forwarded for the policy simulations to 2010 using projections on GDP growth, trends in energy-intensity of production in key sectors and trends in fossil-fuel prices.

In the analysis that follows, we differentiate between observations generated by "standard" and "non-standard" models from the literature. We define standard models as ones that are static, assume perfectly competitive, constant returns to scale EITE industries, employ the Armington description of bilateral trade and assume that labor and capital are perfectly mobile across sectors but immobile across regions.

4.3 Analysis of competitiveness results

Now we turn to an analysis of the relationship between the different measures of competitiveness and the stringency of the carbon policies modeled in the CGE experiments. The stringency of the policy is measured by the unilateral abatement rate of the regulating country or region (termed the coalition in our discussion). We focus on the competitiveness measures identified in Table 1.

Figure 1 plots the output reduction in EITE sectors from unilateral climate change policy against the abatement rate of the coalition. Points represent simulation results. The blue points represent observations generated by a standard CGE model from our sample. Orange points represent observations generated by models that deviate from the standard CGE model in the sample in at least one dimension. The line is the local linear fit through the unweighted points, and the shaded area is the 95 percent confidence interval. A regression analysis to complement the graphical analysis is included as Appendix B.

EITE sector output

Output in EITE sectors is negatively related to the abatement rate and the studies appear to be in some agreement about the magnitude of the effect. For a 20 percent reduction in coalition emission levels from the pre-policy baseline, the models predict approximately a 5 percent reduction in EITE output in the region, a prediction that is significantly different from no effect at the 95 percent confidence interval.[8] While there are some outliers that predict significantly larger reductions in

[8] NB — the confidence intervals described in the figures do not account for the fact that multiple observations come from the same study, likely violating the assumption that all observations are independent. In formal regression

output, the large majority of predictions cluster quite closely to the fitted line. Among the outliers, the most dramatically different outcomes come from Babiker (2005), a study focused on exploring the effect of assuming different market structures in EITE sectors. Assuming both increasing returns to scale in these industries and that the traded goods are homogenous leads to much larger reductions in output in these sectors. There are two reasons for this. First, the scale of the domestic industry will shrink in response to the new regulation as firms must cover the cost of complying with it. This loss of scale also causes per unit costs of production to rise due to the increasing-returns nature of the industry. This results in a more elastic response to the policy than in a constant-returns industry, all else equal. Second, assuming homogeneous goods trade in these sectors implies that world demand for EITE goods can quite easily be re-sourced from other countries when the cost of production rises under regulation. In contrast, assuming Armington trade in these sectors makes these adjustments more difficult, as consumers view goods sourced from different countries as imperfect substitutes.[9]

EITE sector exports, imports and employment

Far fewer studies report the changes in exports, imports or employment levels in EITE sectors and there appears to be more variance in the predictions of the models regarding these outcomes. These studies are reported in Figures 2, 3, and 4. With respect to exports, we find that the average model reports approximately a 9 percent reduction in exports at the 20 percent abatement level. However, there are observations roughly evenly distributed between predicting smaller increases in exports of EITE goods and reductions of as large as 30 percent of pre-policy levels. Nevertheless, the models collectively predict a reduction in exports that is significantly different from zero at the 95 percent confidence interval. In contrast, there is no discernable relationship across the studies between the import volumes and abatement. Employment levels within EITE sectors shows a very weak relationship — negative and possibly decreasing with the abatement rate in its central tendency but with wide error bands.

Carbon leakage

While leakage is not a measure of competitiveness per se, it is a commonly reported statistic in these studies and, as we argued above, a key response to unilateral action that policy makers might legitimately want to consider on welfare grounds. Figure 5 shows the leakage estimates produced

analysis where we cluster standard errors at the level of the study to account for this, we continue to find statistically significant effects for EITE output changes and welfare changes. Tables describing the results of these regressions and a detailed description of the estimation strategy are included in Appendix B.

[9] Other structural interpretations of gravity models, such as the widely discussed Eaton and Kortum (2002) Ricardian model of bilateral trade, imply similar trade elasticities and would, therefore, yield similar responses. The Eaton-Kortum model introduces these frictions via the assumption that firms within an industry receive random productivity draws. This, combined with the assumption of trade costs, implies a limited ability in the world economy to switch among supply sources.

by the different studies in our sample. The leakage rates displayed are all defined as the change in emissions from the pre-policy baseline outside of the regulated jurisdiction divided by the change in emissions within the jurisdiction. Thus a leakage rate of 0.2 indicates that 20 percent of the abatement that takes place under the policy within the regulated region is offset by increases in emissions elsewhere.

The figure shows that leakage rates are consistently positive across the studies — typically in the range 10 to 30 percent. They also show some linear association with the abatement rate simulated. The models show fairly good agreement on the leakage rates — similar to the results for changes in EITE sector output levels — with the exception of a few outliers. Once again, the most noticeable outlier is the Babiker (2005) study which focuses on varying the assumption regarding market structure and the homogeneity of the traded goods. One configuration of this model produces a leakage rate of over 100 percent.

Welfare levels

Finally, we examine the effect of abatement on the welfare level of the representative agent in the regulating region. Figure 6 plots the fractional change in the money-metric welfare level of the representative agent in the coalition against the unilateral abatement rate. All of the welfare observations in the sample exclude the environmental benefits of controlling pollution levels, so they are best interpreted as a measure of the social cost of abatement. As we would expect, the studies predict negative welfare effects from climate policy.[10] For example, for a 20 percent reduction in coalition emissions, the experiments predict a money-metric welfare loss approximately equal to 1 percent of pre-policy GDP, with most observations in the sample lying between 0 and 2 percent. Visual inspection of the trend clearly shows a negative and downward-sloping tendency in the data, and the welfare effects are, on average small, and the data reject, at most abatement rates, the null hypothesis that the welfare effect is zero. Some outliers register significantly larger welfare losses — as large as approximately a 7 percent reduction from pre-policy levels.[11]

Discussion

In summary, the models in our sample show some agreement that EITE output, exports, and employment will fall and welfare effects will be negative. The main outliers in the analysis of the output changes concern deviations from the typical assumptions regarding market and international trade structure. In particular, scope for increasing returns to scale in EITE industries and assuming a greater degree of homogeneity in traded goods both promote a larger relocation of EITE industries abroad in response to unilateral climate policy leading to much more dramatic reductions in output

[10] Although, it is theoretically possible that countries that specialize in exporting EITE goods could generate strong enough terms of trade advantages to offset the direct abatement costs associated with unilateral climate policy.

[11] We focused in the preceding discussion on the relationship between abatement rates and outcome measures. Some of the studies in our sample report carbon prices instead of or in addition to abatement rates. We observe similar relationships in the data when we examine relationships between carbon prices and outcome measures.

and exports (and larger leakage rates). The scope for market power and increasing returns to scale in these industries is fairly well established, although it is unclear how strong an effect these features should exert on the results of the CGE experiments here, given the high degree of sectoral aggregation assumed in these models. Nevertheless, it is surprising that more models have not explored the importance of these assumptions. There is some added computational complexity associated with modeling this type of behavior, which may explain the choice to use competitive, constant-returns to scale markets in most studies.[12]

The assumption of homogeneous goods trade is less well established. The gravity models of international trade, from which are derived the trade elasticities used to calibrate the Armington-based models in our sample are among the most successful empirical models in economics. A justification for larger elasticities (a consequence of assuming more homogeneous trade) would, therefore, have to explain this departure from the empirical evidence. One possible argument raised by Babiker (2005) is based on the time horizon considered. Gravity model estimates, based on either variation in prices across regions or time are probably best thought of as reflecting short to medium term time horizons.

In a related study, Balistreri and Rutherford (2012) conducts unilateral climate policy experiments in a model in which trade and market structures for EITE goods are based on the Melitz (2003) structural interpretation of the gravity model. The Melitz framework features imperfect (monopolistic) competition and firms of varying levels of productivity. The resulting model generates equilibria in which large, productive firms serve export markets while smaller, less productive firms serve domestic markets. Moreover, changes in output prices (due to trade liberalization, for example) or costs (due to environmental regulation, for example) result in changes in industry-wide productivity. Introducing this framework to study unilateral climate policy, Balistreri and Rutherford (2012) find results similar to those generated by introducing economies of scale in Babiker (2005) experiments. The introduction of climate policy causes a loss of economies of scale in the regulating regions, resulting in a strongly elastic response of bilateral trade, more relocation of EITE production to unregulated regions of the world economy and larger carbon leakage rates. Unlike the Babiker (2005) study, Balistreri and Rutherford (2012) takes the trade elasticity values implied by gravity model estimates as given. Thus they do not find the dramatically larger effects associated with relaxing both market and trade structure found in the former study.

5 Future research: what's missing from CGE models?

The most illuminating insight that comes out of the preceding analysis of the extant literature is that the very few models based on alternative market, trade, and capital mobility structures produce quite different results. In particular, the existence of economies of scale is well established in many

[12] However, it is also worth noting that these features have been present in CGE models of trade liberalization experiments for many years now (Cox and Harris, 1985, 1986).

EITE industries. As a result, it seems like future CGE studies that do not contain some mechanism for modeling scale effects should go to some length to explicitly justify this modeling choice. The issue of the trade structure is more contentious. As we noted, there are by now many econometric estimates of trade elasticities for these sectors. A number of different modeling frameworks — Armington-based or one of the "new new trade theory" models based on the works of Eaton and Kortum (2002) or Melitz (2003) — are capable of capturing these responses. Thus, our finding that approximately 95 percent of existing modeling efforts are based on the Armington assumption is not, in itself, an indictment of the literature. However, modelers should be cognizant of the time horizon the model results are intended to represent. The trade elasticities commonly used probably best describe medium-run time horizons. It seems plausible that longer-term adjustments in the pattern of trade could result in wholesale relocation of EITE industries away from regulating jurisdictions, as described in the extreme cases considered in the Babiker analysis.

There is also evidence from trade liberalization experiments that the extensive margin of trade is more important than previously thought (Kehoe and Ruhl, 2009). These experiments show dramatic growth in trade of new categories of goods in response to liberalization. While the Armington framework may be well-suited to capturing changes in trade flows for broad classes of goods or goods that are heavily traded, applications which place a premium on understanding outcomes for specific industries at a detailed level or for industries which could move from being traded to non-traded goods will likely require a different framework such as one of the new trade models described above. This could be an important issue in the context of competitiveness where the focus of policy makers is often on the impacts of policies in specific, sometimes narrowly circumscribed industries.

In addition to capturing scale effects and changes at the extensive margin of trade, the new trade theory models emphasize the role of firm-level heterogeneity in determining industry-wide adjustments. A very new literature in the analysis of pollution policy takes its cue from these models to explore how firm-level differences pollution intensity might change our understanding of carbon leakage effects and competitiveness impacts of unilateral policies (Holladay, 2010; Wen, 2013). This seems like a natural area for future research.

With respect to modeling capital markets, a number of studies (such as the Böhringer and Rutherford (2010) study considered above) will model both short-run scenarios in which capital is sector-specific and longer-run scenarios in which capital is intersectorally mobile. This is a useful way of bracketing the impacts of an assumption that appears to have an important influence on model results. Nevertheless a treatment of capital markets that adds empirical content to the magnitude of capital flows would be a welcome addition to the literature.

Only a few studies in our survey, (Böhringer et al., 2008; Babiker and Rutherford, 2005; McKibbin and Wilcoxen, 2009), address labour market imperfections (as well as its interactions with imperfect competition in EITE goods markets). The authors typically implement these frictions by parameterizing an economy-wide wage curve that specifies a functional relationship between the equilibrium wage rate and the unemployment rate. However, there are no studies that apply the insights of modern labor search models (see Pissarides (2000) for a review of this literature) to study the unemployment effects of environmental regulation in a rigorous way. It is clear that one of the foremost concerns in the minds of politicians is what effects regulation will have on their jurisdictions if the closing of EITE industries results in local unemployment. The existing CGE models almost all assume full employment and modelers, when pressed to defend this assumption, argue that "eventually" these workers will be reemployed elsewhere in the economy. Nevertheless, important welfare losses may be associated with even temporary unemployment. Modern labor search models have the potential to model these dynamics and the associated welfare costs.

Induced technological change is widely recognized as having a potentially important influence on the costs of climate policy. Therefore, it would be desirable to have descriptions of knowledge accumulation and its effects on competitiveness in CGE assessments of unilateral climate policy. Some progress has been made in incorporating this feature into single-sector macro growth models of climate policy (Popp, 2004). However, to date there is simply not enough empirical evidence to produce credible calibrations of multi-sectoral models (Sue Wing, 2006).

Large-scale carbon emission regulation is a new enough phenomena that the historical record provides little data with which to perform statistical tests of its impacts on the economy. In fact, this is part of the motivation for using CGE models to evaluate policies in the first place. Nevertheless, this state of affairs is changing. Much of Western Europe and parts of North America now have carbon policies (albeit modest ones) in place. A new empirical literature is developing to test the impacts of these regulations (Aichele and Felbermayr, 2010, 2011, 2012, 2013). CGE modelers should develop applications that allow for direct comparisons between the econometric estimates derived from these studies and the policy responses in their models and use these studies as a source of calibration data for key model parameters.

These new regulations also lead to the possibility of developing ex post tests of the performance of CGE models. For example, Kehoe (2005) evaluates the major CGE modeling efforts conducted in anticipation of the North American Free Trade Agreement. His study documented both important successes and failures in the performance of these models — finding agreement on the magnitude of overall trade flows but also changes in bilateral flows, important changes in productivity in response to trade policy and trade in new goods categories that the models missed completely. It would be interesting, in the North American context, conduct a similar type of analysis for British Columbia's new carbon tax or California's new carbon regulations and their effects on the competitiveness of EITE industries located in these jurisdictions.

If one lesson is that ex post analyses can be the genesis of new insights and models, a second is that it is important to recognize the natural limits to the type of inferences that can be derived from CGE models. An example taken, once again, from Kehoe's work demonstrates how much more complicated policy changes that play out in practice can be than how they are modeled in the computer lab. In his evaluation of Spanish tax reforms, he shows that important changes in agricultural productivity and petroleum prices (that were unrelated to the reforms themselves) took place contemporaneously. As a result, the predictions of the ex ante CGE models runs performed rather poorly in a naive comparison to the historical record. However, in ex post runs of the same CGE model which incorporated these productivity changes as assumptions of the model perform far better. It is not reasonable to expect that models will capture all important behavior changes in many of policy environments where CGE models are used, thus consumers of model results will be forever disappointed if they view them as precise quantitative predictions. Moreover, even it were possible to capture "everything", it would be undesirable to do so from an analytical perspective. "Models of everything" do not help us understand the underlying determinants of economic behavior. Naturally, modeling exercises fall along a spectrum from those that are more analytical and theoretical to those that are more applied and quantitative. However, even the most applied CGE models are best viewed as helping analysts understand approximate magnitudes of effects and the key sensitivities displayed by the results in response to changes in assumptions.

6 Conclusions

It is sometimes asserted that "real economists don't talk about competitiveness,"[13] and indeed the term rarely enters the dialogue of professional economists. To some degree, this makes good sense: the welfare of a country is generally untied to the imports, exports, output, or employment in any particular sector of the economy, and it should not normally be considered a role of policy makers to ensure a certain level of sectoral output. Indeed, choosing to maintain the output of a sector through a public policy such as preferential tax treatment can lead to social welfare losses (Böhringer and Rutherford, 1997).

While there may be reasons for pursuing secondary objectives, policy makers should make them explicit; otherwise concerns about sector competitiveness have the potential to be interpreted as rent-seeking by industry sectors seeking protection.

Yet there are a number of reasons for which it is important for economists to concern themselves with the debate over competitiveness. First, from a pragmatic perspective, in the context of unilateral climate policy competitiveness is high on the list of concerns of public policy makers and the public. Economists have a few options in the face of this reality: they can try to convince public policy makers that the concept is not important or not well-defined, they can accept the public's concern but refuse to engage, or they can engage on the public's terms, and try to provide meaningful analysis. The first of these is unlikely to work and the second is unproductive. Finally, as we have seen it is possible to construct coherent economic arguments supporting measures to address competitiveness concerns. Border tax adjustments, for example, are a prescription of economic theory when unilateral designs are the best feasible policy option.

In response to this concern, a large literature has developed, much of it using computable general equilibrium models, to assess potential changes in competitiveness indicators following implementation of carbon policies. Our survey of this literature reveals that there is a substantial

[13] This quote is sometimes attributed to Paul Krugman.

degree of convergence in the literature, at least for two key indicators. Specifically, models estimate that output from energy intensive and trade exposed sectors in the regulating country is likely to be reduced as a result of unilateral climate policies. A 20 percent reduction target might be accompanied with a 5 percent reduction in EITE sector output, while a more stringent 40 percent reduction target might result in a 15 percent reduction in EITE output. The models also show some consistency with respect to estimation of the welfare impacts of unilateral climate policies. In this case, most models predict only very small changes in social welfare, even for quite large mitigation targets.

However, the similarity in results across studies that we observe may be at least partly driven by commonalities in assumptions. The studies we survey typically base international trade on the Armington assumption of differentiated products, assume that industries operate at constant returns to scale and in perfect competition, assume limited capital mobility, and assume frictionless labour markets. Studies that relax these assumptions are relatively few, but have results that deviate significantly from those of more standard models. Additional work to explore alternatives to the common assumptions of CGE models therefore seems in order. Moreover, more work should be conducted to validate the mainstream CGE assumptions, especially by conducting comparisons with econometric studies of policy adoption. These types of comparisons will become increasingly feasible as regional climate policies come online.

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Figures and Tables

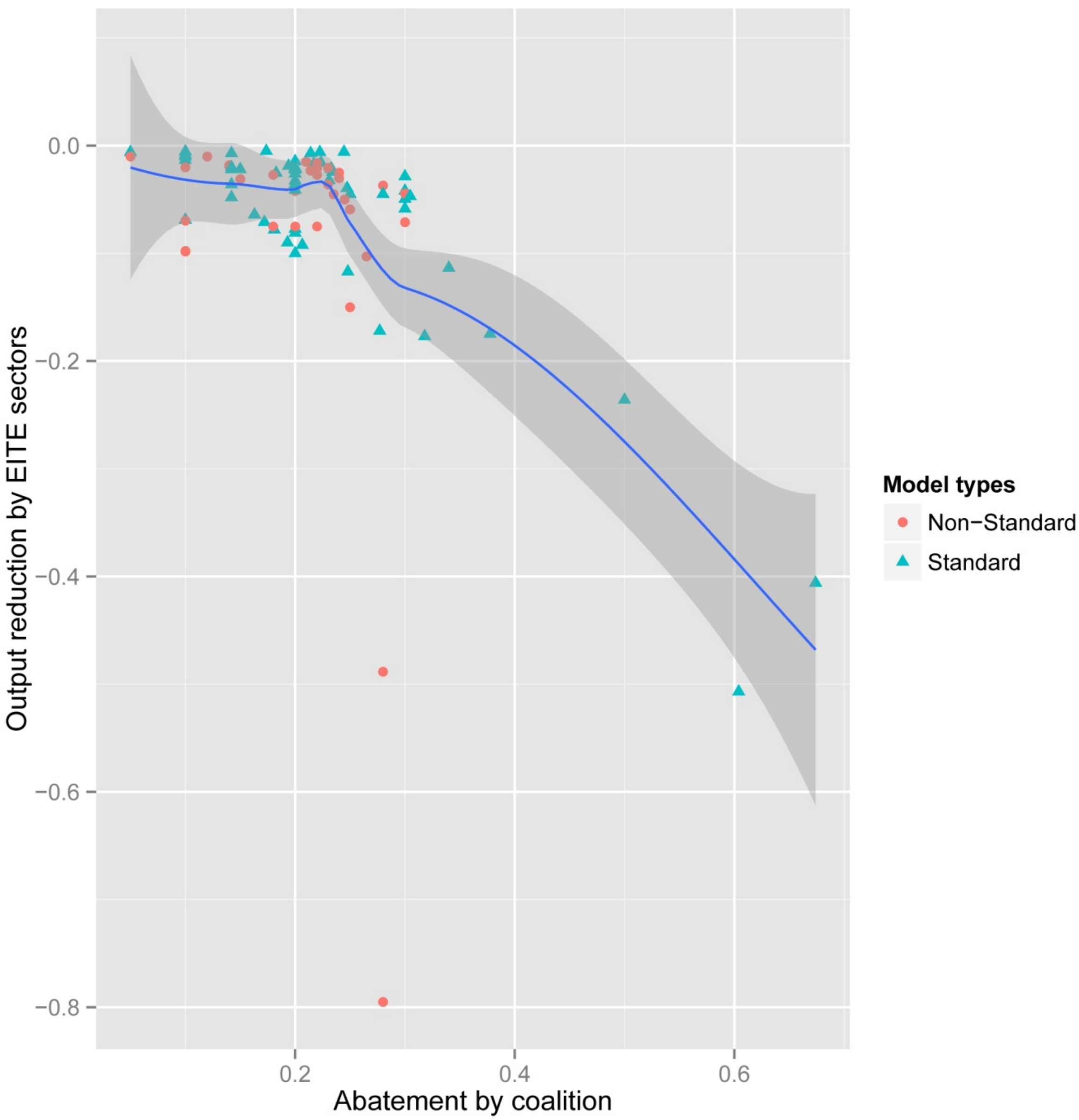

Figure 1: Fractional change in output in EITE sectors from unilateral climate change policy.

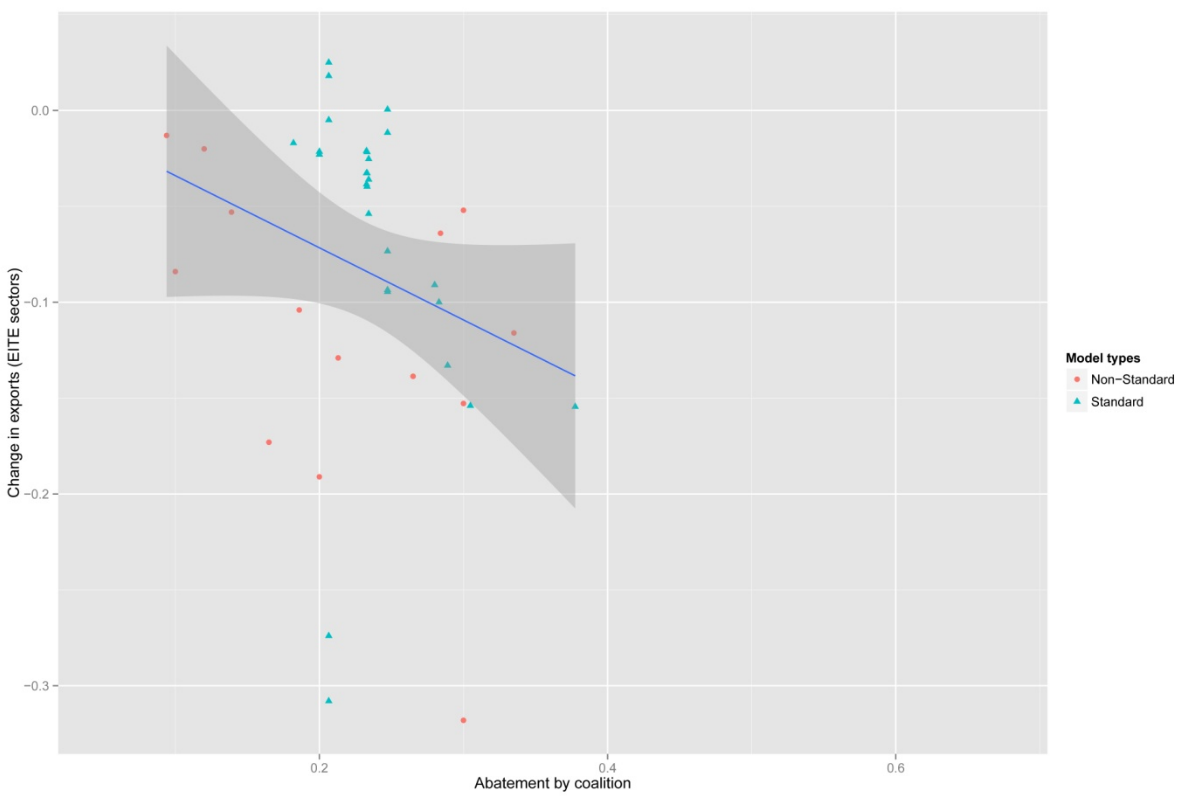

Figure 2: Fractional change in exports in EITE sectors from unilateral climate change policy.

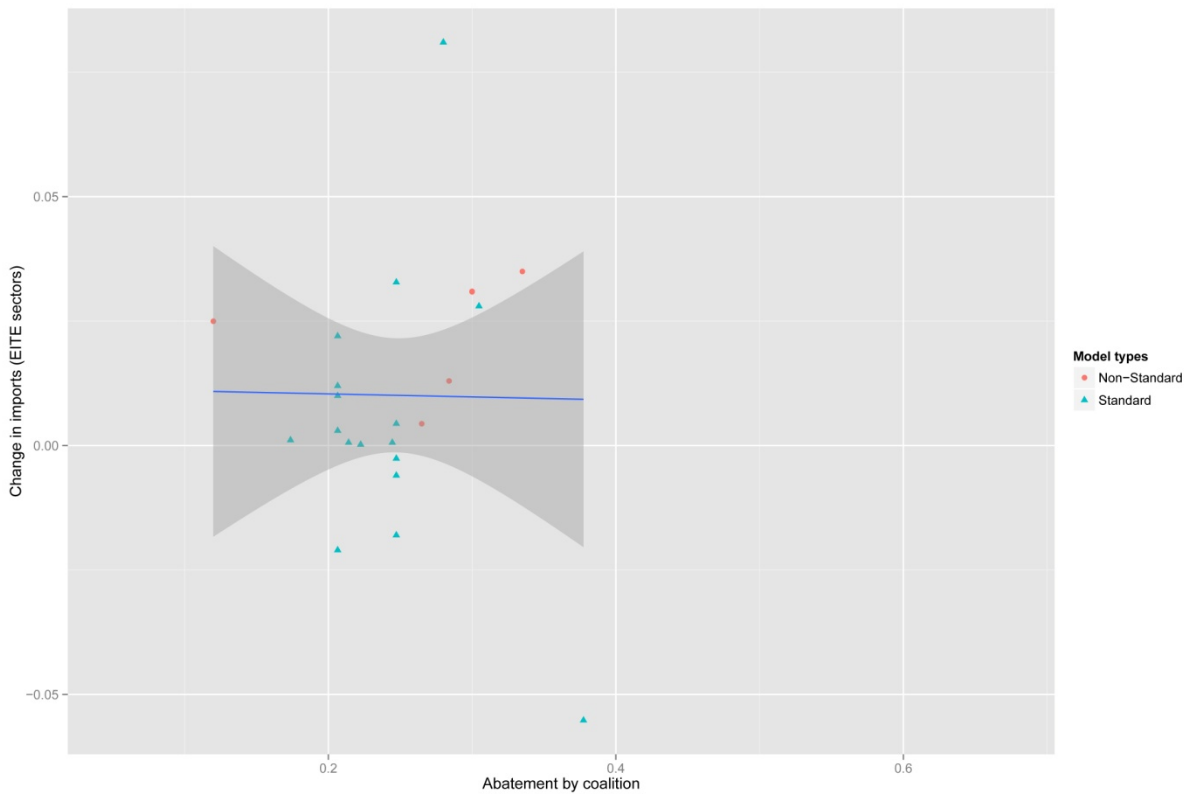

Figure 3: Fractional change in imports in EITE sectors from unilateral climate change policy.

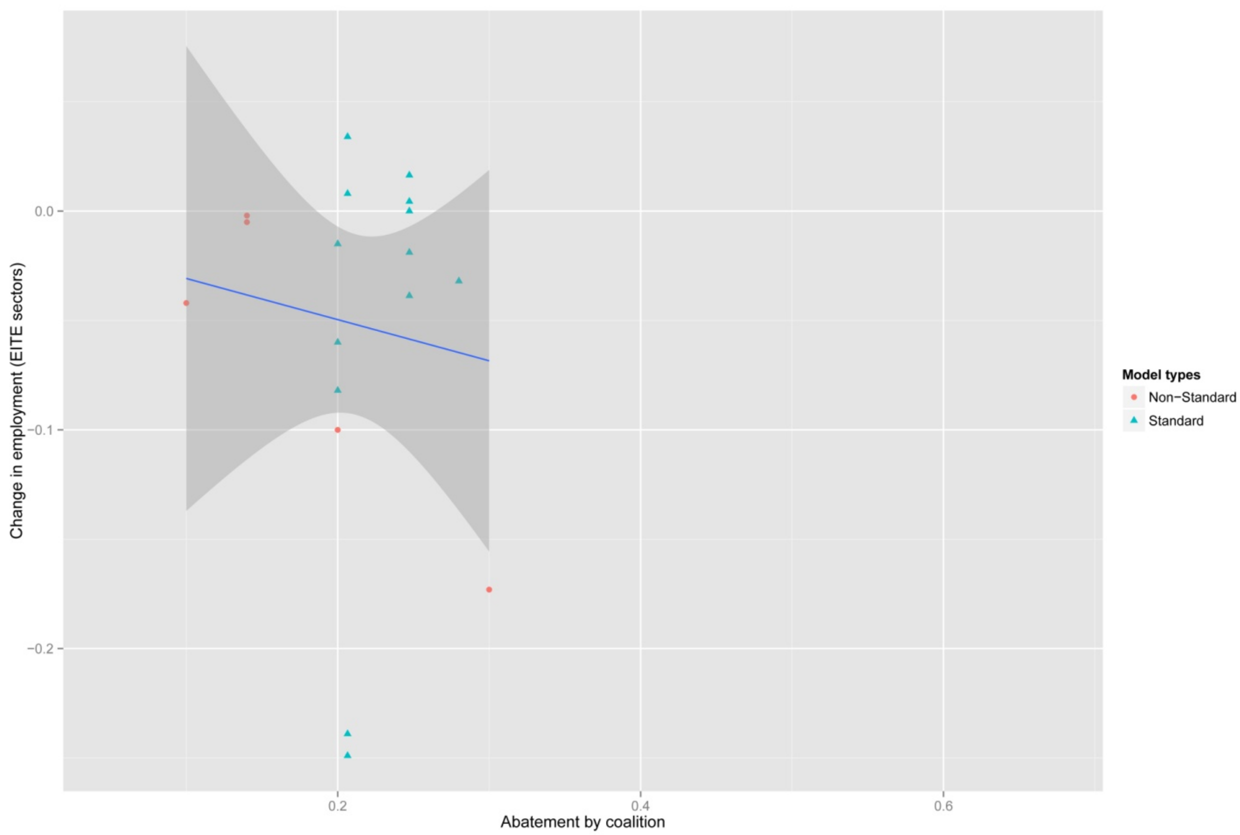

Figure 4: Fractional change in labor employment in EITE sectors from unilateral climate change policy.

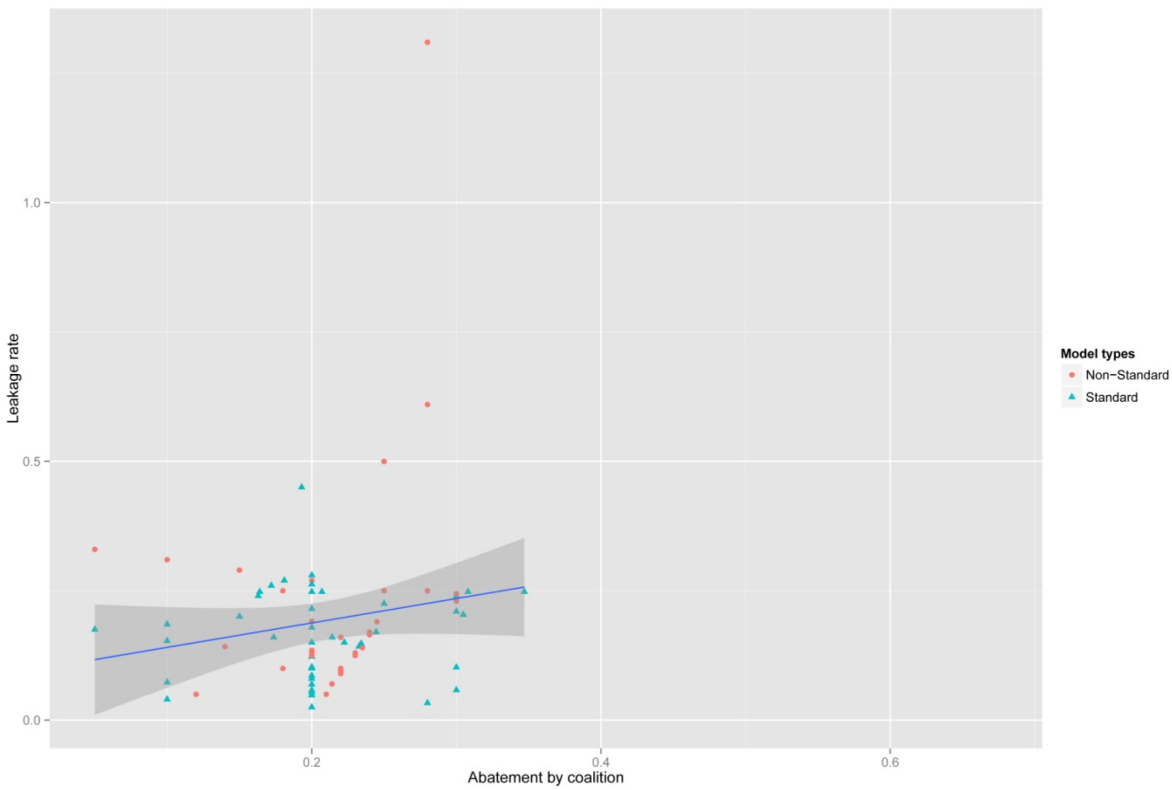

Figure 5: Carbon leakage rate from unilateral climate change policy.

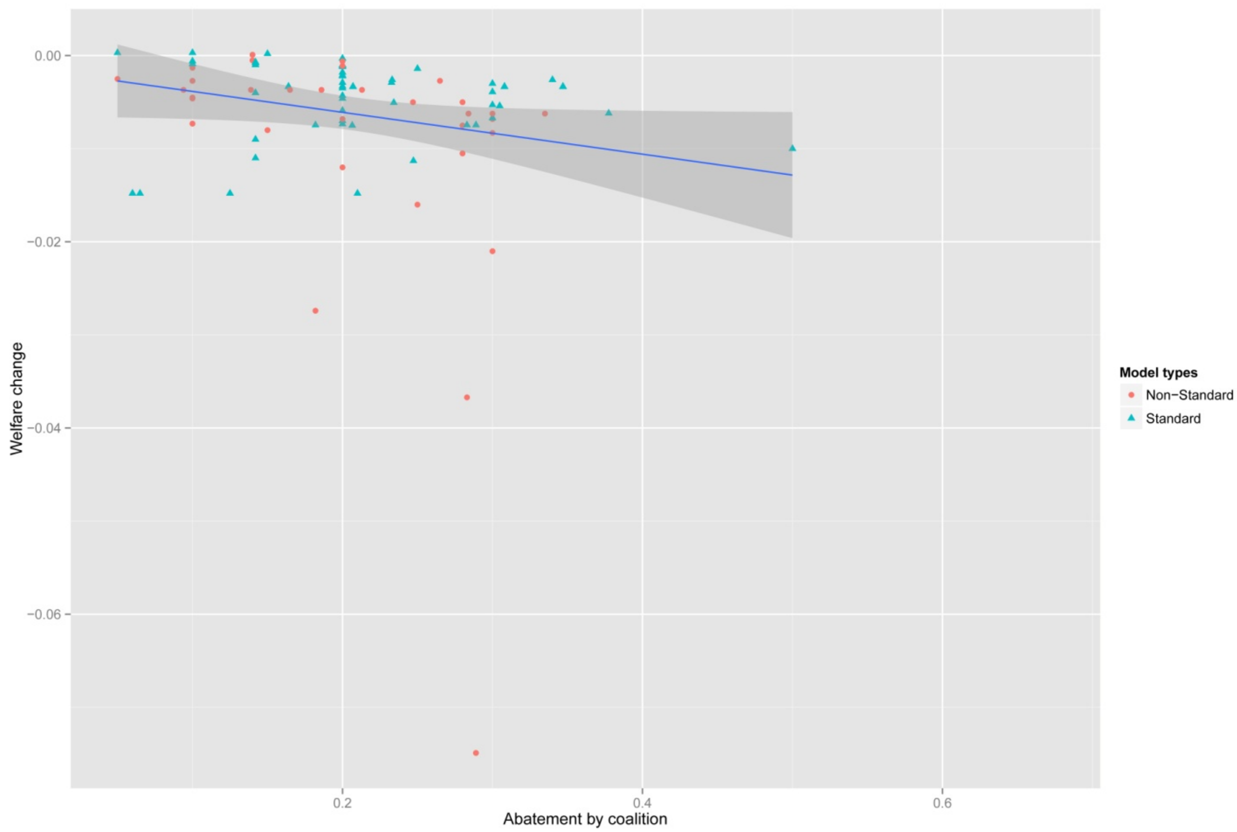

Figure 6: Fractional change in welfare of regional representative agent from unilateral climate change policy.

Indicator	Examples
Exports	Alexeeva-Talebi et al. (2012); Manders and Veenendaal (2008); Jensen and Rasmussen (2000); Takeda et al. (2011); Mattoo et al. (2009); Takeda et al. (2011); Dissou and Eyland (2011); Dong and Walley (2012); Kuik and Hofkes (2010); Dissou et al. (2002); Böhringer and Rutherford (1997); Bruvoll and Faehn (2006); Babiker and Rutherford (2005); Rivers (2010)
Imports	Rivers (2010); Bruvoll and Faehn (2006); Dissou et al. (2002); Manders and Veenendaal (2008); Takeda et al. (2011); Mattoo et al. (2009); Takeda et al. (2011); Dissou and Eyland (2011); Dong and Walley (2012); Kuik and Hofkes (2010)
Employment	Böhringer and Rutherford (1997); Dissou and Eyland (2011); Fischer and Fox (2007); Jensen and Rasmussen (2000); Fischer and Fox (2010); Böhringer and Lange (2005)
Output	Babiker (2005); Babiker and Rutherford (2005); Böhringer et al. (2008); Lin and Li (2012); Alexeeva-Talebi et al. (2012); Peterson and Schleich (2007); Manders and Veenendaal (2008); Böhringer et al. (2010); Böhringer (2002); Dissou (2005); Klepper and Peterson (2004); Böhringer and Lange (2005); Takeda et al. (2011); Babiker et al. (2003); Asafu-Adjaye and Mahadevan (2013); Alexeeva-Talebi et al. (2008,?, 2007); Winchester (2012); Mattoo et al. (2009); Takeda et al. (2011); Böhringer and Rutherford (2010); Dissou and Eyland (2011); Ghosh et al. (2012); Böhringer et al. (2012b); Dong and Walley (2012); Kuik and Hofkes (2010); Dissou et al. (2002); Rivers (2010); Pezzey (1992)

Table 1: Frequently used competitiveness outcome indicators at the sector level. Changes in competitiveness are proxied by changes in the indicators listed.

A Sample Selection Process for Analysis of CGE Literature

Our sample is constructed by searching for articles using Google Scholar. We searched for articles using the following combinations of keywords, combined with "and" and "or" operators: "unilateral", "climate policy", "computable general equilibrium", "competitiveness", "climate change", "leakage", and "border tax". We also increased our sample size by following articles cited by or citing articles that appeared in our initial Google Scholar searches by using the Web of Science. Throughout, our sample focused on the scholarly literature, and did not include literature produced by think-tanks or governments.

Our sample of observations of model experiments is a sub-sample of all model experiments reported in the articles identified above. Specifically, we include only experiments where a subset of countries (a coalition) is adopting a climate policy and other countries are not. The subset sometimes consists of just one country, and sometimes consists of a group of countries, such as the EU, the OECD, or Annex B countries. Our sample is further refined by only including experiments where a "pure" carbon price is adopted, without complementary instruments. For example, we do not include experiments that feature border taxes, export rebates, or output-based allocation of emission permits. We also only include experiments in which revenue raised from the carbon price is returned to the representative household in lump sum. Finally, we only include studies that report output for at least one of the variables in which we are interested. These restrictions significantly reduce the number of observations in our sample, and are designed to ensure that individual experiments are comparable to one another.

In total, our sample includes 54 studies and almost 300 carbon price experiments. While there are surely some studies missed in our sample, we believe that we have not systematically omitted studies from our sample, such that the claims we make should generalize to the broader universe of studies that examine adoption of unilateral climate policy.

Before conducting analysis, we make adjustments to the data to ensure comparability of results. In particular, some studies impose an emission reduction across a coalition of countries, but then report changes in key variables (welfare, EITE output, etc.) for each of the countries in the coalition. Our interest is in the average impact of unilateral emission restrictions across the coalition, and so we produce averages for each of the output variables. Because output changes are typically reported as percent changes, to produce a (weighted) average, we require weights for each country. We obtain weights from GTAP data, and weight data in our sample accordingly. In cases where a study reports changes in EITE output, employment, etc. for each of a number of EITE sectors, we aggregate the results, again using weights from GTAP.

B Regression Analysis of CGE Literature

Table 2 shows the results of an OLS regression of the fractional change in EITE output against the coalition abatement rate (coalitionabatement), the square of the abatement rate (sqindp) and a host of dummy variables capturing different characteristics of the studies in the sample: whether EITE markets were modeled based on some form of imperfect competition (imperfectcomp); whether the model included myopic dynamics (recursive); whether the model included forward-looking dynamics (dynamics); whether the model was based on the Armington description of international trade (armington); whether the model assumed capital mobility across sectors within a region (seckmobile); whether the model assumed capital mobility across regions (regkmobile); and whether the model treated labour markets as imperfectly clearing (labour).

The first two column of the table shows a regression of the EITE output change on the level of carbon abatement in the coalition. The second column repeats the same regression but also includes the dummy variables described above, which characterize each model in the sample. The third and fourth columns are equivalent, but also include the square of the abatement level. In each case, standard errors are clustered at the level of the study to accomodate correlated errors for scenarios produced by the same model.

The results on the abatement variables echo the graphical analysis from Figure 1, indicating that EITE sector output falls with the abatement rate. Additionally, when we consider a quadratic relationship, the coefficients take on the expected signs, suggesting that the rate of change of EITE sector output loss is increasing in the amount of emissions abatement. Among the dummy variables, the use of the Armington assumption in a model appears to have a substantial influence on the predicted change in output. When the Armington assumption is used, models on average predict a drop in output that is significantly smaller. The main alternative to the use of the Armington assumption in our sample of studies is to assume that traded goods are perfectly homogenous. This assumption leaves far more scope for good production to relocate in response to the cost increase caused by the introduction of climate policy.

When capital is assumed to be mobile between sectors, models find a somewhat larger reductions in EITE output associated with a given level of emissions abatement. In contrast, little effect on EITE output can be attributed to the assumption regarding capital mobility between regions. Assuming some form of imperfect competition in these sectors also led to larger reductions in EITE output for a given level of emission reduction. Likewise, the assumption of imperfect labour markets aggravates the output reduction in EITE sectors. In contrast to these results, static, recursive dynamic, and forward-looking dynamic models do not appear to give measurably different output.

Table 3 shows regression results in the same format at Table 2, where the dependent variable is now the fractional change in coalition welfare levels. As suggested by the graphical analysis in Figure 6, the regression results indicate a moderate negative welfare effect of abatement. The results on the dummy variables give some intuition for the different results. Models using the Armington assumption show smaller welfare losses. Once again, the main alternative to the Armington assumption in our model sample is homogeneous trade. Introduction of unilateral emission reductions in the presence of homogenous trade creates a large distortion, so these results are expected. Surprisingly, the coefficient on the imperfect competition dummy is not statistically significant for welfare. Mobility of capital appears to aggravate the welfare losses caused by unilateral introduction of emission reductions, as does the assumption that labour markets do not clear perfectly. Recursive dynamic models appear to be associated with somewhat larger welfare losses than other types of models. Our set of independent variables explains considerably less variation in the data for the welfare effects (R-squared=0.583 in the most parameterized model) than for the EITE output changes (R-squared=0.922).

Table 2: Meta analysis results for outputaveeite

	(1) outputaveeite	(2) outputaveeite	(3) outputaveeite	(4) outputaveeite
coalitionabatement	-0.426***	-0.263***	0.0723	0.385*
	(0.0687)	(0.0294)	(0.0659)	(0.169)
imperfectcomp		-0.0604		-0.0722
		(0.0766)		(0.0773)
recursive		-0.00115		0.00949
		(0.00720)		(0.00906)
dynamic		-0.0281		-0.0185
		(0.0384)		(0.0332)
armington		0.552***		0.552***
		(0.0373)		(0.0346)
regkmobile		0.00185		0.00737
		(0.00595)		(0.00781)
seckmobile		-0.0215**		-0.00923
		(0.00720)		(0.0103)
labour		-0.0229***		-0.0126***
		(0.00582)		(0.00327)
sqindep			-1.167***	-1.466***
			(0.0991)	(0.331)
_cons	0.0343*	-0.516***	-0.0107	-0.589***
	(0.0127)	(0.0392)	(0.00794)	(0.0283)
N	85	85	85	85
R^2	0.121	0.899	0.138	0.922

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Meta analysis results for welfare

	(1) welfareave	(2) welfareave	(3) welfareave	(4) welfareave
coalitionabatement	-0.0226***	-0.0291***	-0.0338**	-0.0608***
	(0.00439)	(0.00390)	(0.0111)	(0.0101)
imperfectcomp		0.00101		0.00139
		(0.00106)		(0.00111)
recursive		-0.00470*		-0.00516*
		(0.00201)		(0.00193)
dynamic		0.00137		0.00139
		(0.00185)		(0.00180)
armington		0.00281***		0.00277**
		(0.000722)		(0.000790)
regkmobile		-0.00198		-0.00228
		(0.00164)		(0.00157)
seckmobile		-0.00427*		-0.00490**
		(0.00157)		(0.00167)
labour		-0.0195***		-0.0196***
		(0.000285)		(0.000326)
sqindep			0.0260	0.0719***
			(0.0195)	(0.0145)
_cons	-0.000931	0.00352	0.0000904	0.00723*
	(0.000808)	(0.00239)	(0.00140)	(0.00311)
N	91	91	91	91
R^2	0.081	0.570	0.083	0.583

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$