



Essays on trade and environment

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ISBN 978-91-7447-805-1

ISSN 1404-3491

Printed in Sweden by Universitetsservice, US-AB, Stockholm 2013

Distributor: Department of Economics, Stockholm University

To Linda and my family

Acknowledgments

"Much learning does not teach understanding."

– Heraclitus, 535 - c. 475 BCE

First and foremost, I would like to thank my supervisor Rikard Forslid as well as Richard Friberg and Henrik Horn for their help through this chapter in my education. You have not only challenged and encouraged me but also provided sharp insights and excellent guidance in a friendly and constructive atmosphere. As I prepare to defend my thesis, I look back on an enriching and rewarding PhD experience. This is due in no small part to the roles you played. A special thank you to Rikard for taking on the role and responsibility of being my advisor. I would also like to thank Karolina Ekholm, not only for being my supervisor during the start of my PhD studies, but also for being my advisor at the Master's level, when my interest in international economic research was first piqued. Moreover, I am thankful for the time you set aside despite your workload and responsibilities at the Central Bank.

To Linda, thank you for everything. I cannot even begin to articulate what it has meant to have you with me through these years. You have put your own career and ambitions on hold so that I could pursue my own. We share many common interests and have shared in many adventures but, I know I have your support when I follow my own interests too. I hope you feel that you can rely on me in the same way I rely on you.

My siblings Colin and Hillary, and my parents Mingy and Bryan, have inspired me in their own very different ways, and for this I am grateful. In retrospect, I can see that each of us has preferred to follow the road not taken. This has helped me stay the course. Thank you for your love and encouragement. I am also grateful to Mingy in particular, for helping us cope with our work-life balance and for becoming such an important figure in Yasmin's life.

Claes, Christina, Maria, and Niclas, I count you as family too. I am very much at home in Sweden and this is due in part to your support. I look back fondly on the many experiences we have shared and I am looking forward to many more. Thank you for everything.

I am deeply appreciative of my colleagues at the Beijer Institute of Ecological Economics for taking me into their research team, for the opportunities they have provided, and for showing their confidence in my research ability. I would also like to thank my colleagues at IVL for their kind support and for granting me leave to follow my PhD

studies. I am also thankful to have been part of the research program ENTWINED, which has provided me with access to an excellent network of researchers who have supported me throughout my PhD and provided me with a number of interesting research ideas.

I am fortunate enough to have embarked on this adventure with excellent study comrades. Thank you Shon Ferguson, Nick Sheard, Daniel Spiro, Anders Åkerman and many others. I feel proud to have shared this experience with you, and even more proud to read your research and hear about your advancing careers.

Whenever I need a diversion from research, I know I can count on “the minds” to plant me firmly on *terra firma*. Thank you for the laughs, great times, and the long conversations about absolutely nothing of substance.

Last but hardly least, I am grateful to Mistra for its support, which was much more than just financial. It is an honor to have been given the chance to research these issues, to pursue a PhD and collaborate with other researchers in Sweden and abroad. Financial support from Jan Wallander’s and Tom Hedelius’ Research Foundation is also gratefully acknowledged.

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Chapter 1

Introduction

The remarkable expansion of international trade has had deep ramifications, not only for where and how we produce, but also for what we consume. Successes in lowering barriers to trade, coupled with technological advances have made countries increasingly interdependent, and contributed significantly to increasing incomes. Indeed, it has become the exception rather than the rule to buy a product produced entirely in one's home country. Nonetheless, there has been a tradition of suspicion between interests, with sharply divergent views on the effects of international trade on the global environment. Trade, it has been suggested, enables footloose firms to seek production locations with weaker regulation, and increased economic activity resulting from trade has in turn spurred the pace of natural-resource depletion. In defense of trade's impact on the environment, it has been pointed out that increasing incomes make stringent environmental standards more affordable. A further effect of international trade is its potential to improve the way we allocate resources. Trade liberalization and environmental protection are held forth as irreconcilable objectives by some, whereas others suggest they are complementary.

While these issues are difficult enough to study on their own, economists have researched the relationship between trade and environment from many other angles. Research has contributed some clarity to this set of nuanced challenges. This context is the point of departure for the work presented in this thesis. The work is comprised of four papers in which diverse aspects of the relationship between international trade and environmental protection are examined.

Border carbon adjustments (BCAs) and strategic climate policy

It is often suggested that countries should use trade measures to reduce carbon emissions abroad. Controversial proposals have been put forward by the USA and the European Union. More proposals are on the horizon and there have been moves to implement such measures. BCA is one such measure. Proponents suggest that such measures would reduce carbon emissions, protect domestic firms from unfair competition, and provide incentives for carbon intensive exporters to clean up their act and sign a multilateral climate agreement. Others maintain that the threat posed by leak-

age is overblown, that BCAs are ineffective at reducing carbon leakage anyway, that these measures will sour trade and climate negotiations and will support protectionist interests.

This paper focuses on an issue, which has been central to the discussion on the potential impact of these measures: can trade measures change the climate policies being pursued by trade partners? In particular, this paper studies how the design of the trade measure affects the incentives of trade partners to pursue more ambitious *unilateral* climate policies. Two trade measures are examined: an import duty of a magnitude determined in part by the difference in emission taxes between importing and exporting jurisdictions (a BCA); a standard import tariff that is not a function of climate policy.

In the paper I show that a BCA has the *potential* to provide the exporter with incentives to adopt a more stringent climate policy, incentives that a tariff does not provide. BCAs (and tariffs) are equally effective in allowing the importer to pursue its climate policy. Hence, the difference between a BCA and a tariff, from the importer's point of view, is the exporter's climate policy response. The paper also demonstrates that the importer can do better by deploying a BCA even when it has deployed its optimal tariff provided the BCA induces the exporter to adopt a more stringent climate policy. The importer's welfare benefit from a BCA, deployed at the optimal tariff, is due to the potential leveraging effect of the BCA on the exporter's emission tax. When policies are chosen sequentially, such that emission taxes are chosen subsequent to the border measure, I show that it is still the exporter's response to the border measure that determines the importer's benefit.

This suggests that while a BCA and a tariff may reduce global emissions by restricting trade, the anticipated emission reductions may be optimistic if the exporter responds by reducing the stringency of its climate policy. Ignoring the exporter's climate policy response may result in an overestimation of the effectiveness of unilateral trade policy in reaching global climate objectives.

Finally, the analysis reconfirms a concern that BCAs and tariffs will support protectionist interests. Even in a setting where information is complete, it is difficult to disentangle protectionist and climate motivations for deploying trade measures as these motivations are largely congruent. There is a discrepancy between the importer's optimal BCA and what would be optimal from a global perspective, even if the BCA induces the adoption of more stringent climate policy. This could make it difficult to establish rules that distinguish measures designed to pursue legitimate climate objectives from those designed to pursue protectionist objectives.

How does the price of electricity affect imports? A study of Swedish manufacturing firms

There is rising concern that the integration of international markets, coupled with asymmetric energy prices across countries, are putting pressure on energy-intensive industries facing competition from abroad. The concern is amplified by the expectation that energy prices will become increasingly asymmetric if ambitious policy commitments

are realized. Increasing energy prices at home, it is argued, will lead to an increase in imports as production is relocated abroad, to areas with lower energy prices. At the same time, there is increasing evidence that importing is driven by more than just cost savings: there are a number of mechanisms that motivate firms to source inputs from abroad. However, relatively few economic studies have focused on importing and there is a dearth of evidence on how firms and their engagement in international markets respond to higher domestic energy prices.

In this paper we examine, both theoretically and empirically, the heterogeneous effects of a domestic energy price increase on the structure of imports at the firm level. The analysis identifies the *magnitude* of the impact of an electricity price increase on the level of imports at the firm level. The paper begins by developing a tractable analytical model of heterogeneous firms that incorporates trade in intermediate inputs. The focus of the study is therefore on trade in intermediate inputs. Trade in final goods is not part of the scope.

The model yields predictions on the extensive and intensive margins of trade. On the extensive margin, the theory predicts that an increase in the domestic price of energy results in less productive firms engaging in the import of intermediate inputs, and that this effect is increasing in the energy intensity of the imports. Likewise, on the intensive margin, the model predicts that an increase in the domestic price of energy will result in a relative increase in the use of imported intermediate inputs, and that this increase is particularly large for energy-intensive imports. In other words, a firm's incentive to source intermediates abroad is greater for products that embody large amounts of energy as a share of their value.

The paper puts forth evidence that both the intensive and extensive margin of imports respond to higher electricity prices. However, the picture is nuanced. The empirical evidence on the extensive margin supports the theory: firms respond to electricity price increases by importing, in particular, more electricity-intensive intermediate inputs from the EU15. However, on the intensive margin, firms increase imports of intermediate inputs but there is no evidence of increased imports of electricity-intensive intermediate inputs.

Trade, Transboundary Pollution and Market Size

An extensive literature explores the mechanisms through which trade can affect the environment. A topical concern is that trade liberalization allows firms to locate production in countries with lower emission standards: the 'pollution haven hypothesis' (PHH). While there is considerable theoretical support and an intuitive appeal for the PHH, it has been hard to identify empirically, and surveys find conflicting results across the literature. Recent studies provide further conflicting evidence.

This paper presents a new set of theoretical reasons that may help reconcile the contradictory empirical results reported in the PHH literature. The analysis juxtaposes relative market size and asymmetric emission tax levels in determining patterns of production and pollution. The theoretical findings suggest that relative market size, ease of abatement and product differentiation may be important variables in empirical

studies examining trade liberalization and transboundary pollution.

The analysis deploys a monopolistic competition trade model with several manufacturing sectors and transboundary emissions generated from the production of manufactured goods with pollution abatement by the firm. To focus on effects related to the monopolistically-competitive framework, it is assumed that countries are identical except for their size. Thus, there is intra-industry trade (within industry trade) with differentiated products, but no role for comparative advantage. In this type of framework, the number of firms increases more rapidly than output as a country becomes larger. The reason for this is that firms concentrate in the larger market to save on transportation costs. This effect has been dubbed the 'home market effect' (HME). At the same time, trade liberalization not only affects the HME but also the PHH. Therefore, the outcome of trade liberalization on global emissions depends on the interplay of the HME and the PHH.

The paper shows how the HME dominates firm location when the size difference between markets is large, in sectors where abatement is easy, and when the degree of differentiation between goods is high. When the HME dominates, trade liberalization will lead firms to concentrate in the larger market. This will decrease global emissions if the larger market has stricter environmental standards. In contrast, the HME is weak when markets are similar in size. Hence it is the PHH that dominates firm location. Trade liberalization then leads firms to concentrate in the country with lower emission taxes, leading to higher global emissions. The analysis suggests that under monopolistic competition and intra-industry trade, trade liberalization between similar countries (of similar size) may increase global emissions, while trade liberalization between dissimilar countries can decrease global emissions if the larger country has a more stringent environmental regulation. Thus relative market size, the level of trade costs, the ease of abatement, and the degree of product differentiation at the sectoral level are relevant variables for empirical studies on trade and pollution.

What's holding it back? A study in organic retail coffee purchases

Many people claim to be willing to buy environmentally-friendly and ethically-labeled products, even if such products are more expensive. Despite these stated intentions the market for environmental and ethically-labeled (EE-labelled) products remains relatively small. Why are market shares of organic and Fairtrade-labeled products not higher, given the stated intentions of consumers? There are several potential explanations. Are EE-labeled products only available in a small fraction of stores, such that it is a lack of access that limits purchases? Or are prices for these products simply too high? Or is the breadth of choice too limited? Or is it the consumers themselves who, consciously or not, exaggerate the extent to which they are willing to buy organic and Fairtrade-labeled products? These questions motivate the present article.

The analysis uses a consumer scan panel of Swedish households' coffee purchases, and stated behavior of these same households, to examine the propensity to buy organic products. Firstly, we relate the stated behavior of a household to the same household's actual shopping choices. We observe the coffee varieties that households buy at the

bar-code level, as well as a number of demographic variables such as area of residence, household income and the number of people in the household. We also observe the age and level of education of the household's primary shopper. The data is sourced from the market research firm GfK. Once a year participating households fill in a questionnaire and answer whether they, to the extent feasible, try to buy organic products when shopping. We find that even households that say they do their utmost to purchase organic products in fact buy mostly conventional coffee. Over the three years examined, the analysis shows that only 22 percent of the coffee purchased was organic for the group that was in total agreement with the statement that 'When I buy groceries I try to the extent feasible to buy organic.'

To systematically investigate coffee choice the analysis combines revealed and stated behavior and apply a discrete-choice, conditional-logit, model of demand. We establish that survey responses have important predictive power for household organic coffee purchases. Furthermore, household willingness to pay is in line with their survey responses. I.e., households that said they try to buy organic products have, as demonstrated through the shopping choices they made in the market, higher choice probabilities for organic labels. Thus, the analysis establishes that stated behavior is indeed informative, but also that even the most keen organic households buy mostly conventional coffee.

While a tendency to verbally profess pro-social behavior is well documented, several other explanations could explain low market shares for EE-labeled products. The demand estimates are used to examine how the choice probabilities of organic coffee would be affected by changes in availability or prices. Three counterfactual scenarios are considered. Firstly, a household might not buy any organic products because these products are simply not available in nearby stores, suggesting lack of access as an explanation for the discrepancy. When there are fixed costs of supplying a particular product, sufficiently many consumers need to share your preferences for that product to be offered. Secondly, for the same reason, there may be a limited overlap of organic labeling with other characteristics that consumers value. A household could very well value organic, but also value a particular brand that is not available as an organic coffee. The value associated with a brand may trump the value associated with organic. Again, with fixed costs of retailing a particular product, sufficient demand for a combination of characteristics is required for the product to be offered. Finally, we examine the effect of lowering prices; a household might sincerely try to buy organic or Fairtrade products but find them too expensive relative to the next-best alternative.

Approximately 11 percent of the coffee purchases of consumers who state that they 'agree' or 'totally agree' to the organic statement are organic. To examine the importance of lack of access *per se* a synthetic counterfactual organic product is introduced and made available in all stores. We equalize the fixed effect for this product to the median fixed effect across all products. The introduction of such a product only marginally increases the share of organic purchases. The results thus indicate that lack of access to organic coffee *per se* is not an important constraint on household purchases. In contrast, when a synthetic brand is introduced where the fixed effect has been set at the 75th percentile at the distribution of fixed effects, we predict a market share among

the stated organic shoppers of some 40 percent. This suggests that a limited overlap between organic and other coffee characteristics is an important constraint facing self-reported organic households. The high price of organic coffee is also an important constraint. We predict that a halving of the organic price premium is associated with a doubling of organic purchases among the self-professed organic households.

Chapter 2

Border carbon adjustments and strategic climate policy

2.1 Introduction

It is often suggested that countries should use trade measures to reduce carbon emissions abroad. Controversial proposals have been put forward by the USA and the European Union. More proposals are on the horizon and there have been moves to implement such measures. Border carbon adjustment (BCA) is one such measure.¹ Proponents suggest that such measures would reduce carbon emissions, protect domestic firms from unfair competition, and provide incentives for carbon intensive exporters to clean up their act and sign a multilateral climate agreement. Others maintain that the threat posed by leakage is overblown, that BCAs are ineffective at reducing carbon leakage anyway, and that these measures will sour trade and climate negotiations and support protectionist interests.

What, then, would be the implications of such measures? There is a very large economic literature focused for the most part on how a trade measure, such as a BCA or an import tariff, could complement a domestic emission tax in order to reduce foreign emissions. In this literature, the exporting countries are often assumed to either have no climate policy in place, or if they have one, that it is unaffected by the import measure. Hence, the focus of this literature is on the response of the exporter's firms to trade policy. The response of the exporter's regulators is ignored. Thus any reduction in emissions on the part of the exporter comes from a change in the composition of the exporter's production, or just simply reduced production if the model is one of partial-equilibrium.

This paper focuses on another issue, that has been central to the discussion on

¹The European Union intended to require non-European airline carriers to buy emission credits for fuel consumed on transcontinental flights to and from Europe as of January 2012, in effect a form of BCA. The legislation was postponed due to international pressure. The Waxman-Markey bill (H.R. 2454, the American Clean Energy and Security Act of 2009) was passed by the US House of Representatives but failed in the Senate, and included a provision for a BCA.

the potential impact of trade measures aimed at reducing foreign carbon emissions: can trade measures change the climate policies being pursued by trade partners? In particular, this paper studies how trade measure design affects the incentives of trade partners to pursue more ambitious *unilateral* climate policies. Two trade measures are examined: an import duty of a magnitude determined in part by the difference in emission taxes between importing and exporting jurisdictions (a BCA); a standard import tariff, that is not a function of climate policy.²

The model I use is a standard one-sector, two-country partial-equilibrium model with climate damages from emissions and where production and consumption of the single good occurs in both countries. Three policies are chosen endogenously: the importer's government chooses a border measure (BCA or tariff) and an emission tax, whereas the exporter's government chooses an emission tax only. To begin, each government chooses its respective policies simultaneously. I also examine a sequential game setting.

I show that a BCA can provide the exporter with incentives to adopt a more stringent climate policy, incentives that a tariff does not provide. The BCA's effect on the exporter's incentives has two components. The first is the change in the exporter's terms-of-trade. This alone induces the exporter to adopt a weaker climate policy and is the only component when the border measure is a tariff. The second component captures potential climate policy benefits, which arise because of the fundamental difference between the tariff and the BCA: the BCA drives a wedge between consumer prices at home and abroad that is a function of the emission taxes, i.e. the magnitude of the BCA is decreasing in the exporter's emission tax. However, these climate policy benefits can induce the exporter to adopt a stronger climate policy only if the exporter's climate policy is weak. This suggests that a necessary condition for the BCA to induce the exporter to adopt a more stringent climate policy is that the exporter cares about climate damages.

When policies are chosen simultaneously, both BCAs (and tariffs) are equally effective in allowing the importer to pursue its climate policy. Hence, the difference between a BCA and a tariff, from the importer's point of view, is the exporter's climate policy response. I also show that the importer can do better by deploying a BCA even when it has deployed its *optimal tariff* provided the BCA induces the exporter to adopt a more stringent climate policy. The importer's welfare benefit from a BCA, deployed at the optimal tariff, is due to the *potential* leveraging effect of the BCA on the exporter's emission tax. When policies are chosen sequentially, such that emission taxes are chosen subsequent to the border measure, I show that it is still the exporter's response to

²A tariff and BCA are not necessarily mutually exclusive. A tariff could very well be structured in a way to accomplish BCA like objectives. For example, the Harmonised System Convention, Art. 3.3 recognizes that from the 6 digit onward, tariff classifications are determined nationally. Therefore, a country could distinguish between goods that are produced in a climate friendly way by adjusting classifications from 6 digits onward, and then applying a lower tariff to these goods. This would be a way of applying tariffs that recognize regulatory efforts undertaken by the exporter. Even so, this does not compromise the analysis undertaken here.

the border measure that determines the importer's benefit.

This suggests that while a BCA and a tariff may reduce global emissions by restricting trade, the anticipated emissions reductions may be optimistic if the exporter responds by reducing the stringency of its climate policy. Moreover, ignoring the exporter's climate-policy response may then result in an overestimation of the effectiveness of unilateral trade policy in reaching global climate objectives.

Finally, I reconfirm a concern that BCAs and tariffs will support protectionist interests. Even in a setting where information is complete, it is difficult to disentangle protectionist and climate motivations for deploying trade measures, as these motivations are largely congruent. There is a discrepancy between the importer's optimal BCA and what would be optimal from a global perspective, even if the BCA induces the adoption of more stringent climate policy. This could make it difficult to establish rules that distinguish measures designed to pursue legitimate climate objectives from those designed to pursue protectionist objectives.

Despite the extensive economic literature on the impact of BCAs there is relatively little economic theory that examines their impact on exporters' and importers' unilateral incentives to regulate the climate. One such paper is Helm et al. (2012). They study a setting where two countries play a sequential policy game, where tariffs are bound by a trade agreement but the BCA is not. The importer deploys a BCA and the exporter can respond by either taxing exports (thereby avoiding the BCA) or retaliating with tariffs of its own. The exporter does not care about climate damages. They find that the equilibrium is one where the BCA is deployed and the exporter collects export tax revenue. Another related study is Tarui et al. (2010). They examine the impact of a tariff in a strategic, partial-equilibrium setting and show that a tariff is a poor instrument in terms of its ability to induce the exporter to adopt a more ambitious climate policy. Unlike these studies, this paper is concerned with the features of the trade measure (BCA or tariff) and the resulting impact on unilateral incentives.

A trade measure that seeks to leverage climate policy and provide an additional incentive for the government of the exporting country to sign on to a multinational climate agreement would be akin to a trade sanction used to punish free-riding and enforce cooperation on the provision of a public good. The use of trade policy in this way has been studied by a number of economists, see Barrett (1997), Ederington (2001a) and Limao (2005), among others.³ More recently, two studies have examined the effect of imposing a tariff, contingent on participation in a climate agreement. Böhringer et al. (2011) use a CGE model where non-coalition countries do not care about climate damages and can respond to the BCA by: implementing climate policy and thereby avoiding the BCA; adopting retaliatory tariffs or by doing nothing. They show that Annex-I countries could use a BCA to motivate China and Russia to adopt a more stringent climate policy but other countries would respond with retaliatory tariffs.

³Interestingly, BCA could be consistent with GATT Article III. Absent the BCA, foreign firms operating in a jurisdiction with weaker climate policy are afforded an unfair advantage over domestic firms. The BCA then could be applied to imports, so that domestic firms are subject to "treatment no less favorable."

Tian and Whalley (2010) examine a similar setting using a CGE model with global warming where a tariff is applied contingent on participation. In contrast to Böhringer et al. (2011), they find that trade would need to be severely restricted to induce large, rapidly-growing developing countries - such as Brazil, Russia, India and China - to join a multilateral climate agreement. Unlike this literature, this paper focuses on the impact of a border measure on climate policy outside of any international agreement. I examine the setting where the border measure is deployed irrespective of the exporter's climate-policy. The question is how the exporter's climate policy choice rule changes in response to the border measure design.

This paper is organized as follows: Section 2.2 sets forth the basic economic environment. Section 2.3 examines the strategic impact of a tariff on unilateral climate policy when a tariff and emission taxes are chosen simultaneously. The innovation in the paper is discussed in Section 2.4, which introduces the BCA policy. Sections 2.5 and 2.6 then examine the strategic impact of a BCA, first in a simultaneous and then in a sequential policy game. Conclusions are presented in Section 2.7.

2.2 The economic environment

Assume a one-sector, two-country partial-equilibrium model where production generates emissions that cause climate damage. The two countries - "home" and "foreign" - denoted $i \in (h, f)$ trade a good. The countries employ three endogenous instruments. Each country chooses a specific domestic emission tax t_i , and the home country has the option of deploying a border measure, which is defined shortly. Production and consumption of the good occurs in both the home and foreign countries, and production generates carbon emissions. Foreign is the natural exporter of the good.

Climate damages in country i are an increasing, convex function of global emissions: $Z_i(e_w)$ where $e_w \equiv e_h + e_f$, and consumer utility is separable in consumption and climate damages.

$$v_i = U(c_i) - Z_i(e_w)$$

The function U denotes the utility derived from the consumption of c_i units of the good.⁴ Consumers maximizing utility set marginal utility equal to price

$$p_i = \frac{dU(c_i)}{dc_i}$$

yielding demand as a function of price; $C(p_i)$, which is decreasing and convex in p_i . In country i , the good y_i is produced by employing a clean factor l_i and generating emissions e_i such that

$$y_i = F_i(l_i, e_i).$$

The revenue from the emission tax in country i is $t_i e_i$. The producer's problem is

$$\max_{l_i, e_i} p_i F_i(l_i, e_i) - w_i l_i - e_i t_i.$$

⁴Throughout the paper upper case denotes a function and lower case denotes a level.

Wages are normalized to unity: $w_i = 1$. The corresponding first-order conditions, under the assumption of competitive supply, are

$$\begin{aligned} p_i \frac{\partial F_i}{\partial l_i} &= 1, \text{ and} \\ p_i \frac{\partial F_i}{\partial e_i} &= t_i, \end{aligned}$$

which yield the respective factor demand functions $L_i(p_i, t_i)$ and $E_i(p_i, t_i)$. The respective supply functions for each country are therefore

$$Y_i(p_i, t_i) \equiv F_i(L_i(p_i, t_i), E_i(p_i, t_i)),$$

which are increasing and concave in p_i and decreasing and linear in t_i . Emissions from home and foreign are

$$e_i = E(p_i, t_i) \equiv \theta Y_i(p_i, t_i).$$

where θ is emission intensity, which is fixed and identical in both countries. Firms do not have the option to reduce their emission tax bill by abating.

2.2.1 Market Equilibrium

Consider a specific charge at the border deployed by home on imports from foreign. For the time being, let the border measure be a standard import tariff, denoted τ . Local consumer prices follow the no-arbitrage condition

$$p_h = p_f + \tau. \tag{2.1}$$

Home's imports and foreign's exports are, respectively,

$$\begin{aligned} M(p_h, t_h) &\equiv C_h(p_h) - Y_h(p_h, t_h) \\ X(p_f, t_f) &\equiv Y_f(p_f, t_f) - C_f(p_f). \end{aligned}$$

Market clearing requires imports of good y in home to be equal to exports of good y from foreign.

$$M(p_h, t_h) = X(p_f, t_f) \tag{2.2}$$

Some asymmetry between home and foreign is necessary in order for foreign to export to home. Assume that home and foreign produce utilize different technologies; this is the standard technology motive for trade.

Consumer demand and producer technology, together with the no-arbitrage condition in Equation (2.1) and the market clearing condition in Equation (2.2), yield equilibrium prices in terms of home's and foreign's emission taxes and the tariff. Equilibrium prices can then be expressed as a function of the policy variables $\hat{P}_i(\tau, t_h, t_f)$, where the *hat* denotes the equilibrium price. As a notational simplification write the equilibrium price as simply \hat{P}_i .

2.2.2 Government objectives

Governments maximize the sum of consumer surplus, producer surplus and government revenue, less damages from greenhouse-gas emissions.⁵ Home and foreign welfare are, respectively,

$$W_h(\tau, t_h, t_f) = CS(\hat{P}_h) + PS_h(\hat{P}_h, t_h) + t_h E_h(\hat{P}_h, t_h) + \tau M(\hat{P}_h, t_h) - Z_h(E_w(\hat{P}_i, t_i))$$

$$W_f(\tau, t_h, t_f) = CS(\hat{P}_f) + PS_f(\hat{P}_f, t_f) + t_f E_f(\hat{P}_f, t_f) - Z_h(E_w(\hat{P}_i, t_i))$$

World welfare is the sum of home and foreign welfare $W_w = W_h + W_f$.

Assumption 2.1. *Own welfare is increasing in the emission tax abroad. Formally, $\frac{\partial W_h}{\partial t_f} > 0$ and $\frac{\partial W_f}{\partial t_h} > 0$.*

Indeed one of the motivations for engaging in climate negotiations is to induce other countries to increase the stringency of climate policy abroad. Each country prefers trade partners to raise their emission tax.

2.2.3 First-best climate and trade policies

Border measures (BCAs and tariffs) are being put forward as a policy to mitigate global climate damages. To illustrate this formally consider the global regulator's problem, which is

$$\max_{\tau, t_i} W_w(\tau, t_i)$$

Solving the resulting three first-order conditions simultaneously yields the solution to the problem expressed implicitly. Second order conditions for a maximum are assumed to be fulfilled.

$$\begin{aligned} t_i^G &= \sum_i \eta_i(\tau, t_h, t_f) \\ \tau^G &= 0 \end{aligned}$$

Thus $\eta_i(\tau, t_h, t_f) \equiv \frac{\partial Z_i(E_w(\hat{P}_i, t_i))}{\partial e_w}$ is the marginal damage from emissions. As a notational simplification write marginal damage as simply η_i . This result is derived in Appendix 2.A.1. The first-best tariff is, as expected, zero when emission taxes in both countries are at the first-best (Pigouvian) level.⁶

⁵Consumer surplus is $CS(\hat{P}_i) = u(c(\hat{P}_i)) - \hat{P}_i \cdot c(\hat{P}_i)$; producer surplus is $PS_i(\hat{P}_i, t_i) = \hat{P}_i \cdot Y_i(\hat{P}_i, t_i) - L_i(\hat{P}_i, t_i) - t_i \cdot E_i(\hat{P}_i, t_i)$.

⁶Symmetric emission taxes at home and foreign is a consequence of the economic set-up where the marginal utility of income is set to be equal to unity in both countries. Relaxing this assumption for one, would change this result, as discussed by Keen and Kotsogiannis (2011) who show that symmetric carbon pricing need not be Pareto efficient.

However, a positive tariff can improve global welfare when emission taxes deviate from the Pigouvian level. The first-order condition on the global regulator's choice of tariff (taking other policies as given) is

$$\frac{\partial W_w}{\partial \tau} = \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} \left(t_h - \sum_i \eta_i \right) + \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial \tau} \left(t_f - \sum_i \eta_i \right) + \tau \frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} = 0.$$

This shows that global welfare *may* increase for a positive τ when emission taxes deviate from the first-best level, i.e. $t_i < t_i^G$. The outcome depends on the relative reduction of home's and foreign's emissions in response to the tariff. This effect is driven by τ 's zero first-order effect on welfare derived from consumption and positive first-order effect through reduced emissions. A small τ is no longer simply a protectionist instrument but can also be used to achieve global climate policy objectives. A tariff's potential to improve global welfare by reducing emissions is highlighted by Gros (2009) and elaborated on by Keen and Kotsogiannis (2011).⁷

The next section examines the *unilateral* incentives facing regulators setting climate policy when home's regulator deploys a tariff.

2.3 Simultaneously chosen tariff and emission taxes

The contribution of the paper is an illustration of the impact of a BCA on emission tax choices. However, it is instructive to first examine the impact of a tariff to provide a benchmark for the BCA results. Suppose home's regulators choose a tariff without considering how the tariff and climate policy interact. This implies that home's regulators do not recognize that a reduction in their tariff could lead to the adoption of a lower emission tax. Trade regulators and climate regulators set their policies independently of each other: tariffs and carbon taxes are set simultaneously. This setting is consistent with the view put forward by many, including the WTO itself, that trade negotiations and climate negotiations should be conducted separately.⁸ Formally, this is modeled as a simultaneous move game where each policy is chosen taking the other policies as given. This section examines Nash policy choices and then examines how home's and foreign's emission taxes respond when home's tariff choice is constrained from the optimal choice.

Foreign's climate policy problem is

$$\max_{t_f} W_f(\tau, t_h, t_f).$$

The corresponding first-order condition is

$$\frac{\partial W_f}{\partial t_f}(\tau, t_h, t_f) = X \frac{\partial \hat{P}_f}{\partial t_f} + (t_f - \eta_f) \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) - \eta_f \frac{\partial E_h}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} = 0. \quad (2.3)$$

⁷This observation is much older however, and relates to the theory of distortions literature, see for example Kemp and Nagishi (1969).

⁸Pascal Lamy's speech at the Informal Trade Ministers' Dialogue on climate change — Bali, Indonesia in 2007 made this point in more subtle terms. In the academic literature Bhagwati (2002) makes the point that trade and trade alone should be dealt with at the WTO.

The derivations are provided in Appendix 2.A.2. The first term captures the change in foreign's terms-of-trade. An increase in foreign's emission tax changes the relative price of domestic goods to home's goods. The term enters positively, since $\frac{\partial \hat{P}_f}{\partial t_f} > 0$.⁹ Foreign is able to use its climate policy to sell its goods to home's consumers at a higher price.

The second term is the change in 'net domestic climate damages' from own emissions. This refers to the effectiveness with which foreign's emission tax targets the climate externality. The term is a function of the difference between the marginal damage from domestic emissions and the revenue generated by the emission tax. A definition from Barrett (1994) is useful here.

Definition 2.1. “Weak” (“strong”) unilateral climate policy is one where the emission tax is set below (above) the marginal damage from emissions; $t_i < \eta_i$ ($t_i > \eta_i$).

The third and final term captures the response of emissions abroad to t_f (foreign's leakage term). In this setting, leakage occurs via the indirect effect of the emission tax on consumer prices abroad. The term in Condition (2.3) is therefore *marginal leakage*, which is the type of leakage that will be discussed henceforth.¹⁰

A further observation from Equation 2.3 is that in an autarky, foreign's Nash emission tax choice rule is $t_f^{\text{autarky}} = \eta_f < t_f^G$. Climate damages in the other country are not considered and the unilateral emission tax is therefore inefficiently low. This is a special case of the Samuelson rule, see Samuelson (1954). Trade distorts foreign's emission tax choice such that it lies above or below marginal climate damages.

Now turn to home's optimal choice of t_h and τ , for a given t_f . Home's problem is

$$\max_{\tau, t_h} W_h(\tau, t_h, t_f)$$

and the corresponding first-order conditions are

$$\begin{aligned} \frac{\partial W_h}{\partial t_h}(\tau, t_h, t_f) = & -M \frac{\partial \hat{P}_f}{\partial t_h} + \tau \left(\frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} \right) \\ & + (t_h - \eta_h) \left(\frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right) - \eta_h \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_h} = 0 \end{aligned} \quad (2.4)$$

$$\frac{\partial W_h}{\partial \tau}(\tau, t_h, t_f) = -M \frac{\partial \hat{P}_f}{\partial \tau} + \tau \frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} + (t_h - \eta_h) \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} - \eta_h \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial \tau} = 0. \quad (2.5)$$

The steps to the derivation are described in Appendix 2.A.2. The terms in both conditions capture the incentives facing regulators choosing climate and trade policy.

⁹See Appendix 2.A.3 for the derivation of how prices change with policy.

¹⁰Another way leakage is calculated is to take the ratio of the increase in emissions abroad and the decrease in domestic emissions resulting from a given change in the domestic emission tax. This is referred to by some as *average leakage*.

The first term of Equation (2.4) captures the change in home's terms-of-trade. The term enters negatively, since $\frac{\partial \hat{P}_f}{\partial t_h} > 0$. The second term captures the increase in tariff revenue generated by an increase in the level of imports as the emission tax increases. The term enters positively. The third term captures the change in net climate damages from home emissions. An increase in t_h results in a change in emissions. The impact of this term depends on the strength of home's emission tax. The final term captures the response of emissions abroad to t_h (home's leakage term). The terms for the condition on $\frac{\partial W_h}{\partial \tau}$ are analogous.

Solving Equations (2.3), (2.4) and (2.5) simultaneously yields the Nash policy choices $\{\tau^n, t_h^n, t_f^n\}$. These can be expressed implicitly as

$$\begin{aligned}\tau^n(\cdot) &= \frac{1}{\frac{\partial X}{\partial p_f}} X + \eta_h \theta \frac{\frac{\partial Y_f}{\partial p_f}}{\frac{\partial X}{\partial p_f}} \\ t_h^n(\cdot) &= \eta_h \\ t_f^n(\cdot) &= \eta_f + \frac{\Theta_{f,\tau}}{\left(\frac{\partial E_f}{\partial p_f} \frac{\partial \bar{p}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right)}\end{aligned}\tag{2.6}$$

where

$$\Theta_{f,\tau} \equiv \frac{1}{\Omega} \frac{\partial Y_f}{\partial t_f} (M - \eta_f \theta \frac{\partial Y_h}{\partial p_h}) \geq 0$$

is obtained using the derivations provided in Appendix 2.A.3. Home's Nash tariff $\tau^n(\cdot)$ is the sum of two terms. The first is the inverse of the elasticity of foreign's export supply function, which is a standard result in the literature (see for example Graafland (1949)). In the absence of any climate damages, this is the only term that would determine the choice of the optimal tariff. A standard result in the optimal tariff literature is that the optimal tariff is zero if the export supply elasticity is large. The zero optimal tariff hinges on home not having any market power in trade.

The second term of $\tau^n(\cdot)$ captures the benefit of reducing emissions in foreign resulting from a restriction in trade. In contrast to the first term, the second term is not necessarily zero when the export supply elasticity is large, because $\frac{\partial Y_f}{\partial p_f}$ enters.

Home's optimal emission tax is set to equal marginal damage when it can set its border instrument $\tau^n(\cdot)$ without constraint. Home uses the emission tax to target the climate externality and the border measure to target the terms-of-trade externality: this is a finding reported by Markusen (1975) and discussed in a similar setting by Ederington (2001b) and Copeland and Taylor (2004).

Foreign's optimal emission policy, on the other hand, may be set above or below marginal damage; the outcome depends on the sign of the parameter $\Theta_{f,\tau}$, which depends in turn on the characteristics of the sector.

2.4 A BCA policy

So far I have reiterated results that are discussed in the literature on the interaction of trade policy and environmental policy. My focus shifts now to the contribution of my

paper: the impact of a BCA on emission tax choices.

A BCA is defined here as a specific duty on imports that is a function of the difference in trade partners' emission taxes. This formalization embodies some of the key features of proposals being discussed by policymakers. In contrast, the tariff analyzed in the previous sections is a charge at the border that is not a function of domestic climate policy. Formally, the BCA is defined as a duty levied on imports of the magnitude

$$B(\beta, t_h, t_f) \equiv \beta(t_h - t_f)\theta_M.$$

$\beta > 0$ is the degree of adjustment, chosen by home's regulators. $\beta = 1$ means the BCA provides full adjustment for a difference in emission taxes. The emission tax is charged per unit of carbon embodied in the imported good. This means that the difference in the emission taxes should be applied to $\theta_M M$, the emissions embodied in imports. Emission taxes are chosen endogenously, which means that for a positive B the asymmetry between the countries must be such that the emission taxes are chosen with $t_h > t_f$.

A practical issue confronting the designers of BCA policy is what emission intensity (θ_M) to apply in calculating the level of the adjustment. It is a non-trivial task to calculate the emissions embodied in imports. Accurately estimating the embodied carbon of exports would require knowing the embodied emissions of the inputs used in production. However, assumptions could be used to help reduce this complexity. For example it could be simpler to use some average emission intensity for a sector abroad or the emission intensity of a sector at home. However, the benchmarking method chosen has been shown to have important economic effects.¹¹ For the purpose of this study, θ_M will be treated as a parameter. This means that θ_M may or may not accurately reflect actual emission intensity.¹²

A feature of the BCA specified here is that it explicitly recognizes foreign's and home's climate policy efforts. I.e., the level of the BCA is decreasing in t_f . Implementing this could prove complex, partly because there are many measures that can be pursued to reach climate objectives (for example subsidies, research and development, and technology standards). Comparing climate policies between countries could be difficult. However, I abstract from this problem by requiring both home and foreign to regulate climate with an emission tax. Thus, climate policy efforts undertaken by each country are directly comparable.

Actual and proposed BCA policies adopt modified or somewhat simplified designs. For example, the Waxman-Markey bill (H.R. 2454, the American Clean Energy and Security Act of 2009) was passed by the US House of Representatives but failed in the Senate. The bill would have required specified importers to purchase US allowances after 2020, to cover emissions embodied in imports.¹³ Imports from some countries would have been exempt from border measures including, but not limited to, those

¹¹See Mattoo et al. (2009), and Keen and Kotsogiannis (2011) for example

¹²Emission intensity is identical in both home and foreign. If it were not, the BCA rule might be $\beta(t_h\theta_h - t_f\theta_M)$.

¹³These would include firms in energy intensive trade exposed sectors as defined in the bill. Also, the

meeting standards of adequate effort.¹⁴ The emission intensity of imports would be based on a benchmark derived using the national average carbon intensity for the exporting industry. The exact modalities for deriving the benchmark are not specific in the proposal.¹⁵ The features of this policy suggest a binary recognition of foreign climate efforts where the level of the adjustment applied to imports follows

$$\hat{B}(t_f) = \begin{cases} t_h G(\theta_f), & \text{no exemption} \\ 0, & \text{otherwise} \end{cases}$$

where $G(\theta_f)$ is a function describing the benchmarking methodology, which in turn is a function of θ_f , the emission intensity of production abroad.

2.5 Simultaneously chosen BCA and emission taxes

This Section contrasts a carbon tariff (examined in Section 2.3) and a BCA with respect to the implications for climate policy choices in a simultaneous setting. Home's trade regulators choose the BCA at the same time as home's and foreign's regulators choose t_i . This means the impact of trade policy on emission taxes is not considered. This analysis is therefore analogous to Section 2.3, the only difference being that home's choice variable is β , rather than τ .

As with the tariff, the simultaneous game implies that the BCA rule is common knowledge when the game is played. Market equilibrium is resolved after the policies are chosen. Local consumer prices follow the no-arbitrage condition

$$P_h = P_f + B. \quad (2.7)$$

A fundamental distinction between the tariff and the BCA follows immediately from this condition. The BCA drives a wedge between home and foreign consumer prices that is a function of the emission taxes. This has immediate implications for how a change in an emission tax affects price levels. For example,

$$\frac{\partial P_h}{\partial t_i} = \frac{\partial P_f}{\partial t_i} + \frac{\partial B}{\partial t_i},$$

and

$$\frac{\partial B}{\partial t_h} = \beta \theta_M > 0, \quad \frac{\partial B}{\partial t_f} = -\beta \theta_M < 0$$

Thus a BCA introduces additional terms in home's and foreign's response functions over the tariff.

quantity of allowances purchased by foreign firms would be adjusted for any free allowances received by US firms.

¹⁴Adequate effort would require: the country is party to an international agreement with emission reduction targets at least as stringent as the United States; or party to multi- or bilateral agreements with the United States for that sector; or having lower energy or GHG intensity than the comparable American sector.

¹⁵For a more thorough discussion of the Waxman-Markey bill see Fischer and Fox (2011).

The economic set-up under the BCA is the same as the set-up under the tariff. However, some adjustments to the notation are required. The outcome of the market stage of the BCA game yields equilibrium prices that are now a function of β and home's and foreign's emission taxes. Denote this equilibrium price with a *tilde*, such that $\tilde{P}_i(\beta, t_h, t_f)$. Home's and foreign's welfare functions are also analogous. However, instead of the tariff, the border measure is B .

Foreign's and home's policy problems are, respectively

$$\max_{t_f} W_f(\beta, t_h, t_f)$$

$$\max_{\beta, t_h} W_h(\beta, t_h, t_f).$$

The associated first-order conditions are

$$\frac{\partial W_f}{\partial t_f}(\beta, t_h, t_f) = X \frac{\partial \tilde{P}_f}{\partial t_f} + (t_f - \eta_f) \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \tilde{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) - \eta_f \frac{\partial E_h}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_f} = 0, \quad (2.8)$$

$$\begin{aligned} \frac{\partial W_h}{\partial t_h}(\beta, t_h, t_f) &= -M \frac{\partial \tilde{P}_f}{\partial t_h} + B \left(\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} \right) \\ &+ (t_h - \eta_h) \left(\frac{\partial E_h}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right) - \eta_h \frac{\partial E_f}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} = 0, \end{aligned} \quad (2.9)$$

$$\begin{aligned} \frac{\partial W_h}{\partial \beta}(\beta, t_h, t_f) &= -M \frac{\partial \tilde{P}_f}{\partial \beta} + B \frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial \beta} + (t_h - \eta_h) \frac{\partial E_h}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial \beta} \\ &- \eta_h \frac{\partial E_f}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial \beta} = 0. \end{aligned} \quad (2.10)$$

The solution to these three first-order conditions is denoted $\{\beta^b, t_h^b, t_f^b\}$. The equilibrium charge at the border is $b^b \equiv \beta^b (t_h^b - t_f^b) \theta_M$. The policy choices, expressed implicitly are

$$\begin{aligned} b^b(\cdot) &= \frac{1}{\frac{\partial X}{\partial \tilde{p}_f}} X + \eta_h \theta_f \frac{\frac{\partial Y_f}{\partial \tilde{p}_f}}{\frac{\partial X}{\partial \tilde{p}_f}} \\ t_h^b(\cdot) &= \eta_h \\ t_f^b(\cdot) &= \eta_f + \frac{\Theta_{f,B} + \Theta_{f,L}}{\left(\frac{\partial E_f}{\partial p_f} \frac{\partial \tilde{p}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right)} \end{aligned}$$

where

$$\Theta_{f,B} \equiv \frac{1}{\Omega} \frac{\partial Y_f}{\partial t_f} \left(M - \eta_f \theta_h \frac{\partial Y_h}{\partial p_h} \right) \leq 0$$

$$\Theta_{f,L} \equiv \beta^b \theta_M \frac{1}{\Omega} \left(M \frac{\partial M}{\partial p_h} - \eta_f \theta_h \frac{\partial Y_h}{\partial p_h} \frac{\partial X}{\partial p_f} \right) > 0$$

are obtained using the derivations in Appendix 2.A.3.

The structure of home's optimal policy pair (b^b, t_h^b) can be compared with (τ^n, t_h^n) , described in Equation (2.6). When home can set both instruments without constraint it uses the emission tax to target domestic emissions (home chooses t_h^b in accordance with the Samuelson rule), and the BCA is set to target the trade distortion and emissions abroad. The structure of b^b includes two terms that are entirely analogous to the terms describing τ^n : the inverse elasticity of export supply $X \frac{1}{\frac{\partial X}{\partial p_f}}$, which is the standard motivation for a tariff, and a term that captures the benefit of reducing foreign's emissions resulting from a trade restriction. This means that for a given t_f , home's optimal policy pair is the same under a BCA or a tariff.

However, foreign's emission tax choice is different under a BCA: $t_f^b(\cdot)$ includes an additional effect captured by the parameter $\Theta_{f,L}$, which is strictly positive. The term enters here because of the BCAs dependence on t_f and it suggests that the BCA has the *potential* to induce foreign to increase t_f (note that $\Theta_{f,B}$ and $\Theta_{f,\tau}$ from Equation (2.6) both include the same terms).

To investigate foreign's response to the BCA further, consider how foreign's emission tax choice responds to β , holding t_h constant. Treat β as an exogenous variable for the moment and differentiate Equation 2.8 with respect to β and evaluate the resulting expression at t_f^n . Formally,

$$\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}(\beta, t_h, t_f^n).$$

The resulting expression is quite involved. However, imposing linearity yields a more tractable expression.

Assumption 2.2. *Consumers have quadratic utility from consumption, and climate damages enter linearly*

$$v_i = c - \frac{c^2}{4} - \eta_i e_w.$$

Demand is therefore $C_i(p_i) = 2(1 - p_i)$. Production of good y_i is undertaken with a Leontief production technology where production requires fixed inputs of labor l_i and emissions e_i . Firms have no option to abate their carbon emissions. Wages in home and foreign are normalized to one. The production function for the y sector is

$$Y_i = F(e_i, l_i) = \min \left\{ \sqrt{2a_i l_i}, \frac{e_i}{\theta_i} \right\}$$

where θ_i and a_i denote emission intensity and productivity, respectively. The corresponding marginal cost and supply functions, determined under the assumption of competitive supply, are $MC(y_i, t_i) = \frac{y_i}{a_i} + \theta_i t_i$ and $Y_i(p_i, t_i) = a_i(p_i - \theta_i t_i)$ respectively.

I will refrain for the moment from plugging in the explicit functional forms to keep the derivations tractable.¹⁶ Applying this assumption yields

$$\begin{aligned} \frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}(\beta, t_h, t_f^n) &= \frac{\partial X}{\partial p_f} \frac{\partial \tilde{P}_f}{\partial \beta} \frac{\partial \tilde{P}_f}{\partial t_f} \\ &+ \Theta_{F,\beta} \left[(t_f^b - \eta_f) \frac{\partial C_h}{\partial p_h} - \left(t_f^b - \frac{(\theta_h + \theta_f)}{\theta_f} \eta_f \right) \frac{\partial Y_h}{\partial p_h} \right] \end{aligned} \quad (2.11)$$

where

$$\Theta_{F,\beta} \equiv \frac{\theta_f \frac{\partial Y_f}{\partial t_f}}{\beta \theta_M \frac{\partial M}{\partial p_h} + \frac{\partial Y_f}{\partial t_f}} > 0.$$

The derivation of this condition is provided in Appendix 2.A.2. The generalized response function, derived without imposing Assumption 2.2, is provided in Appendix 2.A.4.

Equation 2.11 captures how foreign regulators would adjust their Nash emission tax in response to a change in β . The first term of the expression captures the commercial component of foreign's incentives. This term is strictly negative and captures the change in foreign's terms-of-trade as t_f and β change. If home's border measure were a tariff, as opposed to a BCA, this term would be the only term in the condition and it would enter negatively: increasing the level of a tariff, for a given t_h , does *not* induce foreign to increase the level of its emission tax. This term is small if foreign's export supply is much more elastic than home's import demand.¹⁷

A further effect of a BCA over a tariff on foreign's emission tax choice is captured by the term in square brackets, which is strictly positive when foreign's Nash emission policy is weak.¹⁸ Equation 2.11 shows that a necessary condition for the extra BCA term to strengthen the strategic complementarity of t_f and β is that t_f^b is weak.

Proposition 2.1. *Under the assumption of linear supply, demand and climate damage functions, a BCA will induce foreign to adopt a higher emission tax provided t_f^b is weak and $\frac{\partial X}{\partial p_f} \gg \frac{\partial M}{\partial p_h}$.*

Proof. The result follows directly from Equation 2.11 and Appendix 2.A.3. \square

¹⁶Section 2.6.1 provides a numerical example using these functional forms.

¹⁷This follows directly from the price changes derived in Appendix 2.A.3.

¹⁸To see this recall that $\frac{\partial C_h}{\partial p_h} < 0$ and $\frac{\partial Y_h}{\partial p_h} > 0$. If $t_f^b < \eta_f$ then

$$\left((t_f^b - \eta_f) \frac{\partial C_h}{\partial p_h} - \left(t_f^b - \frac{(\theta_h + \theta_f)}{\theta_f} \eta_f \right) \frac{\partial Y_h}{\partial p_h} \right) > 0.$$

The equilibrium policy choices under a BCA suggest that the difference between the BCA and the tariff hinge on foreign's emission tax response. How, then, would home's emission tax choice differ if β is constrained to be below β^b (because of a trade agreement, for example). A first point is that under a constrained β , home would prefer a weak emission tax. To illustrate this, set $\beta = 0$ in the first-order Condition (2.9) to obtain

$$\frac{\partial W_h}{\partial t_h}(0, t_h, t_f) = \underbrace{-M \frac{\partial \tilde{p}_f}{\partial t_h}}_{\text{positive}} + (t_h - \eta_h) \underbrace{\left(\frac{\partial E_h}{\partial p_h} \frac{\partial p_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right)}_{\text{negative}} - \underbrace{\eta_h \frac{\partial E_f}{\partial p_f} \frac{\partial p_f}{\partial t_h}}_{\text{positive}} = 0.$$

The first and third terms - the distortion to home's terms-of-trade and home's leakage term, respectively - enter positively (see Appendix 2.A.3). The sign of the condition depends on the strength of home's climate policy. The only way the first-order condition can be fulfilled for an interior solution is if home's emission tax policy is weak. This result also holds if home's border measure is a tariff.

Lemma 2.1. *In the absence of a BCA or a tariff in a simultaneous game, home's Nash emission tax policy is weak.*

This reflects a general result. When multiple policy instruments are available to governments, a constraint on a subset of policies can be mitigated as governments substitute towards unconstrained instruments. Dixit (1985), Copeland (1990) and Bagwell and Staiger (2001), among others, examine the issue. If β (or τ) is constrained then home has an incentive to use its emission tax to subsidize its producers and would prefer to adopt a weak climate policy. The protection afforded by the border measure is substituted by an adjustment to the unconstrained policy, which in this example is a relaxing of climate policy.

Home emission tax choice increases as β increases from zero. To illustrate this, treat β as an exogenous variable for the moment and differentiate Condition (2.9) with respect to β and evaluate at t_h^n . Formally,

$$\frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h}(\beta, t_h^n, t_f).$$

Again, this expression is quite involved. However, imposing linearity (as per Assumption 2.2) yields

$$\begin{aligned} \frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h}(\beta, t_h^n, t_f) = & -\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial \beta} \frac{\partial \tilde{P}_f}{\partial t_h} + \frac{\partial B}{\partial \beta} \left(\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} \right) \\ & + (t_h^n - \eta_h) \theta_M \frac{\partial C_h}{\partial p_h} \Theta_{H,\beta} \end{aligned} \quad (2.12)$$

where

$$\Theta_{H,\beta} \equiv \frac{\theta_h \frac{\partial Y_h}{\partial t_h}}{\frac{\partial Y_h}{\partial t_h} - \beta \theta_M \frac{\partial M}{\partial p_h}}.$$

The derivation of this condition is discussed in Appendix 2.A.2. The generalized response function, derived without imposing Assumption 2.2, is provided in Appendix 2.A.4.

The first two terms in this equation capture commercial and government revenue effects from an increase in both β and t_h . The first term captures the commercial gain from the restriction of trade. The second term captures the increase in border revenue generated by the increase in imports as home's emission tax is increased. These two terms would be the only terms if home's border measure were a tariff rather than a BCA. Moreover, under the tariff these terms would enter positively.

A further effect of the BCA over a tariff is captured by the third term. An increase in t_h increases the level of the BCA. This in turn increases home's consumer price, which results in a reduction in home demand and a reduction in domestic emissions.

Under an optimal BCA, or tariff, home's emission tax choice rule is the same. I.e., $t_h^b = t_h^n = \eta_h$. However, foreign's emission tax choice under a BCA is different than it would be under a tariff - moreover the BCA may induce foreign to choose a higher t_f . There are two components to foreign's incentives. One is commercial, which provides foreign with an incentive to decrease its emission tax in β . The second component is related to climate damages. Both can work towards inducing foreign to adopt a weaker climate policy, or they can work against each other. The latter effect dominates, provided foreign has little influence on price and has a weak climate policy.

2.5.1 A BCA deployed with a Nash tariff

Can home improve its welfare if it deploys a BCA when it can also deploy a unilaterally optimal tariff? I will argue, yes. The additional benefit of the BCA over the optimal tariff stems from the BCA affecting foreign's climate policy incentives in a way the tariff cannot. Suppose home deploys a charge at the border that is the sum of a tariff and a BCA: $T \equiv \tau + B$. The no-arbitrage condition is therefore

$$p_h = p_f + T.$$

Equilibrium market prices are denoted by $\bar{P}_i(\tau, \beta, t_h, t_f)$. The problems facing home and foreign's policy makers are therefore

$$\max_{\beta, \tau, t_h} W_h(T(\tau, \beta, t_h, t_f), t_f, t_h) \quad (2.13)$$

$$\max_{t_f} W_f(T(\tau, \beta, t_h, t_f), t_f, t_h). \quad (2.14)$$

Home's and foreign's policies are chosen simultaneously. Clearly, if home is constrained from deploying a BCA, i.e. $\beta = 0$, then the equilibrium is in fact the Nash policy choices $\{\tau^n, t_h^n, t_f^n\}$, identical to those characterized in Equation (2.6). This economic environment yields the following Proposition and Corollary:

Proposition 2.2. *With linear demand, supply and climate-damage functions, a BCA deployed at $\{\tau^n, t_h^n, t_f^n\}$ will induce foreign to adopt a higher emission tax provided t_f^b is weak and $\frac{\partial X}{\partial p_f} \gg \frac{\partial M}{\partial p_h}$.*

Proof. The proof is provided in Appendix 2.A.5. \square

Corollary 2.1. *With linear demand, supply and climate damage functions, if home deploys a small BCA at $\{\tau^n, t_h^n, t_f^n\}$ then home will decrease the level of T provided foreign's best-response in β is to increase t_f .*

Proof. The proof is provided in Appendix 2.A.5. \square

Thus, deploying a BCA may provide home with a benefit beyond what the optimal tariff can achieve. This means that using trade policy to affect emission tax choices abroad has the potential to improve home's welfare. The tariff meets home's protectionist objectives and a BCA provides an additional margin on which home can affect foreign's emission tax choice. Moreover, home's terms-of-trade externality decreases in foreign's emission tax, which allows home to lower the optimal total border charge T . Home's emission tax choice rule is unchanged.

Foreign need not respond to the BCA by increasing its emission tax. If foreign does not care about climate damages ($t_f^n \approx 0$), and/or if $\frac{\partial X}{\partial p_f} < \frac{\partial M}{\partial p_h}$, for example then foreign will respond to the BCA by decreasing its emission tax. A BCA deployed in such a setting would make home worse off. I.e., home would not choose to deploy a BCA when the optimal tariff has been deployed.

The simultaneous policy game discussed here supposes that trade negotiators do not recognize the impact of trade policy on home's and foreign's emission taxes. However, using the BCA to leverage climate policy suggests a setting in which trade regulators recognize that home's and foreign's unilateral climate policy choices can be affected by the choice of BCA. This suggests a game where policies are chosen sequentially. This is considered in the next section.

2.6 Forward looking BCA regulators

Dropping the tariff from the analysis returns the discussion to the case where home chooses β and t_h and foreign chooses t_f . A BCA that is chosen recognizing the impact of the BCA on home's and foreign's emission taxes suggests a two-stage game, where Nash emission taxes are chosen after home has chosen β . The impact of a BCA with consideration of the dependence of t_f and t_h on β is examined in this section. Here, home is a Stackelberg leader. The problem is solved by backwards induction.

In this sequential setting, deploying the BCA requires a commitment on the part of home to set a BCA policy in the first stage. The commitment would be to reduce the charge at the border for an increase in t_f . Implicitly, this discussion assumes that home actually follows through with the commitment.

Home's and foreign's respective climate policy problems are

$$\max_{t_i} W_i(\beta, t_h, t_f).$$

The respective first-order conditions are Equations (2.8) and (2.9). Solving these two equations simultaneously for t_h and t_f yields the Nash solution to the second stage of

the game where each emission tax is expressed as a function of β only $\{t_h^B(\beta), t_f^B(\beta)\}$. In the first stage of the policy game, home's problem is

$$\max_{\beta} W_h(\beta, t_h^B(\beta), t_f^B(\beta))$$

Applying the envelope theorem yields the following first-order condition, evaluated at t_i^B

$$\frac{dW_h}{d\beta}(\beta, t_h^B(\beta), t_f^B(\beta)) = \frac{\partial W_h}{\partial \beta} + \frac{\partial W_h}{\partial t_f} \frac{dt_f^B}{d\beta} = 0. \quad (2.15)$$

The two terms in the condition capture the benefit accrued to home by deploying a border measure when climate policies are chosen subsequent to β . The first term would be the only effect if there were no strategic interaction between β and the emission taxes, as would be the case, for example, if the policy game were played simultaneously. The second term captures the effect of the sequential timing of the trade regulator's problem; this is the potential leveraging effect of β . Home's benefit in β depends, therefore, partly on how β leverages climate policy, since $\frac{\partial W_h}{\partial t_f} > 0$ by Assumption 2.1. Together, these two terms suggest that the potential benefit accrued from the BCA has a climate policy leveraging component that may or may not be positive, as I shall demonstrate, and a term that captures the standard motivation for a tariff $\frac{\partial W_h}{\partial \beta}$. It also suggests that home may choose a higher charge at the border if it can leverage foreign's emission tax, i.e., if $\frac{dt_f^B}{d\beta} > 0$.

The sequential timing means the Nash emission taxes enter home's BCA problem as a function of β . Hence the functions $\frac{\partial t_f^B}{\partial \beta}$ and $\frac{\partial t_h^B}{\partial \beta}$ describe how the Nash equilibrium emission taxes respond to a change in β . To characterize these functions, solve the following pair of equations

$$\frac{d}{d\beta} \frac{\partial W_i}{\partial t_i}(\beta, t_h^B(\beta), t_f^B(\beta))$$

for $\left\{ \frac{dt_f}{d\beta}, \frac{dt_h}{d\beta} \right\}$. Totally differentiating these equations¹⁹ reveals that this system is a function of six terms: the derivatives of the functions $\frac{\partial W_h}{\partial t_h}$ and $\frac{\partial W_f}{\partial t_f}$ with respect to t_h, t_f and β evaluated at t_i^B . The inverse function theorem states that there exists a solution to this system, provided the Jacobian is non-zero at the Nash equilibrium:

¹⁹Total differentiation yields the second-order derivatives

$$\frac{d}{d\beta} \frac{\partial W_f}{\partial t_f} = \frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f} \frac{dt_h}{d\beta} + \frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} \frac{dt_f}{d\beta} + \frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f} = 0$$

$$\frac{d}{d\beta} \frac{\partial W_h}{\partial t_h} = \frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} \frac{dt_h}{d\beta} + \frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h} \frac{dt_f}{d\beta} + \frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h} = 0$$

$J(\beta, t_h^B(\beta), t_f^B(\beta)) \neq 0$. The solution to $\frac{dt_i}{d\beta}$, provided it exists, is

$$\begin{aligned} \frac{dt_h}{d\beta} &= |J|^{-1} \left[\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f} \cdot \frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h} - \frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h} \cdot \frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} \right] \\ \frac{dt_f}{d\beta} &= |J|^{-1} \left[\frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h} \cdot \frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f} - \frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f} \cdot \frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} \right]. \end{aligned} \quad (2.16)$$

A locally stable solution around the Nash equilibrium requires

$$J(\beta, t_h^B(\beta), t_f^B(\beta)) > 0$$

These conditions are quite involved. However, imposing linearity as per Assumption 2.2 yields a more tractable set of conditions. With linearity the pair of functions $\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}$ and $\frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h}$ have already been characterized in Equations (2.11) and (2.12) respectively. Second-order conditions require that $\frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} < 0$ and $\frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} < 0$. What remains to characterize are $\frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f}$ and $\frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h}$, which are (after imposing the linear functions as per Assumption 2.2)

$$\frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f}(\beta, t_h^B(\beta), t_f^B(\beta)) = \overbrace{\frac{\partial X_f}{\partial t_h} \frac{\partial \tilde{p}_f}{\partial t_f}}^{\text{positive}} \quad (2.17)$$

$$\frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h}(\beta, t_h^B(\beta), t_f^B(\beta)) = - \overbrace{\frac{\partial M}{\partial t_f} \frac{\partial \tilde{p}_f}{\partial t_h}}^{\text{positive}} - \overbrace{\beta \theta_M \frac{\partial M}{\partial t_h}}^{\text{positive}}. \quad (2.18)$$

The first term in each of these conditions enters positively. Condition (2.18), however, introduces a negative term. An increase in t_f reduces the revenue generated by the BCA, and as β increases the strategic complementarity of t_f to t_h weakens.

Proposition 2.3. *With linear demand, supply and climate-damage functions, a very small BCA will result in foreign and home adopting a higher emission tax if*

$$\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}(0, t_h^B(0), t_f^B(0)) \geq 0.$$

Proof. By Equation (2.16), $\frac{dt_h}{d\beta} > 0$ and $\frac{dt_f}{d\beta} > 0$ require only that $\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}(0, t_h^B(0), t_f^B(0)) \geq$

0. This follows from the fact that

$$\begin{aligned}
\frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f} (0, t_h^B(0), t_f^B(0)) &> 0 \text{ by Equation 2.17,} \\
\frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h} (0, t_h^B(0), t_f^B(0)) &> 0 \text{ by Equation 2.18,} \\
\frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} (0, t_h^B(0), t_f^B(0)) &< 0 \text{ by the second-order condition,} \\
\frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} (0, t_h^B(0), t_f^B(0)) &< 0 \text{ by the second-order condition, and} \\
\frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h} (0, t_h^B(0), t_f^B(0)) &> 0 \text{ by Lemma 2.1.}
\end{aligned}$$

□

This proposition would also hold if home's border measure were a tariff instead of a BCA, provided foreign has no power to influence prices. I.e., the elasticity of export supply is infinitely large. In this case, foreign's best-response to the very small tariff, taking t_h as given, is zero. Formally $\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} (0, t_h^B(0), t_f^B(0)) = 0$.

Increasing τ allows home to pursue a higher emission tax, and foreign follows suit by the strategic complementarity of t_h and t_f . The outcome of a sequential tariff game is provided in Appendix 2.A.6.

In both the simultaneous and the sequential policy games, the impact of the BCA on home's welfare depends on foreign's response to the BCA. In the sequential game, the leveraging effect of the BCA provides home with an additional incentive to deploy a BCA (over the simultaneous game), provided foreign's response to the BCA is an increase in its emission tax.

2.6.1 A numerical example: comparing a tariff and a BCA

A numerical example, in the sequential game setting, is used to contrast the impact of the BCA and the tariff on climate policy choices. The functions are defined in Assumption 2.2.

Emission intensity is $\theta = \frac{1}{5}$, marginal damages are $(\eta_h, \eta_f) = (\frac{1}{3}, \frac{1}{8})$ and labor productivities are $(a_h, a_f) = (2, \frac{7}{3})$. Computations yield the solution to Equation (2.16) under the assumption of a very small BCA.

$$\begin{aligned}
\frac{dt_h}{d\beta}(t_i^B, \beta = 0) &= 0.24 \\
\frac{dt_f}{d\beta}(t_i^B, \beta = 0) &= 0.21
\end{aligned}$$

In this example, the small BCA results in *both* home and foreign adopting a stronger emission tax. The sequential tariff game is solved in Appendix 2.A.6. The numerical

computations yield the solution to Equation (2.A.30), which characterizes how emission taxes respond to a very small tariff

$$\begin{aligned}\frac{dt_h}{d\tau}(t_i^N, \tau = 0) &= 4.22 \\ \frac{dt_f}{d\tau}(t_i^N, \tau = 0) &= -0.84\end{aligned}$$

The tariff results in foreign adopting a weaker emission tax but home adopting a stronger emission tax. The optimal policy choices under a tariff are compared to the policy choices made under the optimal BCA:

$$\begin{aligned}\tau^N &= 0.04 > b^B = 0.02 \\ t_h^N &= 0.31 < \eta_h < t_h^B = 0.62 \\ t_f^N &= 0.11 < \eta_f < t_f^B = 0.55 \\ e_w(\tau^N, t_h^N, t_f^N) &= 0.40 > e_w(\beta^B, t_h^B, t_f^B) = 0.37 \\ V_w(\tau^N, t_h^N, t_f^N) &= 0.85 < V_w(\beta^B, t_h^B, t_f^B) = 0.86.\end{aligned}$$

Here, b^B is less than τ^N . Note that under a BCA, home's emission tax is set over marginal damage whereas under a tariff it is under marginal damage. The policy choices determine trade levels, which are positive and global emissions are decreasing in both τ and β . The solutions for the tariff and BCA games are presented graphically in Figure 2.1.

Global and foreign welfare increase for a small β but then fall as β approaches β^B . From the global welfare point of view, home chooses a β that is too high. However, for moderate levels of adjustment, both home and foreign benefit with the BCA. In the sequential game, home uses the BCA to target its terms-of-trade externality and leverage foreign's emission tax. In meeting these objectives (characterized with Equation 2.15), home goes too far in shifting the burden of mitigating climate emissions to foreign. This computational example shows that a BCA can be used to enhance global welfare and align the incentives of trade partners to reach climate-policy objectives. However, there is little to suggest that home's unilateral objective will coincide with the global objective. Designing rules to manage the deployment of these unilateral trade measures will be difficult, since the climate and protectionist objectives are largely congruent.

2.7 Concluding remarks

Working with a standard partial-equilibrium trade model with welfare-maximizing governments, I have compared how a BCA and a tariff affect incentives to set climate policy in both importing and exporting countries. The analysis focuses in particular on the strategic interaction between trading partners working to reconcile trade and climate externalities.

BCAs are often studied in the context of their effectiveness in dealing with an importer's exposure to leakage. The expectation is that leakage weakens the importer's

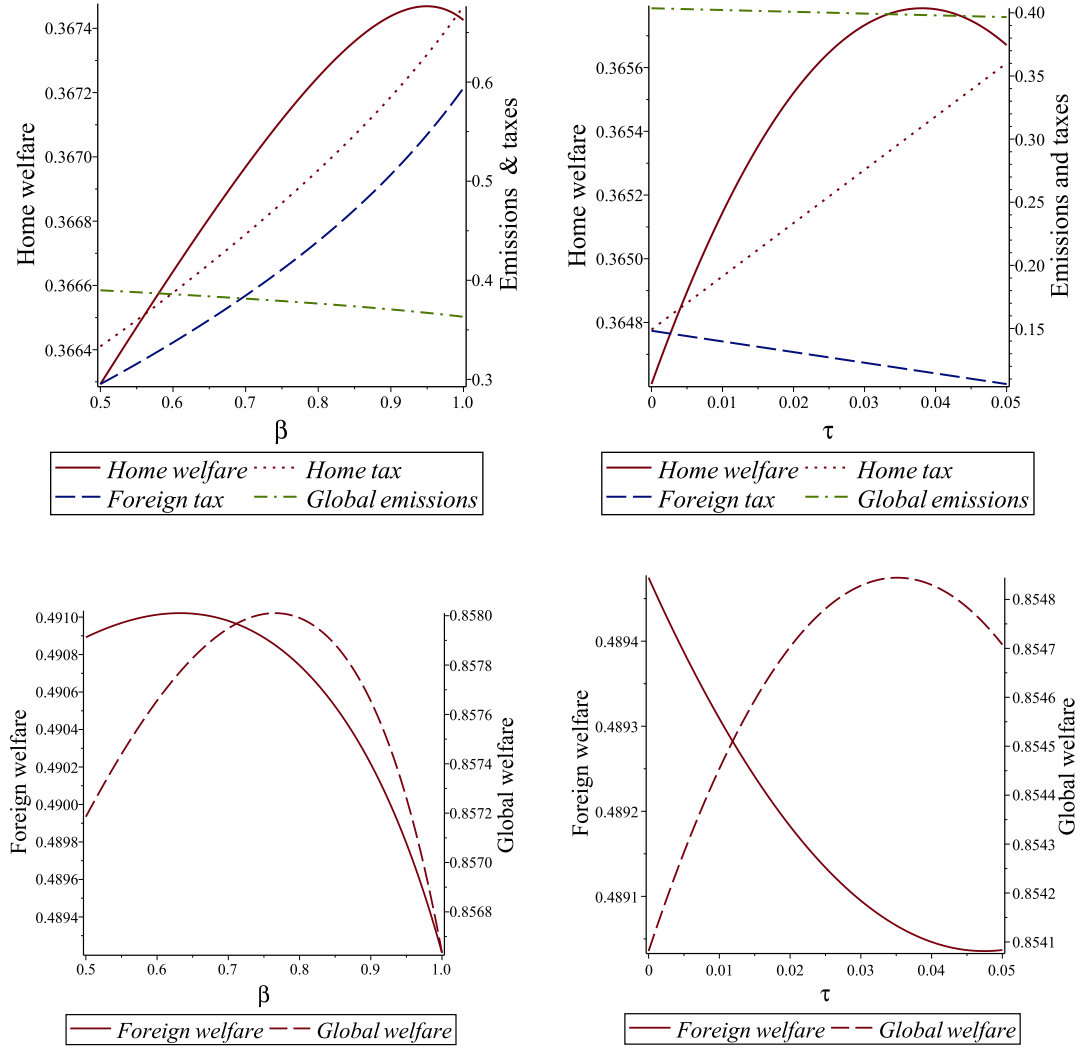


Figure 2.1: Home and Foreign emission taxes, global emissions, and welfare responses to a BCA and tariff when policymakers are forward looking.

incentives to adopt a more ambitious climate policy and that deploying a BCA will, by restricting imports, strengthen these incentives by mitigating leakage. However, leakage is often - implicitly or explicitly - studied in terms of the importer's partial problem, in that the exporter's climate-policy choice is ignored; as noted earlier, many studies consider the effects of increasing the importer's emission tax, or tariff, holding the exporter's emission tax constant, or assuming it does not exist.

This paper relaxes this constraint and shows that leakage does not figure in the importer's policy choices when both trade partners interact strategically. In a simultaneous policy game, BCAs (and tariffs) do not mitigate the effect of leakage on the importer's Nash emission tax choice. As the importer tightens climate policy, the motivation for deploying a BCA is about reaching domestic objectives, including the collection of tax/border revenue from the exporter's firms. This holds true even when the importer's tax or border measure deviates from the Nash policy choice. The upshot is that the deployment of a BCA/tariff to mitigate the effect of leakage on the choice of emission tax is distinct from reducing emissions by restricting imports. These effects are not usually distinguished.

These points are more than just semantics. They are important, partly because they suggest that designing a BCA/tariff to target leakage and thereby support more ambitious domestic climate policy may be misguided. It might be better to deploy a BCA/tariff to leverage the exporter's climate-policy and target global emissions. This would emphasize a BCA design that recognizes the exporter's climate policy efforts. Without this feature, the BCA may be no different from a tariff in terms of effects on the incentives facing the exporter's climate regulators, and - as this paper demonstrates - a tariff is a poor instrument in this regard.

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2.A Appendices

2.A.1 Derivation of first-best climate and trade policies

The global regulator's simultaneous choice of first-best climate policy and trade policy is derived from the following triplet of first-order conditions

$$\begin{aligned}\frac{\partial W_w}{\partial t_i} &= 0. \\ \frac{\partial W_w}{\partial \tau} &= 0.\end{aligned}$$

The solution to these equations is

$$\begin{aligned}t_i^G &= \eta_h + \eta_f \\ \tau^G &= 0.\end{aligned}$$

To derive this, consider first the choice of t_f^G . The partial derivative of the consumer surplus term is (recognizing that in optimum $\frac{\partial U(C_f(p_f))}{\partial c_f} = \hat{p}_f$)

$$\frac{\partial CS_f(\hat{P}_f)}{\partial t_f} = -\frac{\partial \hat{P}_f}{\partial t_f} C_f(p_f).$$

This is a standard result, known as Roy's identity. Likewise, the producer surplus term is obtained recognizing that in optimum $\frac{\partial TC}{\partial y_f} = \hat{p}_f$ and $\frac{\partial TC}{\partial t_f} = e_f$. This yields

$$\frac{\partial PS_f(\hat{P}_f, t_f)}{\partial t_f} = y_f(\hat{P}_f, t_f) \frac{\partial \hat{P}_f}{\partial t_f} - e_f(\hat{P}_f, t_f).$$

This is also a standard result, referred to as Hotelling's lemma. Substituting these results into the global regulator's problem, after some simplification, results in the following:

$$\begin{aligned}\frac{\partial W_w}{\partial t_f} &= \tau \left(\frac{\partial M_h}{\partial p_h} \frac{\partial p_h}{\partial t_f} \right) + t_h \left(\frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} \right) + t_f \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) \\ &\quad - \left(\frac{\partial E_w}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} + \frac{\partial E_w}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) \sum_i \eta_i = 0\end{aligned}\tag{2.A.19}$$

The condition for the choice of home's emission tax and home's tariff are obtained similarly.

$$\begin{aligned}\frac{\partial W_w}{\partial t_h} &= \tau \left(\frac{\partial M_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial M_h}{\partial t_h} \right) + t_h \left(\frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right) + t_f \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_h} \\ &\quad - \left(\frac{\partial E_w}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_h} + \frac{\partial E_w}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right) \sum_i \eta_i = 0\end{aligned}\tag{2.A.20}$$

$$\frac{\partial W_w}{\partial \tau} = \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} \left(t_h - \sum_i \eta_i \right) + \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial \tau} \left(t_f - \sum_i \eta_i \right) + \tau \frac{\partial M_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} = 0. \quad (2.A.21)$$

From Equation 2.A.21 it follows that, at t_i^G , the optimal global tariff is zero. What remains to be shown is that $t_i^G = t_i^G = \sum_i \eta_i$. To prove this, suppose the global regulator sets different tax rates at home and abroad. Without loss of generality, define

$$t_h = A \sum_i \eta_i$$

$$t_f = B \sum_i \eta_i.$$

Substitute these emission taxes into Equations 2.A.19 and 2.A.20. Some rearranging yields

$$A \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} + B \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) = \frac{\partial E_w}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} + \frac{\partial E_w}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f}.$$

$$A \left(\frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} \right) + B \frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_h} = \frac{\partial E_w}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_h} + \frac{\partial E_w}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h}.$$

If $A \neq B$ the solution requires $\frac{\partial E_h}{\partial p_h} \frac{\partial p_h}{\partial t_f} = \frac{\partial E_f}{\partial p_f} \frac{\partial p_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f}$ and $\frac{\partial E_h}{\partial p_h} \frac{\partial p_h}{\partial t_h} + \frac{\partial E_h}{\partial t_h} = \frac{\partial E_f}{\partial p_f} \frac{\partial p_f}{\partial t_h}$ but domestic emissions are decreasing in the domestic emission tax and leakage is positive. The only solution that satisfies Equations 2.A.1 and 2.A.1 is $A = B = 1$.

2.A.2 Derivation of home and foreign best-response functions

Equation (2.3) is obtained as follows. Differentiate Equation (2.2.2) with respect to t_f

$$\frac{\partial W_f}{\partial t_f} = \frac{\partial}{\partial t_f} \left[CS_f(\hat{P}_f) + PS_f(\hat{P}_f, t_f) + t_f E_f(\hat{P}_f, t_f) - \eta_f E_w(\hat{P}_i, t_i) \right]. \quad (2.A.22)$$

Substitute the expressions for $\frac{\partial CS_f(\hat{p}_f)}{\partial t_f}$ and $\frac{\partial PS_f(\hat{p}_f, t_f)}{\partial t_f}$, obtained using Roy's Identity and Hotelling's Lemma, into Equation (2.A.22) to obtain, after some simplification

$$\begin{aligned} \frac{\partial W_f}{\partial t_f} = & -C_f \frac{\partial \hat{P}_f}{\partial t_f} + Y_f \frac{\partial \hat{P}_f}{\partial t_f} - E_f + E_f + t_f \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) \\ & - \eta_f \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} + \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} \right) \end{aligned}$$

Using the definition $X_f = y_f - c_f$ and simplifying further yields

$$\frac{\partial W_f}{\partial t_f} = X_f \frac{\partial \hat{p}_f}{\partial t_f} + (t_f - \eta_f) \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) - \eta_f \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f},$$

which is exactly Equation (2.3).

Now consider how foreign's emission tax response changes with home's tariff. Foreign's best-response function on its emission tax is derived from

$$\frac{\partial W_f}{\partial t_f}(t_f, t_h, \tau) = 0.$$

Solving this first-order condition for t_f yields foreign's best-response on its own emission tax as a function of home's emission tax and tariff. Denote this best-response function $t_f^r = r_f(t_h, \beta)$. To see how foreign's best-response changes in τ , differentiate $\frac{\partial W_f}{\partial t_f}$ with respect to τ and evaluate at t_f^r . Rearranging yields

$$\frac{dr_f(t_h, \tau)}{d\tau} = -\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} \left(\frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} \right)^{-1} \Big|_{t_f^r}$$

The second-order condition imposes $\frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f}(t_f, t_h, \tau) < 0$ and the sign of the response function therefore depends only on the sign of $\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f}(t_f, t_h, \tau)$, which is derived below.

$$\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} = \frac{\partial}{\partial \tau} \left\{ X_f \frac{\partial \hat{P}_f}{\partial t_f} + (t_f - \eta_f) \left(\frac{\partial E_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial E_f}{\partial t_f} \right) - \eta_f \frac{\partial E_h}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_f} \right\}$$

This equation is quite involved, however imposing linear supply, demand and climate damages, as per Definition 2.2 simplifies the resulting expression to

$$\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} = \frac{\partial X_f}{\partial p_f} \frac{\partial \tilde{P}_f}{\partial \tau} \frac{\partial \tilde{P}_f}{\partial t_f} < 0, \quad (2.A.23)$$

which is strictly negative. Deriving home's function $\frac{\partial W_h}{\partial t_h}$ and $\frac{\partial}{\partial \tau} \frac{\partial W_h}{\partial t_h}$ is done similarly. Deriving home and foreign's response functions under a BCA is done similarly recognizing however that the no-arbitrage condition is defined by Equation (2.7) rather than Equation (2.1). The additional terms in these response functions under a BCA are obtained from Equations 2.A.24 and 2.A.25.

2.A.3 The effect of policy on prices

Market equilibrium is characterized by the no-arbitrage Equation (2.1) and the market clearing Equation (2.2). With this define the home's price function

$$P_h(p_f, t_h, t_f, \beta) = p_f + B(t_h, t_f, \beta)$$

Rewrite the market clearing condition in terms of demand and supply functions

$$C(p_h) - Y_h(P_h, t_h) = Y_f(p_f, t_f) - C(p_f)$$

Totally differentiate this condition to obtain

$$dp_f = \frac{\frac{\partial Y_f}{\partial t_f} dt_f + \frac{\partial Y_h}{\partial t_h} dt_h - \left(\frac{\partial M}{\partial p_h} \right) \frac{\partial B}{\partial \beta} d\beta}{\left(\frac{\partial M}{\partial p_h} - \frac{\partial X}{\partial p_f} \right)}.$$

In the same way, solve for dp_h . This yields

$$\frac{\partial \hat{P}_j}{\partial t_i} = -\frac{1}{\Omega} \frac{\partial Y_i}{\partial t_i} > 0, \frac{\partial \hat{P}_h}{\partial \tau} = \frac{1}{\Omega} \frac{\partial X}{\partial p_f} > 0, \text{ and } \frac{\partial \hat{P}_f}{\partial \tau} = \frac{1}{\Omega} \frac{\partial M}{\partial p_h} < 0 \text{ where } i, j \in (h, f).$$

and where

$$\Omega(P_h, P_f, t_h, t_f) \equiv \frac{\partial X}{\partial p_f} - \frac{\partial M}{\partial p_h} > 0.$$

In turn, these relationships yield the impact of emission taxes on trade under a tariff.

$$\frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} > 0 \text{ and } \frac{\partial X}{\partial p_f} \frac{\partial \hat{P}_f}{\partial t_f} + \frac{\partial X}{\partial t_f} < 0.$$

In the same way, the price changes under a BCA are derived to be:

$$\begin{aligned} \frac{\partial \tilde{P}_h}{\partial t_i} &= \frac{1}{\Omega} \left(\frac{\partial B}{\partial t_i} \frac{\partial X}{\partial p_f} - \frac{\partial Y_i}{\partial t_i} \right), \\ \frac{\partial \tilde{P}_f}{\partial t_i} &= \frac{1}{\Omega} \left(\frac{\partial B}{\partial t_i} \frac{\partial M}{\partial p_h} - \frac{\partial Y_i}{\partial t_i} \right), \end{aligned} \tag{2.A.24}$$

and

$$\begin{aligned} \frac{\partial \tilde{P}_h}{\partial \beta} &= \frac{1}{\Omega} \frac{\partial B}{\partial \beta} \frac{\partial X}{\partial \tilde{p}_f} \\ \frac{\partial \tilde{P}_f}{\partial \beta} &= \frac{1}{\Omega} \frac{\partial B}{\partial \beta} \frac{\partial M}{\partial \tilde{p}_h} \end{aligned} \tag{2.A.25}$$

$$\tag{2.A.26}$$

2.A.4 Generalized response functions

The generalized response functions are also derived, relaxing the requirements of Definition 2.2. In these derivations $Y_i(p_i, t_i)$ is assumed to be increasing and concave in p_i and decreasing and linear in t_i . Thus firms cannot abate their emissions. $C_i(p_i)$ is decreasing and convex in p_i . $Z_i(e_w)$ denotes the climate damage function of country i and is increasing and convex in global emissions. Marginal damages are denoted $\eta_i = \frac{dZ_i}{de_w}$.

A very small border measure assumption ($\beta = 0$ and/or $\tau = 0$) simplifies these solutions slightly. Consider first the response of foreign and home's Nash emission tax choice to a tariff. These are respectively

$$\begin{aligned}
\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} (0, t_h^n, t_f^n) &= \overbrace{\frac{\partial X_f}{\partial p_f} \frac{\partial \hat{P}_f}{\partial \tau} \frac{\partial \hat{P}_f}{\partial t_f}}^{\text{negative}} + (t_f^n - \eta_f) \theta \left\{ \overbrace{\varphi(f, t_f, \tau) + \frac{\partial Y_f}{\partial t_f} \frac{\partial \Omega}{\partial \tau}}^{\text{positive}} \right\} \\
&\quad - \left\{ \overbrace{\eta_f \theta \varphi(h, t_f, \tau)}^{\text{negative}} \right\} + \frac{\partial \eta_f}{\partial \tau} \\
\frac{\partial}{\partial \tau} \frac{\partial W_h}{\partial t_h} (0, t_h^n, t_f^n) &= - \overbrace{\frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial \tau} \frac{\partial \hat{P}_f}{\partial t_h}}^{\text{positive}} + \left(\frac{\partial M}{\partial p_h} \frac{\partial \hat{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} \right) \\
&\quad + (t_h^n - \eta_h) \theta \left\{ \overbrace{\varphi(h, t_h, \tau)}^{\text{negative}} - \overbrace{\frac{\partial \hat{P}_h}{\partial t_h} \frac{\partial \Omega}{\partial \tau}}^{\text{negative}} \right\} - \overbrace{\eta_h \theta \varphi(f, t_h, \tau)}^{\text{positive}} + \frac{\partial \eta_f}{\partial \tau}
\end{aligned}$$

where

$$\varphi(i, t_j, \tau) = \frac{\partial^2 Y_i}{\partial p_i^2} \frac{\partial \hat{P}_i}{\partial \tau} \frac{\partial \hat{P}_i}{\partial t_j}.$$

Now consider the response of foreign and home's Nash emission tax choice to β . These are respectively

$$\begin{aligned}
\frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f} (0, t_h^b, t_f^b) &= \overbrace{\frac{\partial X_f}{\partial p_f} \frac{\partial \tilde{P}_f}{\partial \beta} \frac{\partial \tilde{P}_f}{\partial t_f}}^{\text{negative}} - (t_f - \eta_f) \theta \left\{ \overbrace{\varphi(f, t_f, \beta) + \frac{\partial \tilde{P}_f}{\partial t_f} \frac{\partial \Omega}{\partial \beta} - \theta_M \frac{\partial M}{\partial p_h}}^{\text{positive}} \right\} \\
&\quad - \overbrace{\eta_f \left\{ \theta \varphi(h, t_f, \beta) - \theta_M \theta \frac{\partial Y_h}{\partial p_h} \right\}}^{\text{negative}} + \frac{\partial \eta_f}{\partial \beta}, \\
\frac{\partial}{\partial \beta} \frac{\partial W_h}{\partial t_h} (0, t_h^b, t_f^b) &= - \overbrace{\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial \beta} \frac{\partial \tilde{P}_f}{\partial t_h}}^{\text{positive}} + \frac{\partial B}{\partial \beta} \left(\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} + \frac{\partial M}{\partial t_h} \right) \\
&\quad + (t_h - \eta_h) \theta \left(\overbrace{\frac{\partial C_h}{\partial p_h} \theta_M + \varphi(h, t_h, \beta)}^{\text{negative}} - \overbrace{\frac{\partial \tilde{P}_f}{\partial t_h} \frac{\partial \Omega}{\partial \beta}}^{\text{negative}} \right) \\
&\quad - \overbrace{\theta \eta_h \varphi(f, t_h, \beta)}^{\text{positive}} + \frac{\partial \eta_f}{\partial \beta}
\end{aligned}$$

where

$$\varphi(i, t_j, \beta) = \frac{\partial^2 Y_i}{\partial p_i^2} \frac{\partial \tilde{P}_i}{\partial \beta} \frac{\partial \tilde{P}_i}{\partial t_j}.$$

Home and foreign's response functions on their respective emission taxes under a BCA are

$$\begin{aligned} \frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f}(0, t_h^b, t_f^b) &= \overbrace{\frac{\partial X}{\partial p_f} \frac{\partial \tilde{P}_f}{\partial t_h} \frac{\partial \tilde{P}_f}{\partial t_f}}^{\text{positive}} + (t_f^N - \eta_f) \theta \left\{ \overbrace{\varphi(f, t_h, t_f) - \frac{\partial \tilde{P}_f}{\partial t_f} \frac{\partial \Sigma}{\partial t_h}}^{\text{negative}} \right\} \\ &\quad - \overbrace{\theta \eta_f \varphi(h, t_h, t_f)}^{\text{negative}} + \frac{\partial \eta_f}{\partial t_h} \\ \frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h}(0, t_h^b, t_f^b) &= - \overbrace{\frac{\partial M}{\partial p_h} \frac{\partial \tilde{P}_h}{\partial t_h} \frac{\partial \tilde{P}_f}{\partial t_h}}^{\text{negative}} + (t_h^N - \eta_h) \theta \left\{ \overbrace{\varphi(h, t_h, t_f) - \frac{\partial \tilde{P}_h}{\partial t_h} \frac{\partial \Sigma}{\partial t_f}}^{\text{negative}} \right\} \\ &\quad - \overbrace{\theta \eta_h \varphi(f, t_h, t_f)}^{\text{negative}} + \frac{\partial \eta_h}{\partial t_f} \end{aligned}$$

where

$$\varphi(f, t_h, t_f) = \frac{\partial^2 Y_f}{\partial p_f^2} \frac{\partial \tilde{P}_f}{\partial t_f} \frac{\partial \tilde{P}_f}{\partial t_h}, \varphi(h, t_h, t_f) = \frac{\partial^2 Y_h}{\partial p_h^2} \frac{\partial \tilde{P}_h}{\partial t_h} \frac{\partial \tilde{P}_h}{\partial t_f}.$$

2.A.5 Proof of Proposition 2.2 and Corollary 2.1

The proposition and corollary are reiterated for convenience.

Proposition 2.2: *With linear demand, supply and climate damage functions, a BCA deployed at $\{\tau^n, t_h^n, t_f^n\}$ will induce foreign to adopt a higher emission tax provided t_f^b is weak and $\frac{\partial X}{\partial p_f} \gg \frac{\partial M}{\partial p_h}$.*

Proof. Home's first-order conditions, following from Equation (2.13), are

$$\begin{aligned} \frac{\partial W_h}{\partial \tau} &= \frac{\partial W_h}{\partial T} \frac{\partial T}{\partial \tau} = \frac{\partial W_h}{\partial T} = 0 \\ \frac{\partial W_h}{\partial \beta} &= \frac{\partial W_h}{\partial T} \frac{\partial T}{\partial \beta} = \Delta \theta_M \frac{\partial W_h}{\partial T} = 0 \\ \frac{\partial W_h}{\partial t_h} &= 0. \end{aligned}$$

Foreign's first-order condition, following from Equation (2.14), is

$$\frac{\partial W_f}{\partial t_f} = 0.$$

Totally differentiate home's welfare function

$$dW_h = \frac{\partial W_h}{\partial T} \left(\frac{\partial T}{\partial \tau} d\tau + \frac{\partial T}{\partial \beta} d\beta + \frac{\partial T}{\partial t_h} dt_h + \frac{\partial T}{\partial t_f} dt_f \right) + \frac{\partial W_h}{\partial t_f} dt_f + \frac{\partial W_h}{\partial t_h} dt_h \quad (2.A.27)$$

and use the envelope conditions (i.e. $\frac{\partial W_h}{\partial T} = 0$, $\frac{\partial W_h}{\partial \tau} = 0$ and $\frac{\partial W_h}{\partial t_h} = 0$) to obtain

$$dW_h(T(\beta, t_h, t_f), t_f, t_h) = \frac{\partial W_h}{\partial t_f} dt_f. \quad (2.A.28)$$

Recall $\frac{\partial W_h}{\partial t_f} > 0$ by Assumption 2.1. This means that there is a margin on which the BCA can further improve home's welfare - home's welfare benefit from a BCA, deployed at the Nash equilibrium, is partly due to the *potential* leveraging effect of the BCA on foreign's emission tax choice.

Home can improve its welfare, by deploying a BCA, if foreign's best-response to an increase in β , at the Nash equilibrium, is to increase t_f^n . This is characterized using Equation (2.11), evaluated at $\{\tau^n, t_h^n, t_f^n\}$ with linear demand, supply and climate damage functions, as per Definition 2.2

$$\begin{aligned} \frac{\partial}{\partial \beta} \frac{\partial W_f}{\partial t_f}(T(\tau^n, \beta, t_h^n, t_f^n), t_h^n, t_f^n) &= \overbrace{\frac{\partial X_f}{\partial p_f} \frac{\partial \bar{P}_f}{\partial \beta} \frac{\partial \bar{P}_f}{\partial t_f}}^{\text{negative}} \\ &+ \Theta_{F,\beta} \left[(t_f^n - \eta_f) \frac{\partial C_h}{\partial p_h} - \left(t_f^n - \frac{(\theta_h + \theta_f)}{\theta_f} \eta_f \right) \frac{\partial Y_h}{\partial p_h} \right] \end{aligned}$$

where

$$\Theta_{F\beta} \equiv \frac{\theta_f \frac{\partial Y_f}{\partial t_f}}{\beta \theta_M \frac{\partial M}{\partial \bar{p}_h} + \frac{\partial Y_f}{\partial t_f}} > 0.$$

This condition is positive provided t_f^n is weak and $\frac{\partial X}{\partial p_f} \gg \frac{\partial M}{\partial p_h}$. \square

Corollary 2.1: *With linear demand, supply and climate damage functions, if home deploys a small BCA at $\{\tau^n, t_h^n, t_f^n\}$ then home will decrease the level of T provided foreign's best-response in β is to increase t_f*

Proof. How would home respond to foreign's response to a very small BCA? Home's first-order condition on T is

$$\begin{aligned} \frac{\partial W_h}{\partial T}(T(\tau^n, \beta, t_h^n, t_f^n), t_h^n, t_f^n) &= -M \frac{\partial \bar{P}_f}{\partial T} + T \frac{\partial M}{\partial p_h} \frac{\partial \bar{P}_h}{\partial T} \\ &+ (t_h - \eta_h) \frac{\partial E_h}{\partial p_h} \frac{\partial \bar{P}_h}{\partial T} - \eta_h \frac{\partial E_f}{\partial p_f} \frac{\partial \bar{P}_f}{\partial T} = 0. \end{aligned}$$

Assuming linear demand, supply and climate damages as per Assumption 2.2, Home's best-response to an increase in t_f , evaluated at $\{\tau^n, t_h^n, t_f^n\}$ is

$$\frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial T} (T(\tau^n, \beta, t_h^n, t_f^n), t_h^n, t_f^n) = - \overbrace{\frac{\partial M}{\partial p_h} \frac{\partial \bar{p}_h}{\partial t_f} \frac{\partial \bar{p}_f}{\partial T}}^{\text{positive}} - \overbrace{\beta \theta_M \frac{\partial M}{\partial p_h} \frac{\partial \bar{p}_h}{\partial T}}^{\text{negative}},$$

which is strictly negative at $\beta = 0$. \square

2.A.6 Forward looking tariff regulators

Suppose trade regulators recognize the impact trade policy has on home and foreign's unilateral climate policy choice. The analysis now examines the extent to which the tariff can be used to *leverage* climate policy. This suggests a two stage game where, in the first stage, home chooses a tariff τ and in the second stage home and foreign's regulators set their respective emission taxes simultaneously. This Section therefore examines the impact of τ with consideration of the dependence of t_f and t_h on τ : home is a Stackelberg leader. The problem is solved by backwards induction.

The conditions describing home and foreign's emission tax choices are identical to conditions (2.3) and (2.4). The simultaneous solution of these two equations yields the Nash emission taxes, each of which are a function of τ . This pair of policies is denoted $\{t_h^N(\tau), t_f^N(\tau)\}$, where the superscript N denotes the Nash equilibrium outcome of the sequential game.

In the first stage of the policy game home chooses its optimal tariff τ recognizing the dependency of the emission taxes on its choice of tariff

$$\max_{\tau} W_h(\tau, t_h^N(\tau), t_f^N(\tau)).$$

Applying the envelope theorem yields the following condition evaluated at t_i^N

$$\frac{dW_h}{d\tau}(\tau, t_h^N(\tau), t_f^N(\tau)) = \frac{\partial W_h}{\partial \tau} + \frac{\partial W_h}{\partial t_f} \frac{dt_f^N}{d\tau} = 0, \quad (2.A.29)$$

The two terms in the condition capture the benefit accrued to home by deploying a border measure when climate policies are chosen subsequent to τ .

With sequential timing, home's problem in the first stage is characterized by emission taxes that are a function of τ ; the functions $\frac{dt_f^N}{d\tau}$ and $\frac{dt_h^N}{d\tau}$ describe how the Nash equilibrium emission taxes respond to a change in τ . To characterize these functions solve

$$\frac{d}{d\tau} \frac{\partial W_i}{\partial t_i}(\tau, t_h^N(\tau), t_f^N(\tau)) = 0$$

for $\left\{\frac{dt_f}{d\tau}, \frac{dt_h}{d\tau}\right\}$. Totally differentiating these equations reveals that this system is a function of six terms; the derivatives $\frac{\partial W_h}{\partial t_h}$ and $\frac{\partial W_h}{\partial t_f}$ with respect to t_h, t_f and τ evaluated at t_i^N . Apply the inverse function theorem and require the Jacobian to be non-zero and

positive at the Nash equilibrium for a stable solution. The solution to $\frac{dt_i}{d\tau}$, provided it exists, is

$$\begin{aligned}\frac{dt_h}{d\tau} &= \frac{1}{|J|} \left[\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} \cdot \frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h} - \frac{\partial}{\partial \tau} \frac{\partial W_h}{\partial t_h} \cdot \frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} \right] \\ \frac{dt_f}{d\tau} &= \frac{1}{|J|} \left[\frac{\partial}{\partial \tau} \frac{\partial W_h}{\partial t_h} \cdot \frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f} - \frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f} \cdot \frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} \right]\end{aligned}$$

I will only consider locally stable solutions around the Nash equilibrium. This requires that the eigenvectors of the Jacobian matrix are negative and from this it follows that $|J|_{t_i^N} > 0$. The solution shows how the three endogenous policies (t_h, t_f, τ) interact in this setting to determine the impact of τ on unilaterally chosen emission taxes.

The partial derivatives $\frac{\partial}{\partial \tau} \frac{\partial W_h}{\partial t_h}$ and $\frac{\partial}{\partial \tau} \frac{\partial W_f}{\partial t_f}$ have already been characterized in Section (2.3) and $\frac{\partial}{\partial t_h} \frac{\partial W_h}{\partial t_h} < 0$, $\frac{\partial}{\partial t_f} \frac{\partial W_f}{\partial t_f} < 0$ by the second-order condition. To characterize the remaining two functions, take the partial derivatives of conditions (2.3) and (2.4) with respect to t_h and t_f respectively, applying linear functions as per Definition 2.2, to obtain

$$\frac{\partial}{\partial t_h} \frac{\partial W_f}{\partial t_f} (\tau, t_h^N(\tau), t_f^N(\tau)) = \overbrace{\frac{\partial X}{\partial p_f} \frac{\partial p_f}{\partial t_h} \frac{\partial \hat{p}_f}{\partial t_f}}^{\text{positive}} \quad (2.A.30)$$

$$\frac{\partial}{\partial t_f} \frac{\partial W_h}{\partial t_h} (\tau, t_h^N(\tau), t_f^N(\tau)) = - \overbrace{\frac{\partial M}{\partial p_h} \frac{\partial p_h}{\partial t_f} \frac{\partial \hat{p}_f}{\partial t_h}}^{\text{negative}}. \quad (2.A.31)$$

The term in each of these conditions enters positively when climate policies of both countries move together. Home and foreign's climate policies are strategic complements to one another.

Chapter 3

How does the price of electricity affect imports? A study of Swedish manufacturing firms¹

3.1 Introduction

There is rising concern that the integration of international markets, coupled with asymmetric energy prices across countries, are putting pressure on energy intense industries facing competition from abroad. Increasing energy prices at home, it is argued, will lead to an increase in imports, as production is relocated abroad to areas with lower energy prices. The concern is amplified by the expectation that energy prices will become increasingly asymmetric if ambitious policy commitments are realized.² At the same time, there is increasing evidence that importing is driven by more than just cost savings; there are a number of mechanisms that motivate firms to source inputs from abroad. However, relatively few economic studies have focused on importing, and there is a dearth of evidence on how firms and their engagement in international markets respond to higher domestic energy prices.

In this paper we examine, both theoretically and empirically, the heterogeneous effects of a domestic energy price increase on the structure of imports at the firm level. We seek to identify the *magnitude* of the impact of an electricity price increase on the level of imports at the firm level. We begin by developing a tractable analytical model of heterogeneous firms that incorporates trade in intermediate inputs. The focus of our study is therefore on trade in intermediate inputs. Trade in final goods is not part of the scope.

The model yields predictions on the extensive and intensive margins of trade. On the

¹This paper is co-authored with Shon Ferguson.

²Consider for example the potential impact on German and Japanese energy prices as nuclear power plants are taken offline. Also consider that under the Copenhagen Accord, the USA pledged that it will reduce greenhouse gas emissions by 17% from 2005 levels by 2020. Likewise, the EU has pledged a reduction of between 20-30% from 1990 levels by 2020.

extensive margin, the theory predicts that an increase in the domestic price of energy results in less productive firms engaging in the import of intermediate inputs, and that this effect is increasing in the energy intensity of the imports. Likewise, on the intensive margin, the model predicts that an increase in the domestic price of energy will result in a relative increase in the use of imported intermediate inputs, and that this increase is particularly large for energy-intensive imports. In other words, a firm's incentive to source intermediates abroad is greater for products that embody large amounts of energy as a share of their value.

We find evidence that both the intensive and extensive margin of imports respond to higher electricity prices. However, the picture is nuanced. The empirical evidence on the extensive margin supports the theory: firms respond to electricity price increases by importing, in particular, more electricity-intensive intermediate inputs from the EU15.³ However, on the intensive margin, firms increase imports of intermediate inputs but there is no evidence of increased imports of electricity-intensive intermediate inputs.

We test the hypotheses derived from our theory with a rich data-set covering Swedish manufacturing sectors from the year 1998 through 2007. During this time period the domestic price of electricity for industrial consumers in Sweden increased significantly, after a long period of low and stable prices. Sweden had faced relatively low prices until 2002, but prices converged towards levels paid in Germany, and the EU15 average, from 2003 onward. Firms hedge their exposure to changes in the price of electricity. For example, some firms engage in long-term contracts with electricity suppliers. With this in mind, we adopt a difference-in-difference approach between the years 2001 and 2005, to bracket delayed adjustment to firm electricity costs.

Distinctive features of the data are the availability of foreign inputs at the product level for individual firms, and electricity costs for each firm. This level of detail makes it possible to construct a disaggregated picture of the domestic electricity use avoided by a firm through the use of foreign intermediate inputs, and enables us to disentangle the effects that determine a firm's import decision, and thereby identify the impact of the electricity price increase. Our identification strategy, therefore, uses the electricity price increase, cross-firm variation in Swedish electricity costs, and cross-product variations in the electricity-intensity of intermediate inputs to estimate how the structure of electricity-intensive imports respond at the firm level.

The paper continues with a description of the Swedish electricity market in Section 3.2. The related literature is reviewed in Section 3.3. The theoretical model is presented in Section 3.4, and the data and descriptive statistics are discussed in Section 3.5. The empirical specification and results of the extensive and intensive margin analysis are described in Sections 3.6 and 3.7 respectively. Conclusions are presented in Section 3.8.

³The EU15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom. In May 2004, ten additional countries joined the Union.

3.2 The Swedish Electricity Market

In terms of per capita usage, Sweden is one of the most electricity-intensive economies in the world. Only Island, Norway, Canada and Finland rank higher. This is due to several factors, including: the Swedish economy's relatively large share of electricity-intensive industrial production; a colder climate, and; historically low electricity prices, which have provided an incentive to use electricity as an energy resource in households and industrial sectors. In contrast, per capita electricity use in the U.S. is 10% lower than in Sweden, and in the EU15 it is, on average, 54% lower. In 2008, Swedish hydro-power met 47% of Swedish electricity demand, whereas nuclear power met 42%. The remaining 11% was produced using fossil and bio-fuels. Sweden participates in the Scandinavian electricity market, which helps to even out electricity prices across the region.

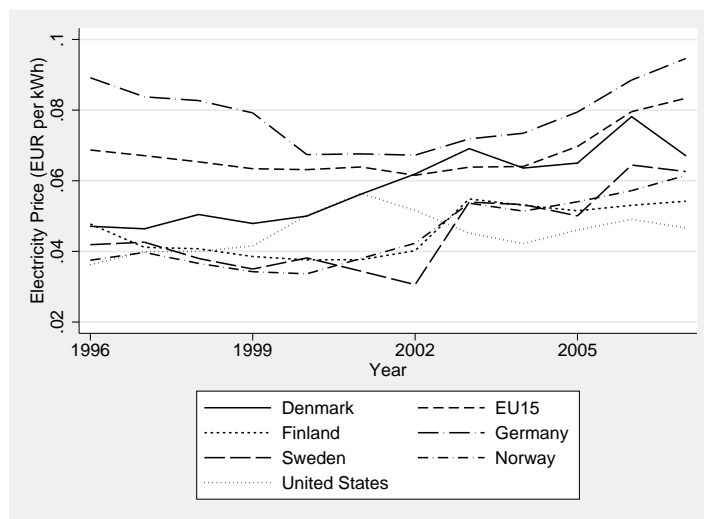


Figure 3.1: Average annual nominal electricity prices paid in Sweden and other countries. Source: Eurostat, U.S. Energy Information Administration.

Figure 3.1 illustrates that prior to 2002 Swedish electricity prices were low relative to continental Europe, but they increased in 2003, converging toward levels paid in Germany and the average EU15 price. Importantly for the analysis undertaken here, the price of electricity in Sweden increased relative to the price paid across Sweden's major trading partners. This increase in Sweden's electricity price is a critical aspect of our identification strategy. As far as trade in intermediate inputs is concerned, Sweden imports mostly from the other Scandinavian countries and the other members of the EU15. Moreover, Sweden's electricity price is correlated with the electricity prices of neighboring countries, which are also Sweden's major trading partners. The other top five countries from which Sweden imports are Russia, Chile, Poland, the US and China. Our identification strategy also exploits this variation in electricity prices across import origins.

The change in Sweden's electricity price between 2002 and 2004 was driven by several

factors. For one, electricity markets in Scandinavia became more closely integrated with those of continental Europe, leading to a convergence in prices. The abruptness of the increase in Swedish electricity prices was caused by a particularly dry summer in 2002, which led to decreased hydro-power production and a spike in electricity prices in the winter of 2003. Water levels in the hydro-power magazines did not return to normal until the end of 2004.

The launch of the European Union's Emission Trading System in 2005 - a policy initiative to tackle emissions that cause climate change - likely influenced electricity prices across Europe. The introduction of tradeable emissions permits was intended to increase the cost of producing energy with greenhouse gas intensive technologies and fuels. Swedish electricity production is dominated by low emission technologies (hydro-power and nuclear power). However, the introduction of the EU's climate policy may have affected the relative price of electricity and other, more emissions intense, energy sources. Sorting out the impact of the EU ETS on the Swedish electricity market is a research question in its own right, but some suggest that the price of emissions permits has had a significant impact on the price of electricity in the Nordic countries. Another confounding factor was sporadic closures of nuclear power plants, which restricted electricity supply.

About one third of Swedish industrial energy use in 2008 was electricity. The top six sectors, defined at the two-digit level, accounted for approximately 88% of industrial electricity use (in 2008), with the pulp, paper and paper products sector accounting for approximately 33-40% of industrial electricity use over the period from 1998 to 2008.⁴ At the same time there is significant variation across each of these sectors with respect to their electricity intensity.

Firms can, and do, manage the risk of electricity price changes by engaging in longer-term contracts and hedging. Thus, the electricity costs paid by many firms are distinct from the daily electricity spot price. The dramatic price spike in the inter-day electricity price at the end of 2002 (that saw electricity prices reach over 1 SEK/kWh) was likely mitigated, to varying degrees, by long-term contracts and futures hedging strategies deployed by firms. This variation is discussed in Section 3.5.

Finally, from 1998 to 2007, the Swedish economy grew steadily. This also played a role in determining the evolution of Swedish electricity prices. Swedish GDP grew by 2.5% in 2002, 2.3% in 2003 and 4.2% in 2004. Changes in demand are therefore also a key consideration when studying the impact of higher electricity prices on firm behavior.

3.3 Related Literature

Trade in intermediate inputs is significant and growing, and is now a salient feature of international production. Economic research efforts match this trend, and there is

⁴The next two most important sectors are basic metals accounting for approximately 13-20%, and chemicals and chemical products with approximately 12-18%, respectively. These figures are obtained from our data, which we will discuss shortly. The sectors are defined at the NACE two-digit level.

a sizable literature examining the economic impact of a change in the relative price of imports. The theory we develop extends the trade models of heterogeneous firms (à la Melitz (2003)) to include costly trade in, and production utilizing, imported intermediate goods. In particular, our theory draws on the contribution by Kasahara and Lapham (2013). They show that lowering tariffs on imported intermediate inputs can result in substantial aggregate productivity and welfare gains. In their approach firms can, in addition to serving the domestic market, export final goods, import intermediate inputs or do both. Increasing returns to scale production technology deployed by firms means that accessing markets abroad (for sales of final goods and purchasing intermediate goods) increases firm productivity. Thus, the demand for imported intermediates is partly derived from the "love of variety" in production, but also from changes in the tariffs applied to imports. Another study that has drawn on this approach is Amiti and Davis (2012). They study the impact of trade liberalization on the wages paid by firms. Trade liberalization is shown to increase wages most for those working at the most international firms: those firms that are engaged in both exporting and importing. Unlike these studies, our model examines how imports are used by some firms to mitigate a domestic factor price increase. Thus, the demand for imported intermediates is partly derived from "love of variety" in production as in Kasahara and Lapham (2013), but also from changes in the price of electricity at home relative to abroad.

International trade in intermediate goods, equated by some with the term "offshoring," has been studied in a neoclassical setting by Grossman and Rossi-Hansberg (2008). They extend the Heckscher-Ohlin trade model to incorporate a technology where tasks necessary for the production of a final good can be moved offshore. However, in our study we are interested in the intensive and extensive margins of firm-level imports.

A change in the real exchange rate has also been used as a way to identify the trade impact of a change in the relative price of imports. In the face of a real exchange rate shock, Norwegian importers and exporters shed labor. However, according to Ekholm et al. (2012), only the exporters increased labor productivity. Tomlin (2010) also studies the effect of real exchange rates on export behavior. Schmitz Jr (2005) studies the impact of imports of low-cost Brazilian iron ore on the U.S.-Canada iron ore sector in the 1970s. In response to this shock, labor productivity in the sector doubled. In contrast to these studies, the focus of our study is on the impact of an increase in a domestic factor price on a firm's choice to employ imported inputs in production.

3.4 Theoretical Model

The model examines the use of imported intermediate inputs in production, where firms are subject to an exogenous domestic electricity price increase. Firms make their decisions contingent on this electricity price. The economy consists of a monopolistic competitive industry (manufacturing) that is engaged in the production of differentiated goods, using intermediate inputs, under increasing returns. Firms engaged in the

production of final goods are heterogeneous in productivity and face fixed importing costs, analogous to the fixed cost for exporting deployed by Melitz (2003). However, in our setting there is no exporting activity and this means that there is an outside sector that balances trade: this is a partial equilibrium theory.

Consumer preferences are such that there is constant elasticity of substitution between manufactured final goods, following Dixit and Stiglitz (1977). Consumers allocate revenue R across varieties $i \in \Omega$ to solve

$$\min R = \sum_{i \in \Omega} p_i c_i \text{ s.t. } U_j \geq \left(\int_{i \in \Omega} c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \quad (3.4.1)$$

where $\sigma > 1$ is the elasticity of substitution between final good varieties, p_i is the consumer price of variety i , and c_i is the quantity of variety i demanded. Solving the consumer's problem yields the demand curves for each variety i :

$$c_i = \frac{p_i^{-\sigma}}{P^{1-\sigma}} R, \quad (3.4.2)$$

where

$$P \equiv \left(\int_{i \in \Omega} p_i^{1-\sigma} di \right)^{\frac{1}{1-\sigma}} \quad (3.4.3)$$

is the price index of manufacturing goods.

The production side of the model is derived from Kasahara and Lapham (2013). In our case, firms producing final goods must pay a fixed cost F to enter the manufacturing sector. After having sunk F , the firm observes its own electricity efficiency coefficient φ_i drawn, from a cumulative distribution $G(\varphi_i)$. Once firms observe their productivity⁵ draw they have the option to exit the market and therefore not engage in production. If the firm does choose to produce, it must bear an additional fixed cost f . This allows the firm to access domestic intermediate inputs for production. If the firm wants to access *imported* intermediate inputs for production, then it must incur an additional fixed cost f_m , which is a beachhead cost for importing intermediates. There are thus two types of firms active in the market: type-D firms that use only domestic intermediate inputs, and; type-M firms that also employ imported intermediate inputs. Therefore, the production technology exhibits variable and fixed cost components.

The production of intermediate inputs is undertaken in both domestic and foreign countries under perfect competition. Production follows a Cobb-Douglas technology that combines electricity e with a non-electric factor k to produce a quantity of intermediate inputs

$$x_j = e_j^\delta k_j^{1-\delta}, \quad (3.4.4)$$

where the subscript $j \in (d, f)$ denotes domestic and foreign respectively. δ captures the share of electricity used in production. Producers of the intermediate inputs pay a

⁵The focus of the analysis is on how electricity is used in production. Insofar as the theory is concerned, the terms electricity efficiency and productivity are synonymous.

price ρ_j for e_j and 1 for the factor k_j . The cost minimization problem facing domestic and foreign firms is

$$\min_{e_j, k_j} C(e_j, k_j) = \rho_j e_j + k_j \quad (3.4.5)$$

$$\text{such that } 1 = e_j^\delta k_j^{1-\delta} \quad (3.4.6)$$

$$\text{and } e_j > 0, k_j > 0. \quad (3.4.7)$$

The solution yields p_{x_d} and p_{x_f} , which are the prices of each domestic and foreign intermediate variety, respectively. We express this as the ratio

$$\frac{p_{x_d}}{p_{x_f}} = \rho^\delta, \quad (3.4.8)$$

where $\rho \equiv \frac{\rho_d}{\rho_f}$. These intermediate goods are supplied to the firms producing the final good, which are denoted by subscript i . These firms employ intermediate varieties x_j in the production of a quantity of final good, denoted X . We assume a Cobb-Douglas technology that combines electricity l_i with intermediate inputs, while the quantities of domestic intermediate inputs $x_{d,i}$ and, for type-M firms, quantities of imported intermediate inputs $x_{f,i}$ are combined via a CES production function:

$$X(\varphi_i, m_i) = \varphi_i l_i^\alpha \left[(x_{d,i})^{\frac{\gamma-1}{\gamma}} + m_i (x_{f,i})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{(1-\alpha)\gamma}{\gamma-1}}.$$

The parameter φ_i captures the productivity of firm i . Designate φ_i as the firm's in-house productivity, which can be augmented by buying intermediate inputs. This productivity augmentation is driven by the increasing returns to variety in the assembly of intermediate inputs, which is a result of the CES production in the square brackets. Firms can substitute between domestic and foreign intermediate inputs in production with a constant elasticity $\gamma > 1$: accessing foreign intermediate inputs augments total factor productivity. In this setting, the term *variety* refers to horizontally-differentiated products.⁶ The binary variable $m_i = (0, 1)$, which assumes a value of 1 for a type-M firm. The Cobb-Douglas output elasticity of the in-house electricity use is captured by $\alpha \in (0, 1)$. In-house electricity use is l_i , which is supplied at a price ε_i . Therefore, the share of intermediate inputs used in the production of the final good is $1 - \alpha$.

The model is solved contingent on domestic and foreign electricity prices paid: a firm's cost minimization problem is solved taking the electricity prices as given. The problem facing the firm producing the final good is therefore

$$\min_{l_i, x_{d,i}, x_{f,i}} C(l_i, x_{d,i}, x_{f,i}) = \varepsilon_i l_i + p_{x_d} x_{d,i} + p_{x_f} x_{f,i} \quad (3.4.9)$$

⁶This approach is also used by Kasahara and Lapham (2013), although the use of his class of production technology follows from earlier work in macroeconomics, growth and international economics. See for example Grossman and Helpman (1991) and Ethier (1987).

$$\text{such that } 1 = \varphi_i l_i^\alpha \left[(x_{d,i})^{\frac{\gamma-1}{\gamma}} + m_i (x_{f,i})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{(1-\alpha)\gamma}{\gamma-1}}$$

$$\text{and } l_i > 0, x_{j,i} > 0.$$

Cost minimization means that a type-M firm's demand for imported intermediates can be expressed as a function of the demand for domestic intermediates. The first-order conditions of Equation (3.4.9), together with Equation (3.4.8), imply the following result:

$$\frac{x_{f,i}}{x_{d,i}} = \left(\frac{p_{x_d}}{p_{x_f}} \right)^\gamma = \rho^{\delta\gamma} \quad (3.4.10)$$

Equation 3.4.10 shows that, relative to the demand for domestic varieties, the demand for imported intermediates increases in the relative price of domestic varieties. The relative price of domestic and foreign intermediate inputs is, in turn, a function of ρ , the relative electricity price paid by domestic and foreign intermediate firms as derived with Equation (3.4.8). The relative demand for imported intermediates is also increasing in both δ (the electricity intensity of intermediates inputs), and γ (the degree to which foreign and intermediate varieties can be substituted for one another). Likewise, equilibrium demand for electricity by firm i is

$$l_i = x_d \rho^\delta \frac{\alpha}{\varepsilon_i (1 - \alpha)} [1 + m_i \rho^{\delta(\gamma-1)}]. \quad (3.4.11)$$

A firm's output can therefore be expressed as

$$X(\varphi_i, m_i) = \varphi_i \lambda_i l_i^\alpha [(1 + m_i \rho^{\delta(\gamma-1)}) x_d]^{(1-\alpha)}. \quad (3.4.12)$$

Firm productivity can therefore be expressed as the product of a distribution of in-house productivity φ_i and a distribution of productivity enhancements from importing λ_i , where

$$\lambda_i \equiv [1 + m_i \rho^{\delta(\gamma-1)}]^{\frac{1-\alpha}{\gamma-1}} \quad (3.4.13)$$

is a productivity-enhancement term capturing two effects. The first is the productivity benefit of employing imported intermediate inputs: $\lambda_i = 1$ for type-D firms and $\lambda_i > 1$ for type-M firms. This is driven by the love of variety characteristic of firm i 's production technology. The second is from a change in ρ , suggesting that an increase in the relative price of domestic electricity leads to an increase in the benefit from using imported intermediates.

Having observed their productivity draws, firms follow a decision process where they maximize profit contingent on electricity prices. Each firm operates under increasing returns to scale at the plant level, and, following Dixit and Stiglitz (1977), we assume there to be a large number of monopolistically-competitive firms in the manufacturing sector. The elasticity of demand σ is therefore equal to the elasticity of substitution between any pair of differentiated goods. Firms set prices as a function of their marginal cost

$$p_i = \frac{\sigma}{\sigma - 1} \frac{1}{\Gamma \varphi_i \lambda_i} \quad (3.4.14)$$

where $\Gamma \equiv \alpha^\alpha (1 - \alpha)^{1-\alpha}$. This pricing rule is analogous to Melitz (2003). Revenue for the firm is therefore

$$r_i = R \left[\frac{\sigma}{\sigma - 1} \frac{1}{P\Gamma\varphi_i\lambda_i} \right]^{1-\sigma} \quad (3.4.15)$$

where $R = P_j C = \int_{i \in \Omega} r(i) di$ is aggregate income equal to total expenditure. The profits of type-D and type-M firms are therefore

$$\pi(\varphi_i, 0) = \frac{r_i}{\sigma} - f \quad (3.4.16)$$

$$\pi(\varphi_i, 1) = \frac{r_i}{\sigma} - f_m - f \quad (3.4.17)$$

respectively. Substituting Equation (3.4.15) into Equation (3.4.16) and Equation (3.4.17) yields

$$\pi(\varphi_i, 0) = B \left[\frac{1}{\varphi_i\lambda_i} \right]^{1-\sigma} - f, \quad (3.4.18)$$

$$\pi(\varphi_i, 1) = B \left[\frac{1}{\varphi_i\lambda_i} \right]^{1-\sigma} - f_m + f, \quad (3.4.19)$$

where $B \equiv \frac{R}{\sigma} \left[\frac{\sigma}{P(\sigma-1)\Gamma} \right]^{1-\sigma}$. The model yields empirically-testable propositions on both the extensive and intensive import margins.

3.4.1 Extensive Margin Predictions

Assume the productivities of the manufacturing firms producing good i follow the Pareto distribution with $G(\varphi|\varphi_M) = (\varphi/\varphi_M)^k$, where k is the shape parameter. The model yields the solution for the productivity cutoffs for type-M firms.⁷

$$\varphi_M^{\beta(\sigma-1)} = \Theta_M \left[\beta \left(1 - \left(\frac{1}{\lambda_i} \right)^{\sigma-1} \right) + \left(\frac{f_m + f}{f} \right)^{\beta-1} \left(\frac{1}{\lambda_i} \right)^{\beta(\sigma-1)} - \frac{f_m}{f_m + f} \right] \quad (3.4.20)$$

where

$$\Theta_M \equiv \frac{1}{F} \left(\frac{f_m + f}{\beta - 1} \right) \quad (3.4.21)$$

and

$$\beta \equiv \frac{k}{(\sigma - 1)} > 1 \quad (3.4.22)$$

This expression describes the impact of an increase in the relative price of domestic electricity on the productivity cut-off for type-M firms. The function $\varphi_M^{\beta(\sigma-1)}$ depends on the relative price of domestic to foreign electricity ρ , which enters here via λ_i only. In order to guide our empirical analysis we are interested in knowing: (1) how the import cutoff changes as the relative price of domestically-produced electricity changes,

⁷Closed form solutions for φ_D and P are provided in Appendix 3.A.1.

i.e., $\partial\varphi_M^{\beta(\sigma-1)}/\partial\rho$, and; (2) how the responsiveness of the cutoff to electricity prices varies for imports of high- versus low-electricity-intensive goods, i.e. $\partial^2\varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta$. We summarize the results of these comparative statics in the following, empirically testable, proposition:

Proposition 3.1. *The productivity cut-off for type-M firms is falling in ρ . The productivity cut-off falls faster in ρ for more electricity-intensive intermediate inputs, provided $\rho > 1$. Formally:*

$$\frac{\partial\varphi_M^{\beta(\sigma-1)}}{\partial\rho} < 0, \quad (3.4.23)$$

$$\frac{\partial^2\varphi_M^{\beta(\sigma-1)}}{\partial\rho\partial\delta} < 0 \quad \text{if} \quad \rho > 1 \quad (3.4.24)$$

When $\rho < 1$, $\partial^2\varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta < 0$ holds, provided

$$1 - \alpha < -\frac{1}{\rho^{\delta(\gamma-1)}} \left(\frac{1 + \rho^{\delta(\gamma-1)}}{\delta \ln \rho} + (\gamma - 1) \right)$$

Proof. See Appendix 3.A.2. □

The first part of Proposition 3.1 is straight forward: a higher relative price of electricity at home leads less productive firms to begin importing. The second part of Proposition 1 establishes the conditions under which the extensive margin of imports is more sensitive to highly electricity-intense imports. It is important to note that the sign of the cross derivative depends on ρ . The sign is unambiguously negative if the domestic electricity price is higher than the electricity price abroad, i.e $\rho > 1$. In this case, an increase in the electricity intensity of intermediates, δ , will induce less productive firms to start importing intermediates in response to an increase in ρ .

On the other hand, the sign is ambiguous when the domestic electricity price is lower than the electricity price abroad, i.e., $\rho < 1$. In this case, an increase in the electricity intensity of intermediate inputs may or may not induce less-productive firms to start importing intermediates in response to an increase in ρ . Formally, this is the case where $\partial^2\varphi_M^{\beta(\sigma-1)}/\partial\rho\partial\delta > 0$. In some cases, increasing the electricity intensity of intermediates may not steepen the response of $\varphi_M^{\beta(\sigma-1)}$ to the electricity price increase.

This result suggests that firms start to source electricity-intensive intermediate inputs from abroad even when Sweden's electricity price is relatively low. The outcome depends on the relative productivity gain from importing versus the difference in the level of the electricity price at home and abroad, which is captured by the restriction on the parameter α .

3.4.2 Intensive Margin Predictions

We derive an expression that describes firm demand for intermediate inputs contingent on a firm i being type-M. There is no international trade in final goods, hence demand for final good i must equal output from firm i . With this, we obtain firm i 's demand for domestic and imported intermediate inputs.

$$x_d = \rho^{-\alpha\delta} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{1 + m_i \rho^{\delta(\gamma-1)}} \frac{R}{\Theta_x P^{1-\sigma}} \quad (3.4.25)$$

$$x_f = \rho^{(\gamma-\alpha)\delta} \frac{(\lambda_i \varphi_i)^{\sigma-1}}{1 + m_i \rho^{\delta(\gamma-1)}} \frac{R}{\Theta_x P^{1-\sigma}} \quad (3.4.26)$$

where $\Theta_x \equiv \left(\frac{\sigma}{\Gamma(\sigma-1)} \right)^\sigma \left(\frac{\alpha}{(1-\alpha)} \right)^\alpha$.

A change in ρ affects firm-level demand for imported intermediate inputs x_f in several ways. First is the direct reduction in cost resulting from avoided domestic electricity prices. This is captured by $\rho^{(\gamma-\alpha)\delta}$. Second, importing allows type-M firms to keep marginal costs down, resulting in increased demand for their final good, which in turn increases the demand for imports. This is captured by the term $(\lambda_i \varphi_i)^{\sigma-1}$. Third is a productivity effect. Accessing foreign inputs increases productivity, which in turn drives down the demand for imports; the productivity benefits of variety are enhanced in ρ . This is captured by the denominator term $1 + m_i \rho^{\delta(\gamma-1)}$. Finally, a change in ρ affects the price index, $P^{1-\sigma}$. We would expect that an increase in the price of electricity would result in higher price levels. This suggests that $\partial P^{1-\sigma} / \partial \rho > 0$.

Thus, a domestic electricity price increase affects demand for the final good, drives an increase in the demand for imports, and at the same time enhances the productivity benefit of importing, which serves to decrease the demand for imports. A change in ρ can affect demand for x_f via several channels that can confound each other. We therefore derive our testable hypotheses for the intensive margin of imports from Equation (3.4.10), which we summarize with the following proposition:

Proposition 3.2. *Relative to a firm's demand for domestic intermediate inputs, demand for imported intermediates increases in ρ . The relative demand for a domestic intermediate input increases faster in ρ for a more electricity-intense intermediate input. Formally*

$$\frac{\partial \ln \left(\frac{x_{f,i}}{x_{d,i}} \right)}{\partial \ln \rho} = \delta \gamma > 0,$$

$$\frac{\partial^2 \ln \left(\frac{x_{f,i}}{x_{d,i}} \right)}{\partial \ln \rho \partial \delta} = \gamma > 0.$$

Proof. The first part of Proposition 2 follows directly from logging both sides of (3.4.10) and solving the derivative with respect to ρ . The second part of Proposition 2 follows from taking the second derivative with respect to δ . \square

This model enables us to show how an increase in the relative price of domestically sourced inputs, driven in this case by the price of electricity, induces less productive firms to source inputs from abroad. The impetus to substitute toward inputs from abroad is not only derived from the direct savings from cheaper foreign inputs, but through several channels. Equations 3.4.25 and 3.4.26 show how a change in ρ affects the demand for intermediate inputs both directly, and via λ and $P^{1-\sigma}$. This exemplifies the particular challenges of identifying the impact of input price changes on importing activity. These results guide our approach to the data as well as our empirical strategy.

3.5 Data and Descriptive Statistics

The data we analyze was obtained from the Swedish Survey of Manufacturers, conducted by Statistics Sweden (the Swedish government's statistical agency). We use data for 1998-2007, which covers 4194 firms (four-digit NACE Rev.1.1 codes 10.30-37.20) with 10 or more employees. The survey contains information on output, value-added, employment, capital stocks, investment and value of other primary factors of production that allow for the calculation of total factor productivity at the firm level. We merge this data with customs data on firm-level imports from the rest of the world. We deflate the import data using two-digit CN product-specific price indices in order to control for fluctuations in import values over time that are not driven by a general change in the price of imported goods. We then aggregate the import data to the four-digit ISIC Rev. 3.1 level.

The electricity data also comes from Statistics Sweden and includes the quantity and cost of electricity purchased each year. The energy survey covers all manufacturing firms with more than 10 employees from the year 2000 onwards. Prior to 2000 the electricity survey included a smaller sample of firms. The electricity data is available at the plant level but we aggregate it to the firm level in order to match the import data, which is only available at the firm level. The distribution of electricity costs across six electricity-intensive sectors, defined at the two-digit NACE level, are presented in Figure 3.2. The figure illustrates the significant variation in firm electricity cost, even within two-digit industry classifications.

As noted earlier, firms write contracts to hedge against the risk of electricity price increases. The annual firm electricity cost adapts slowly in our data, which is most likely due to the use of long-term contracts. We do not observe firm-level data on the use of electricity futures markets. However, forward pricing contracts on the futures market extend up to three years, which implies that an increased percentage of firms would be exposed to higher prices by 2005. We therefore use the years 2001 and 2005 to bracket our difference-in-difference regression analysis. Moreover, the opportunity cost of consuming electricity instead of selling it onwards is the same regardless of whether firms have long-term contracts or take offsetting positions on the futures market.

One challenge is to find a variable that captures the share of electricity embodied in imports of intermediate inputs for narrowly defined products. We use the share of electricity embodied in Swedish-manufactured goods as our measure for the share of

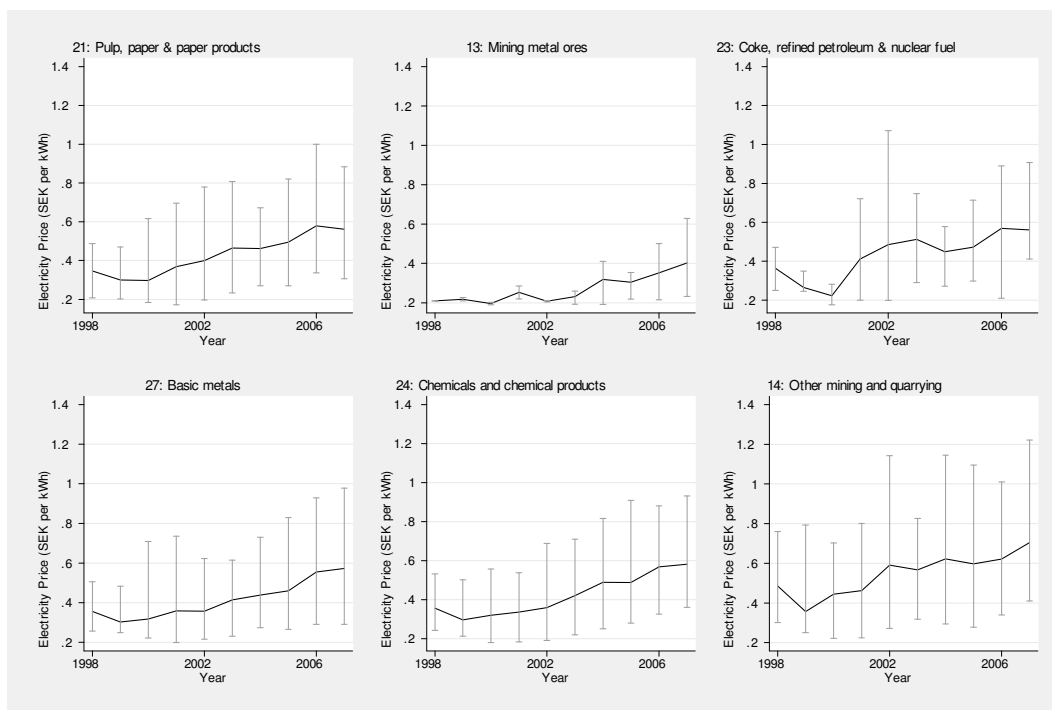


Figure 3.2: Electricity price distribution for six electricity intense sectors, by two-digit NACE industry classification, showing the mean electricity price in SEK/kWh and the 5th and 95th percentile limits of the electricity prices paid by firms within the sector. Sources: Statistics Sweden and authors' calculations.

electricity embodied in imports. This proxy represents the opportunity cost of producing or buying the input domestically instead of importing from abroad. We define electricity intensity embodied in goods as the ratio of electricity cost to total raw-materials and intermediate-input cost. We first calculate the average electricity intensity of each Swedish ISIC Rev. 3.1 sector over the years 1998-2000. We match firms to the most appropriate ISIC Rev. 3.1 product code using a concordance from the NACE Rev. 1.1 level. Defining the electricity intensity as a share of inputs is more appropriate for our purposes than using share of value added. Value added itself is endogenous to electricity prices, while input costs are likely to be more exogenous. Moreover, using the input cost share provides a measurement with the useful property that it controls for changes in the cost of inputs in general. The ten most electricity-intensive intermediate inputs are listed in Table 3.1.

We restrict the set of imported goods and the set of importing firms to ensure that we focus exclusively on imports of intermediate inputs in the analysis. The data reveals that firms import not only intermediate inputs but also a significant amount of final goods.⁸ We use EUROSTAT's "Main Industrial Grouping" end-use categories based on the NACE Rev.2 classification defined in 2007 to distinguish intermediate inputs

⁸This is a characteristic of international trade that is documented by Bernard et al. (2012).

Table 3.1: Sweden’s most electricity-intensive imported intermediate inputs by ISIC Rev 3.1 code with the highest electricity intensity

Electricity intensity ¹	ISIC Rev. 3.1	Description
81.6%	1310	Mining of iron ores
51.7%	2693	Manufacture of structural non-refractory clay and ceramic products
26.2%	1421	Mining of chemical and fertilizer minerals
24.9%	2694	Manufacture of cement, lime and plaster
18.0%	1429	Other mining and quarrying n.e.c.
12.4%	1320	Mining of non-ferrous metal ores, except uranium and thorium ores
9.4%	2696	Cutting, shaping and finishing of stone
8.8%	1030	Extraction and agglomeration of peat
8.3%	2021	Manufacture of veneer sheets; manuf. of plywood, laminboard, etc.
8.2%	2610	Manufacture of glass and glass products

¹ Electricity intensity is defined as the ratio of electricity value to total raw materials and intermediate input value. Based on import products included in the regression from column (4) of Table 3.6.

from final goods. We convert this measure to the more aggregated ISIC Rev. 3.1 classification, in order to match the import data. In addition, we expect the effects we seek to identify to be strongest for firms engaged in international supply chain trade. Indeed, input-output tables typically show that manufacturing sectors mainly use inputs from the same sector in the production process. We thus take the additional step of restricting our regression analysis to including only firms that are themselves producers of intermediate inputs.

Understandably, tariffs have also played a role in determining firm demand for imported intermediate inputs. Therefore, we control for changes in tariff rates imposed on foreign imports. Sweden joined the European Union in 1995. Since then tariffs have set in Brussels. This mitigates, to a degree, the extent to which Swedish industry has exerted influence on tariff rates. Another consideration is that EU import tariffs for pulp and paper products were reduced in 2004 under the Accelerated Tariff Liberalization (ATL) initiative in forest products, negotiated under the WTO. This is a particularly relevant consideration here as the Swedish pulp and paper sector is also the most electricity-intensive industrial sector in Sweden. In our regression analysis, we omit pulp and paper imports in order to ensure that our results are not driven by trade liberalization in forest products, which occurred after 2004. We match tariff data from UNCTAD TRAINS, which is at the six-digit HS level, to our firm-level import data that is coded to six-digit CN. We create a trade-weighted average import tariff faced by each firm in each year and for each product they import. Finally, the European Union expanded in 2004 with the accession of 10 countries: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. Imports from these

countries have been excluded from the analysis.

The correlation coefficients for electricity costs and other firm-level variables for 2001 and for the change between 2001 and 2005 are provided in Tables 3.2 and 3.3, respectively.

Table 3.2: Correlations,¹ 2001

	Electricity Cost	Value import	Employees	Raw Materials	Output
Value import	-0.0264*				
Employees	-0.1991*	0.1447*			
Raw materials	-0.1520*	0.1490*	0.8460*		
Output	-0.1740*	0.1430*	0.9299*	0.9594*	
Productivity	-0.0898*	0.0625*	0.3093*	0.2878*	0.3006*

¹ Based on firms included in the regression from column (4) of Table 3.6, *p<0.01

Table 3.3: Correlations¹, 2005-2001 First Difference

	Electricity Cost	Value import	Employees	Raw Materials	Output
Value import	-0.0089				
Employees	-0.0145	-0.0165			
Raw materials	-0.0423*	0.2193*	-0.2300*		
Output	-0.0340*	0.2083*	0.0444*	0.7090*	
Productivity	-0.0376*	0.0269*	-0.1950*	0.2658*	0.1940*

¹ Based on firms included in the regression from column (4) of Table 3.6, *p<0.01

These correlation coefficients indicate that electricity costs are negatively correlated with productivity and firm size (as proxied by employees), raw materials and output for the cross-section of firms. Import values are positively correlated with the size and productivity measures. The correlation coefficients in Table 3.3 suggest that electricity costs, productivity and firm size are also negatively correlated within firms over time, although this negative relationship is less robust. It is reassuring, however, that electricity costs and import values are negatively correlated with each other and statistically insignificant, since this weakens the possibility that a positive relationship between importing and electricity prices is spuriously driven by demand shocks that would lead simultaneously to greater import requirements and higher firm electricity costs.

3.6 Extensive Margin Analysis

Proposition 3.1 states that increases in an electricity price induce less productive firms to start importing, especially with regards to goods that require significant amounts of electricity to produce in Sweden. We test this using a first-differenced specification between the years 2001 and 2005. First-differencing is appropriate for four main reasons.

First, it removes any problems of cointegration between imports and electricity prices. Second, it removes the need to include lagged import status as an independent variable, which would otherwise be necessary to control for since import status is highly auto-correlated. Third, first-differencing at the firm-product level controls for firm-product fixed effects.

The empirical specification on the extensive import margin tests Proposition (3.1). In the data, firms import multiple products and we observe the year when a firm starts and/or stops importing a particular product. With these observations we define m_{ipt} , which is an indicator variable taking a value equal to one if firm i imports product p in year t and zero otherwise. Our interest is in the change of this indicator variable between 2001 and 2005: $\Delta m_{ipt} \equiv m_{ip,2005} - m_{ip,2001}$. Thus Δm_{ipt} assumes a value of one if a firm i started to import a product p between 2001 and 2005, zero if there was no change in the import status and negative one if a firm stopped importing a product. Also $\Delta m_{ipt} = 0$ for all product codes for a firm where the value of imports equaled zero. Descriptive statistics for Δm_{ipt} are provided in Table 3.4.

Table 3.4: Descriptive statistics for extensive margin dependent variable¹

Δm_{ipt} : Import Status Indicator	Number of observations		
	-1	0	1
All Countries	356	11857	472
Norway+Denmark+Finland	241	12154	290
EU15/Non-Scandinavian	196	12204	285
Non-EU/Non-Scandinavian	148	12346	191

¹ Based on observations from column (4) of Table 3.6. Total observations 12685.

Our benchmark equation tests the impact of the domestic electricity price increase on the propensity to start importing new products. Adapting our theory to the product p , firm i and year t structure of our data yields

$$\begin{aligned} \Delta m_{ipt} = & v_0 + \sum_{r=1}^4 \omega_r (Q_{2001}^r) + \sum_{r=1}^4 v_r (\ln I_p \times Q_{2001}^r) \\ & + v_5 \ln I_p + v_6 \Delta \ln(EP_{it}) + v_7 \Delta \tau_{ipt} + \epsilon_{ipt}. \end{aligned} \quad (3.6.1)$$

The first variable of interest is I_p , which captures the electricity intensity of the imported product (estimated from ISIC Rev 3.1 level). Formally:

$$I_p \equiv \frac{E_{p,1998-2000}}{x_{p,1998-2000}} \quad (3.6.2)$$

$E_{p,1998-2000}$ describes the value of electricity used in the production of an imported product defined using statistics for 1998 through 2000. This is estimated from the electricity used by Swedish manufacturers of these products, which we can obtain from

Table 3.5: Descriptive statistics for the extensive and intensive margin regressions for the year 2005

Variable	obs.	mean	std. dev.	min	max
<u>Panel A: Extensive Margin Independent Variables¹</u>					
I_p : elec. intensity, imported product	12685	0.058	0.090	0.011	0.816
$\Delta \ln(EP_{it})$: change in elec. cost, 2005-2001	12685	0.132	0.163	-0.339	1.611
$\Delta \tau_{ipt}$: change in import tariff	12685	-1.05	0.890	-3.783	0
<u>Panel B: Intensive Margin Variables²</u>					
ΔSM_{ipt} : Import Intensity, Non-Nordic EU, 2005-2001 % change	315	-0.090	1.627	-6.629	5.859
$\Delta \ln(EP_{it})$: change in elec. cost, 2005-2001	315	0.123	0.114	-0.250	0.582
I_p : elec. intensity, imported product	315	0.059	0.068	0.011	0.517
$\Delta \tau_{ipt}$: change in import tariff	315	-1.085	0.763	-3.783	0

¹ Based on observations from column (4) of Table 3.6² Based on observations from column (3) of Table 3.8

our data-set. Likewise, $x_{p,1998-2000}$ is the value of intermediate inputs and raw materials used by Swedish manufacturers in the production of this product. This interaction results in a variable that captures the electricity- intensity of a product produced in Sweden. The descriptive statistics in Panel A of Table 3.5 illustrate that our measure of electricity intensity varies widely across products.

Logged electricity intensity of the product ($\ln I_p$) is interacted with four size-quartile indicator variables Q_{2001}^r , which take the value of one when a firm belongs to productivity quartile r in 2001 and zero otherwise. The productivity-quartile indicator variables and electricity intensity also enter the regression as separate terms, captured by the coefficients ω_r , and v_5 respectively.

The theory suggests that some firms with a productivity below φ_M may start to source inputs from abroad with an increase in electricity price. However, the theory does not say where the productivity threshold lies. The fixed cost of importing might be high enough so that an electricity price increase has no affect on the extensive margin. However, if there is an extensive margin effect, the use of quartile dummies would identify where the effect occurs. Thus a positive v_r identifies firms in quartile r that find it profitable to start importing. The change in the tariff over the period is defined at the firm-product level, and $\Delta \tau_{ipt} \equiv \tau_{ip,2005} - \tau_{ip,2001}$.

The second independent variable of interest is the change in the average annual electricity cost faced by a firm:

$$\Delta(\ln EP_{it}) \equiv \ln(EP_{i,2005}) - \ln(EP_{i,2001}), \quad (3.6.3)$$

calculated using the electricity bill and the quantity of electricity used by each firm in

a given year. The descriptive statistics in Panel A of Table 3.5 suggest that the cost of electricity increased between 2001 and 2005 by an average of 0.13 SEK/kWh, with the change varying highly across firms (from -0.40 to 1.61 SEK/kWh). Panel A of Table 3.5 shows that tariffs decreased by 1% on average.

Table 3.6 presents the baseline results of the extensive margin analysis using a linear probability model. The coefficients capture the change in a firm's probability of importing a given product by productivity quartile between 2001 and 2005. The average change in the probability of exporting for firms in the first quartile is subsumed by the constant term. Since we have first-differenced the data, the unit of analysis is firm-product. Two-digit industry fixed effects are included to control for differential trends in import patterns across sectors.

Column (1) of Table 3.6 presents the results when only electricity intensity and the quartile dummies are included. This yields no significant results. The interactions between the quartile dummies and electricity intensity are added in column (2), where we find that firms in the second quartile of the 2001 productivity distribution started to import new products in general, but especially products that are electricity-intense to produce in Sweden. We add a control for changes in tariffs between 2001 and 2005 in column (3), which is negative and statistically significant at the 5% level. The results for the second quartile of the productivity distribution are robust to controlling for tariffs. Finally, in column (4), we add five-digit industry dummies to control for differential trends in import patterns across sectors in as much detail as is possible. Our result for the second quartile interaction term continues to be significant at the 5% level. The point estimate in column (4) on Q_{2001}^2 suggests that the average probability of a firm in the second productivity quartile importing an intermediate input increased by 3.6% between 2001 and 2005. The point estimate on $I_p \times Q_{2001}^2$ suggests that the increase in the probability of a firm in the second productivity quartile importing a given product increases by an additional 1.1% every time you double the electricity intensity of the imported product. Recall that the electricity intensity of the intermediate inputs varies across several orders of magnitude (see Table 3.5). Moreover, the probability of increasing any given intermediate input is small. Hence, as a percentage increase in probability, these estimates are economically significant.

We find no statistically-significant results for the electricity-cost coefficient. This suggests that heterogeneity in electricity costs does not explain the decision to import. Nevertheless, the average increase in the cost of electricity faced by firms may have had an impact. First-differencing the electricity cost data implies that we cannot measure the effect of the electricity cost increase directly.

Table 3.6: Electricity costs, electricity-intensive products, and the extensive margin of imports¹

Dependent variable: Δm_{ipt} ²	(1)	(2)	(3)	(4)
Q_{2001}^2 : second productivity quartile	0.001 (0.011)	0.036 (0.019)*	0.036 (0.019)*	0.036 (0.019)*
Q_{2001}^3 : third productivity quartile	0.006 (0.011)	0.017 (0.022)	0.018 (0.022)	0.013 (0.023)
Q_{2001}^4 : fourth productivity quartile	0.006 (0.011)	0.034 (0.022)	0.034 (0.022)	0.033 (0.021)
$\ln I_p \times Q_{2001}^2$		0.011 (0.005)**	0.011 (0.005)**	0.010 (0.005)**
$\ln I_p \times Q_{2001}^3$		0.004 (0.005)	0.004 (0.005)	0.002 (0.005)
$\ln I_p \times Q_{2001}^4$		0.009 (0.006)	0.009 (0.006)	0.007 (0.006)
$\ln I_p$: elec. intensity, imported product	0.001 (0.002)	-0.005 (0.004)	-0.005 (0.004)	-0.005 (0.004)
$\Delta \ln(EP_{it})$: elec. cost of firm		-0.001 (0.008)	-0.001 (0.008)	-0.001 (0.009)
$\Delta \tau_{ipt}$: import tariff			-0.004 (0.002)**	-0.004 (0.002)*
Constant	0.010 (0.009)	-0.010 (0.014)	-0.015 (0.014)	-0.014 (0.014)
Industry Fixed Effects	2 Digit	2 Digit	2 Digit	5 Digit
Observations	12685	12685	12685	12685
R^2	0.008	0.008	0.009	0.046

¹ * p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses, clustered at firm-level in all specifications. Pulp and paper imports excluded. Imports from countries that acceded to the EU in 2004 excluded.

² The dependent variable is the change in the import status of a firm at the ISIC Rev. 3.1 product level between 2001 and 2005.

3.6.1 Robustness

We investigate how the extensive margin of imports varies by country of origin. The results are presented in Table 3.7. We expect that imports from Norway, Denmark and Finland should not be affected by electricity price increases in Sweden, since those

countries also experienced similar increases in their electricity prices between the years 2001 and 2005 (see figure 3.1). In column (1) of Table 3.7, the import status variable m_{ipt} is equal to one if the firm imports from Norway, Denmark or Finland and zero otherwise. The dependent variable, Δm_{ipt} , therefore captures the change in a firm's import status with respect to imports from these three countries only. None of the productivity interaction terms are significant in this case, as expected.

In column (2) the dependent variable is the change in the indicator variable equal to one if the firm imports from pre-2004 EU member states, excluding Denmark and Finland, and zero otherwise. Likewise, the dependent variable Δm_{ipt} captures the change in a firm's import status with respect to imports from these countries only. The coefficients on Q_{2001}^2 and $I_p \times Q_{2001}^2$ are significant at the 1% level. The probability of importing a product for firms in the second productivity quartile increased by 1.5% for products embodying no electricity, with a statistically significant interaction with electricity intensity. There is also evidence that firms in the fourth productivity quartile responded similarly. These results suggest that firms are responding to electricity price increases by importing electricity-intensive inputs from non-neighboring European countries that did not experience an increase in electricity prices to the same extent as Sweden over the period from 2001 through 2005.

Finally, in column (3), the dependent variable captures the change in a firm's import status with respect to imports from all countries except the EU15, Norway and the countries that acceded to the EU in 2004. The probability of importing electricity-intensive inputs does not increase from these countries, which may suggest that the fixed cost of importing from these countries may have been prohibitively high for firms to find it profitable to begin importing in response to the higher electricity prices in Sweden. The results are also robust to including a control for firm-level capital intensity and the number of products firms import. These robustness checks are provided in Appendix 3.A.3.

Our assertion that we are estimating causal effects of higher electricity prices on firm behavior would be undermined if higher firm-level demand leads to higher electricity prices. The change in the price of electricity that we observe *could* be due to a demand shock at an aggregate level (the business cycle) or at the level of an individual firm. However, we maintain that this concern does not undermine our analysis. We have shown that there is a negative correlation between firm size and the price they pay for electricity, both across firms in a given year and within firms over time (see Tables 3.2 and 3.3). Thus, firms that grow the fastest seem to pay lower prices over time, which does not support the alternative mechanism where demand shocks are positively correlated with electricity prices. Moreover, our focus on systematic differences in importing high- versus low-electricity-intensive goods and the use of firm fixed effects effectively controls for firm-level shocks. Our measure of cross-product variation in the electricity intensity of imported products is set at pre-2001 levels, and is thus not endogenous to changes in electricity prices by construction.

Table 3.7: The extensive margin of imports by country of origin¹

Dependent variable: Δm_{ipt} ²	(1) Norway, Denmark and Finland ³	(2) Non-Scand. EU15 ⁴	(3) Non-EU, Non-Scand. ⁵
Q_{2001}^2 : second productivity quartile	0.017 (0.017)	0.038 (0.015)***	-0.002 (0.010)
Q_{2001}^3 : third productivity quartile	-0.006 (0.016)	0.017 (0.019)	0.005 (0.010)
Q_{2001}^4 : fourth productivity quartile	0.009 (0.016)	0.031 (0.017)*	-0.000 (0.011)
$\ln I_p \times Q_{2001}^2$	0.003 (0.005)	0.011 (0.003)***	-0.000 (0.003)
$\ln I_p \times Q_{2001}^3$	-0.005 (0.004)	0.006 (0.004)	0.003 (0.003)
$\ln I_p \times Q_{2001}^4$	0.001 (0.004)	0.009 (0.004)**	-0.002 (0.003)
$\ln I_p$: elec. intensity, imported product	-0.000 (0.003)	-0.006 (0.003)**	-0.001 (0.002)
$\Delta \ln(EP_{it})$: electricity price	0.001 (0.006)	-0.000 (0.006)	-0.001 (0.004)
$\Delta \tau_{ipt}$: import tariff	-0.001 (0.002)	-0.003 (0.002)*	-0.003 (0.001)**
Constant	-0.004 (0.011)	-0.016 (0.011)	-0.005 (0.007)
Observations	12685	12685	12685
R^2	0.039	0.036	0.028

¹ * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses, clustered at firm-level in all specifications. Pulp and paper imports excluded. Five-digit industry fixed effects used in all specifications.

² The dependent variable is the change in the import status of a firm at the ISIC Rev. 3.1 product level between 2001 and 2005.

³ Change in a firm's status with respect to imports from Denmark, Finland and Norway only.

⁴ Change in a firm's status with respect to imports from EU15, but excluding Denmark and Finland.

⁵ Change in a firm's status with respect to imports from all countries excluding EU15, Norway and the countries that acceded to the EU in 2004.

3.7 Intensive Margin Analysis

Proposition 3.2 states that higher electricity prices will lead firms to import more of a product that they are already importing, especially when they are products that are relatively electricity-intensive to produce in Sweden. The empirical specification on the intensive import margin is derived by taking the natural log of Equation (3.4.10) and adapting it to the product p , firm i and year t structure of our data. Our interest is in the change in the import of products that a given firm is already importing between 2001 and 2005. We use a first-differencing approach and exploit heterogeneity along two dimensions in firm exposure to the electricity cost shock to identify the impact of the electricity price increase on firm-level demand for imported intermediate inputs. We use both the variation in the electricity costs of firms and also the variation in electricity-intensity of the products they import. Our benchmark equation for testing the impact of the domestic electricity price increase on the relative demand for intermediate inputs is

$$\Delta \ln SM_{ipt} = \gamma_0 + \gamma_1 \Delta \ln(EP_{it}) + \gamma_2 \ln I_p + \gamma_3 \Delta \tau_{ipt} + \eta_{ipt}. \quad (3.7.1)$$

The dependent variable is defined as the change in the ratio of imported intermediate inputs to total intermediate input used by each firm. Formally:

$$\Delta \ln SM_{ipt} \equiv \ln\left(\frac{x_{ip,2005}}{x_{i,2005}}\right) - \ln\left(\frac{x_{ip,2001}}{x_{i,2001}}\right), \quad (3.7.2)$$

where x_{ipt} is the value of imported intermediate by product p by firm i in year t and x_{it} is the value of all intermediate inputs and raw materials used by firm i in year t . Panel B of Table 3.5 indicates that import intensities have decreased by 0.09 log points, which is approximately a 9% decrease in import intensity, with substantial variation across products.

There are two independent variables of principle interest in the intensive-margin analysis. The first is the change in the firm's average annual electricity cost each year. Proposition (3.2) predicts the sign on γ_1 to be positive: an increase in the price of electricity leads to an increase in the intensive margin of imports. Panel B of Table 3.5 indicates that electricity prices for firms in the intensive margin analysis increased by an average of 0.12 SEK/kWh, with substantial variation across firms.

The second variable of interest is I_p , the electricity intensity of the imported product (estimated from ISIC Rev 3.1 level), which we defined with Equation (3.6.2). Proposition (3.2) predicts the sign on γ_2 to be positive: firms will increase their imports of electricity-intensive products more for a given electricity price increase. We also include a control for the change in firm-product level import tariffs in all specifications. Panel B of Table 3.5 indicates that electricity intensity varies highly in this sample, while changes in import tariffs are minimal.

Table 3.8 reports the results of our estimation of Equation (3.7.1) by ordinary least squares. For the full sample, under column (1), there were 502 firm-product observations that entered the intensive margin regressions. Relatively few firms imported the

Table 3.8: The intensive margin of imports by country of origin¹

Dependent variable: $\Delta \ln SM_{ipt}$ ²	(1) All	(2) Norway, Denmark and Finland ³	(3) Non-Scand. EU15 ⁴	(4) Non-EU, Non-Scand. ⁵
$\Delta \ln(EP_{it})$: change in elec. cost	0.502 (0.393)	0.949 (0.608)	0.963 (0.388)**	1.408 (0.808)*
I_p : elec. intensity, imported product	-0.023 (0.115)	-0.257 (0.181)	-0.152 (0.159)	0.065 (0.712)
$\Delta \tau_{ipt}$: change in import tariff	0.086 (0.120)	0.113 (0.220)	-0.018 (0.137)	0.333 (0.351)
Observations	502	275	315	115
R^2	0.006	0.220	0.168	0.275

¹ * (p<0.10), ** (p<0.05), *** (p<0.01). Standard errors clustered at firm-level in all specifications. Five-digit industry fixed effects in all specifications. Pulp and paper imports excluded.

² The dependent variable is the change in the ratio of imports to total intermediate input use between 2001 and 2005, by firm and ISIC Rev. 3.1 product.

³ Sample restricted to include imports from Denmark, Finland and Norway only.

⁴ Sample restricted to include imports from EU15, but excluding Denmark, Finland and Norway.

⁵ Sample restricted to include imports from all countries excluding EU15, Norway and the countries that acceded to the EU in 2004.

same products between the years 2001 and 2005, suggesting that firms substitute readily between product categories. The specification yields estimates that can be interpreted as elasticities, however, the specification yields no statistically-significant results. In column (2), the dependent variable, $\Delta \ln SM_{ipt}$, captures the changes across imported products p from Denmark, Finland and Norway: countries whose electricity price is closely correlated with Sweden's. The electricity price change had no statistically significant effect on firm imports from other Scandinavian countries, as expected.

In column (3), the coefficient on the change in the firm's electricity cost, $\Delta \ln EP_{it}$, is positive and statistically significant at the 5% level. A 1% increase in the electricity price led to a 0.96% increase in the share of imported inputs from the pre-2004 EU member states excluding Denmark and Finland. In column (4), this coefficient is statistically significant at the 10% level, with a 1% increase in the electricity price leading to a 1.4% increase in the share of imported inputs from all countries except for the EU15, Norway and the countries that acceded to the EU in 2004. The coefficients on electricity intensity, I_p , are not statistically significant in any of regressions presented in Table 3.8.

Together, these results on the intensive margin suggest that firms do respond to higher domestic electricity prices by increasing imports of intermediate inputs from countries outside Scandinavia. However, in contrast to the extensive margin analysis, there is no evidence that the increase in imports was especially large for electricity-intensive products.

3.8 Conclusions

The increase in electricity prices experienced in Sweden after 2002 present an opportunity to study the impact of higher energy prices on imports. We develop a model of heterogeneous firms that choose to import intermediate inputs based on the price of electricity at home versus abroad. The model predicts that higher electricity prices encourage less productive firms to begin importing intermediate inputs. The model also predicts that higher electricity prices encourage firms to source a greater share of their intermediate inputs from abroad. These effects are predicted to increase in the electricity intensity of the imported products. We test these prediction using detailed data on firm imports and their electricity costs. On the extensive margin, we find that the probability of importing increased significantly more for electricity intensive products. On the intensive margin, we find that firms that faced the highest cost increases for electricity significantly increased their share of imported intermediate inputs.

Our findings suggest that imports are an important coping mechanism for firms that face a domestic factor price increase. This is valuable insight for policymakers in countries where electricity supply is undergoing a major transformation and higher electricity prices are a possible outcome. In particular, the results highlight an aspect of the importance of trade in intermediate imports.

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3.A Appendix

3.A.1 Solving the Productivity Cutoffs and Price Index

We present here the analytical solutions for the importer cutoff productivity (Equation 3.4.20) and the price index. Setting profits equal to zero in Equation 3.4.18, and rearranging yields an expression for the productivity of the firm that is indifferent between remaining a type-D firm and shutting down:

$$\varphi_D = \left(\frac{f}{B} \right)^{\frac{1}{\sigma-1}}.$$

Likewise, the productivity cutoff for type-M firms is found by setting profits equal to zero in 3.4.19 and rearranging:

$$\varphi_M = \frac{1}{\lambda_i} \left(\frac{f_m + f}{B} \right)^{\frac{1}{\sigma-1}}.$$

We combine these two cutoff equations to obtain the following parameter restriction:

$$\frac{\varphi_M}{\varphi_D} = \left(\frac{f_m + f}{f} \right)^{\frac{1}{\sigma-1}} \frac{1}{\lambda_i} > 1,$$

which is constrained to be greater than 1 to ensure that a necessary condition for becoming a type-M firm is that the productivity draw of the firm is greater than φ_D . The model is closed with the free entry condition

$$F = \int_{\varphi_M}^{\infty} \left(\frac{r_i^m}{\sigma} - f_m - f \right) dG(\varphi) + \int_{\varphi_D}^{\varphi_M} \left(\frac{r_i^d}{\sigma} - f \right) dG(\varphi) = \frac{R}{n\sigma}$$

The model yields analytical solutions for the productivity cutoffs and the price index assuming a Pareto distribution with a shape factor k . We impose the condition for convergence and define $\beta = k(\sigma - 1) > 0$. This yields the explicit solution for the cutoff conditions

$$\begin{aligned} \varphi_D^{\beta(\sigma-1)} &= \left(\lambda_i \frac{f}{f_m + f} \right)^{\beta} \left(\frac{1}{F} \left(\frac{f_m + f}{\beta - 1} \right) \Theta \right) \\ \varphi_M^{\beta(\sigma-1)} &= \frac{1}{F} \left(\frac{f_m + f}{\beta - 1} \right) \Theta \end{aligned}$$

for type-D and type-M firms respectively where

$$\Theta \equiv \left[\beta \left(1 - \left(\frac{1}{\lambda_i} \right)^{\sigma-1} \right) + \left(\frac{f_m + f}{f} \right)^{\beta-1} \left(\frac{1}{\lambda_i} \right)^{\beta(\sigma-1)} - \frac{f_m}{f_m + f} \right]$$

The price index is obtained by integrating across firm productivity

$$P^{1-\sigma} = n \left(\frac{\sigma}{\Gamma(\sigma-1)} \right)^{1-\sigma} \int_{\varphi_D}^{\infty} \left(\frac{1}{\varphi_i \lambda_i} \right)^{1-\sigma} dG(\varphi_i | \varphi_D).$$

The explicit solution is

$$P^{1-\sigma} = n \left(\frac{\sigma}{\Gamma(\sigma-1)} \right)^{1-\sigma} \frac{\beta}{\beta-1} \left(\frac{f}{f_m + f} \right)^{\beta-1} \frac{\varphi_D^{\sigma-1}}{(\varphi_D^{\beta(\sigma-1)} - 1)} \Lambda$$

where

$$\Lambda \equiv \left(\left(1 - \frac{1}{\lambda_i^{(\sigma-1)}} \right) \lambda_i^{\beta(\sigma-1)} + \frac{1}{\lambda_i^{\beta(\sigma-1)}} \left(\frac{f_m + f}{f} \right)^{(\beta-1)} \right)$$

3.A.2 A Proof of Proposition (3.1)

First we show that $\partial \varphi_M^{\beta(\sigma-1)} / \partial \rho < 0$. The sign of the impact of a change in $\frac{\rho_d}{\rho_f}$ on φ_M is derived as

$$\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \rho} = \frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i} \frac{\partial \lambda_i}{\partial \rho}. \quad (3.A.1)$$

It is enough to examine $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}$ alone since $\frac{\partial \lambda_i}{\partial \rho} > 0$ by Equation (3.4.13). Moreover $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}$ is in fact strictly negative. This is derived from

$$\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i} = \frac{\beta(\sigma-1)}{\beta-1} \left(\frac{f_m + f}{F} \right) \left[\frac{1}{\lambda_i^\sigma} - \frac{1}{\lambda_i^{\beta(\sigma-1)+1}} \left(\frac{f_m + f}{f} \right)^{\beta-1} \right], \quad (3.A.2)$$

and by the assumption that only active firms can be importers:

$$\frac{\varphi_M}{\varphi_D} > 1. \quad (3.A.3)$$

Together, these conditions suggest

$$\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \rho} < 0. \quad (3.A.4)$$

Second, we show the conditions under which $\partial^2 \varphi_M^{\beta(\sigma-1)} / \partial \rho \partial \delta < 0$. Formally this is derived by noting first that $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}$ is a function of δ via λ_i alone, hence

$$\frac{\partial}{\partial \delta} \frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \rho} = \overbrace{\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i}}^{\text{negative}} \frac{\partial^2 \lambda_i}{\partial \delta \partial \rho},$$

where $\frac{\partial \varphi_M^{\beta(\sigma-1)}}{\partial \lambda_i} < 0$ by Proposition (3.1). What remains to be characterized is the second term, which is:

$$\frac{\partial^2 \lambda_i}{\partial \delta \partial \rho} = \left(1 + \delta (1 - \alpha) \ln \rho \left(\frac{\frac{(\gamma-1)}{(1-\alpha)} + \rho^{\delta(\gamma-1)}}{1 + \rho^{\delta(\gamma-1)}} \right) \right) \overbrace{\frac{(1 - \alpha) \lambda_i \rho^{\delta(\gamma-1)}}{\rho (1 + \rho^{\delta(\gamma-1)})}}^{\text{positive}}$$

and the sign depends on

$$\text{sign} \left[\frac{\partial^2 \lambda_i}{\partial \delta \partial \rho} \right] = \text{sign} \left(1 + \delta (1 - \alpha) \ln \rho \left(\frac{\frac{(\gamma-1)}{(1-\alpha)} + \rho^{\delta(\gamma-1)}}{1 + \rho^{\delta(\gamma-1)}} \right) \right)$$

which is the condition described in Proposition (3.1).

3.A.3 Further Robustness checks

Table 3.9 summarizes the results of some further robustness checks on the extensive margin. In column (1) we control for the logged number of products that each firm imports. This variable controls for the possibility that the results could be driven by a small number of firms that import many products. The number of imports control is not statistically significant and our baseline results continue to hold. In column (2) we add a control for capital intensity, defined as the logged ratio of tangible capital to output. The capital intensity control is insignificant, which suggests that the results are not being driven by the fact that electricity-intensive inputs may also be more capital-intensive to produce.

Table 3.9: The extensive margin of imports. Some robustness checks.¹

Dependent variable: Δm_{ipt} ²	(1)	(2)
Q_{2001}^2 : second productivity quartile	0.053 (0.020)***	0.052 (0.020)**
Q_{2001}^3 : third productivity quartile	0.035 (0.022)	0.034 (0.023)
Q_{2001}^4 : fourth productivity quartile	0.037 (0.019)*	0.035 (0.019)*
$I_p \times Q_{2001}^2$	0.015 (0.005)***	0.015 (0.005)***
$I_p \times Q_{2001}^3$	0.008 (0.005)	0.008 (0.005)
$I_p \times Q_{2001}^4$	0.008 (0.005)	0.009 (0.005)
I_p : elec. intensity, imported product	-0.004 (0.003)	-0.004 (0.003)
$\Delta \ln(EP_{it})$: elec. price	0.003 (0.009)	0.003 (0.009)
τ_{ipt} : import tariff	-0.004 (0.002)**	-0.004 (0.002)**
Number of imported products ³	0.017 (0.045)	
Capital intensity ⁴		-0.005 (0.005)
Constant	-0.013 (0.013)	-0.021 (0.014)
Observations	14369	14299
R^2	0.042	0.042

¹ * p<0.10, ** p<0.05, *** p<0.01. Standard errors in parentheses, clustered at firm-level in all specifications. Pulp and paper imports excluded. Imports from countries that acceded to the EU in 2004 excluded. Five-digit industry fixed effects used in all specifications.

² The dependent variable is the change in the import status of a firm at the ISIC Rev. 3.1 product level between 2001 and 2005.

³ Logged number of imported products at the ISIC Rev. 3.1 level per firm.

⁴ Logged ratio of tangible capital to output per firm.

Chapter 4

Trade, transboundary pollution and market size¹

4.1 Introduction

An extensive literature explores the mechanisms through which trade can affect the environment. A topical concern is that trade liberalization allows firms to locate production in countries with lower emission standards: the 'pollution haven hypothesis' (PHH).² While there is considerable theoretical support and an intuitive appeal for the PHH, it has been hard to identify empirically, and the surveys by Copeland and Taylor (2004) and Brunnermeier and Levinson (2004) find conflicting results across the literature. Recent studies provide further conflicting evidence.³

The present paper suggests a new set of theoretical reasons that may help reconcile the contradictory empirical results reported in the PHH literature. The analysis juxtaposes relative market size and asymmetric emission tax levels in determining the patterns of production and pollution. Our theoretical findings suggest that relative market size, ease of abatement and product differentiation could be important variables in empirical studies examining trade liberalization and transboundary pollution.

We use a monopolistic competition trade model with several manufacturing sectors and transboundary emissions generated from the production of the manufactured goods with pollution abatement by the firm à la Copeland and Taylor (1994). The model is

¹This paper is co-authored with Rikard Forslid and Toshihiro Okubo.

²We will follow Copeland and Taylor (2004) and distinguish between the pollution haven effect (PHE), meaning that firms adjust their operation or location in response to differences in environmental taxes, and the pollution haven hypothesis (PHH) where trade liberalisation induces firms to relocate to the low tax country.

³Sector level data for pollution intensive industries in the U.S. has not been disproportionately affected by tariff changes Ederington et al. (2005). However, sector level data for the U.S. also shows that higher environmental standards have resulted in an increase in imports from Mexico in dirty industries Levinson and Taylor (2008). At the same time, Japanese sector level data shows increased imports from developing countries in sectors that are mobile and face higher environmental regulation compliance costs Cole et al. (2010).

specified in terms of a transboundary pollutant, and indeed we have greenhouse gas emissions in mind; however, absent welfare considerations, the analysis applies equally to local pollutants. To focus on effects related to the monopolistically competitive framework, we assume that countries are identical except for their size. Thus, there is intra-industry trade (within industry trade) with differentiated products, but no role for comparative advantage. In this type of framework, the number of firms increases more rapidly than output as a country becomes larger. The reason for this is that firms concentrate in the larger market to save on transportation costs. This effect has been dubbed the 'home market effect' (HME) by Helpman and Krugman (1985). At the same time, trade liberalization does not only affect the HME but also the PHH and the outcome of trade liberalization on global emissions will therefore depend on the interplay of the HME and the PHH.

We show how the HME dominates firm location when the size difference between markets is large, in sectors where abatement is easy, and when the degree of differentiation between goods is high. When the HME dominates, trade liberalization will lead firms to concentrate in the larger market. This will decrease global emissions if the larger market has stricter environmental standards. In contrast, the HME is weak when markets are relatively similar in size. Hence it is the PHH that dominates firm location. Trade liberalization then leads firms to concentrate in the country with lower emission taxes leading to higher global emissions. Our analysis suggests that under monopolistic competition and intra-industry trade, trade liberalization between similar countries (of similar size) may increase global emissions while trade liberalization between dissimilar countries can decrease global emissions if the large country has a more stringent environmental regulation.

Interestingly, our results, derived in a model with intra-industry trade, imply a qualification of the results obtained by Copeland and Taylor (1995) where trade is inter-industry (between industries). They show how trade liberalization tends to increase global emissions if the income differences between the liberalizing countries are large, as dirty industries expand strongly in the poor country with low environmental standards. Our results show that market size also matters. If the rich country has a larger market, then the HME may induce firms to stay despite higher emission taxes and trade liberalization may therefore decrease global emissions even if there is a large income difference between the countries.

There is a large theoretical literature that analyses trade and emissions within a neoclassical framework or an oligopolistic strategic setting (see e.g. Copeland and Taylor (2004) and Rauscher (1997)). A relatively smaller literature analyses trade and the environment in models with monopolistic competition. Gurtzgen and Rauscher (2000) examine transboundary pollution in a monopolistic competition framework with two countries and find that tighter environmental policies at home can lead to reduced emissions abroad. However, in contrast to this paper, their model does not feature trade costs and the effects of trade liberalization can therefore not be analysed. Other papers have used trade and geography models to investigate the interplay of trade, agglomeration and emissions. Pfluger (2001) uses a trade and geography model, the footloose

capital model, to include a disutility from local pollution to show that governments set inefficiently low emission taxes as trade costs fall – suggesting a pollution haven effect. Ishikawa and Okubo (2008) also use the footloose capital model to study the different impacts of environmental taxes and quotas for the location of firms as trade is liberalized. Zeng and Zhao (2009) use a trade and geography model with capital, land and labour where pollution harms the productivity of the agricultural sector. Their focus is on how trade liberalization affects the equilibrium location of footloose capital, and some of their results are driven by the HME, as in our model. Unlike Zeng and Zhao (2009), we use a standard one factor Dixit-Stiglitz model with a transboundary pollutant. We also differ from Zeng and Zhao (2009) by including firm abatement à la Copeland and Taylor (1994), which makes the model easily analytically tractable. Finally, we differ by introducing multiple manufacturing sectors in order to be able to focus on how sector level differences, e.g. in abatement technology and level of product differentiation, affect environmental outcomes.

4.2 The Model

This paper builds a two-country monopolistic competition trade model with multiple sectors and abatement costs. The focus of the discussion is how tax rate differentials interact with market size and thus tax rates are set exogenously.

4.2.1 Basics

There are two countries, home and foreign, denoted by $(j, m) \in (h, f)$, an A-sector and K individual M-sectors of manufactures denoted by $k \in (1, K)$. Each country has a single primary factor of production labour, L_j , used in the A-sector and the M-sector. The A-sector is a Walrasian, homogenous-goods sector, which is traded costlessly. M-sectors are characterized by increasing returns, Dixit-Stiglitz monopolistic competition and iceberg trade costs. M-sector firms face constant marginal production costs and fixed costs. Our model assumes that production by firms in the M-sector generates emissions of a transboundary pollutant. These emissions are a pure public bad in that emissions from any country affect welfare in both countries. Consumers in each nation have two-tier utility functions with the upper tier determining the consumer's division of expenditure among sectors and the second tier (CES) dictating the consumer's preferences over the various differentiated varieties within the M-sector.

All individuals in a country have the utility function:

$$U = C_M^\beta C_A^{1-\beta} - g(E_w), \quad \text{where} \quad C_M = \prod_{k=1}^K C_k^{\mu_k}, \quad (4.2.1)$$

where C_A is consumption of the homogeneous good, C_M is consumption of an aggregate of differentiated goods, $\beta \in (0, 1)$, and the sector shares in consumption of differentiated goods, $\mu_k \in (0, 1)$, sum to one, $\sum \mu_k = 1$. The function $g(E_w)$ captures climate damages and is a function of global emissions, which is the sum of emissions generated by the M-sectors in the home and foreign countries, $E_w = \sum_{k=1}^K (E_{h,k} + E_{f,k})$. Differentiated

goods from each manufacturing sector enter the utility function through a sector-specific index C_k , defined by

$$C_k = \left[\int_0^{N_k} c_{ik}^{(\sigma_k-1)/\sigma_k} di \right]^{\sigma_k/(\sigma_k-1)}, \quad (4.2.2)$$

N_k being the mass of varieties in sector k in the country, c_{ik} the amount of variety i consumed in sector k , and $\sigma_k > 1$ the elasticity of substitution in sector k .

The A-sector is subject to constant returns to scale and perfect competition. The unit factor requirement of the homogeneous good is one unit of labour. This good is freely traded and since it is chosen as the numeraire

$$p_A = w = 1; \quad (4.2.3)$$

w being the nominal wage of workers in all countries. Income consists of wage incomes $Y = L$. Each consumer spends an overall share β of his income on manufactures, and the demand for a variety i in sector k is therefore

$$x_{ik} = \frac{p_{ik}^{-\sigma_k}}{P_k^{1-\sigma_k}} \mu_k \beta L, \quad (4.2.4)$$

where p_{ik} is the consumer price of variety i in sector k , Y is income, and

$$P_k \equiv \left(\int_0^{N_k} p_{ik}^{1-\sigma_k} di \right)^{\frac{1}{1-\sigma_k}}$$

is the price index of manufacturing goods in sector k .

Let us also account for the fact that manufacturing activity entails pollution in terms of emissions.⁴ We follow Copeland and Taylor (1994) and assume that each firm i produces two outputs: a manufactured good (x_i) and emissions (e_i). Governments in both countries use emission taxes (production taxes). The tax revenue is used to produce a public good outside of the model. A firm can reduce emissions by diverting a fraction θ_i of the primary factor, labor, away from the production of x_i . Firms pay the fixed overhead costs, and thereafter joint production is given by

$$x_{ik} = (1 - \theta_{ik}) \frac{l_{ik}}{a}, \quad (4.2.5)$$

$$e_{ik} = \varphi_{ik}(\theta_{ik}) x_{ik}, \quad (4.2.6)$$

where l_{ik} is labour demand by firm i in sector k , a is the labour input coefficient, and $0 \leq \theta_{ik} \leq 1$. Emission intensity (e_{ik}/x_{ik}) is determined by the abatement function

$$\varphi_{ik} = (1 - \theta_{ik})^{\frac{1-\alpha_k}{\alpha_k}} \quad (4.2.7)$$

⁴We abstract from emissions related to the consumption of goods and only focus on supply-side emissions.

which is characterized by $\varphi_{ik}(0) = 1$, $\varphi_{ik}(1) = 0$, $\varphi'_{ik}(\cdot) < 0$, and $0 < \alpha_k < 1$. $\frac{1-\alpha_k}{\alpha_k}$ is a measure of the effectiveness of the abatement technology in sector k . Firms in each sector are symmetric in equilibrium, and we therefore drop subscript i from now on. Using (4.2.6) and (4.2.7) to substitute for θ_k in (4.2.5) yields

$$x_k = e_k^{\alpha_k} \left(\frac{l_k}{a} \right)^{1-\alpha_k} \quad (4.2.8)$$

from which we derive the variable cost function. Substituting out θ_k and with the fixed cost being sunk, we obtain the following cost function:

$$C_k = F + \kappa_k (wa)^{1-\alpha_k} t^{\alpha_k} x_k = F + \kappa_k t^{\alpha_k} x_k \quad (4.2.9)$$

where $\kappa_k \equiv \alpha_k^{-\alpha_k} (1 - \alpha_k)^{(1-\alpha_k)}$. We choose units of labour so that $a = 1$. t is the tax on emissions applied by the government. Profit maximization by a manufacturing firm in sector k and country j leads to consumer price

$$p_{jmk} = \frac{\sigma_k}{\sigma_k - 1} \tau_{jmk} \kappa_k t_j^{\alpha_k}, \quad (4.2.10)$$

in country m . Shipping the manufactured good involves a frictional trade cost of the “iceberg” form: for one unit of a good in sector k from country j to arrive in country m , $\tau_{jmk} > 1$ units must be shipped. It is assumed that trade costs are equal in both directions, $\tau_{jmk} = \tau_{mjk}$, and that $\tau_{jjk} = 1$, which allows us to drop the country subscript from trade cost, hence τ_k . The level of emissions for a firm in sector k is given by

$$e_k = \varphi_k x_k. \quad (4.2.11)$$

Thus, local emissions in country j from sector k are given by

$$E_{jk} = e_{jk} n_{jk}. \quad (4.2.12)$$

We note that emission intensity α_k , elasticity of substitution σ_k and trade costs τ_k are sector-specific parameters. With these sector-specific parameters having been established, we turn to analyse one representative M-sector and therefore omit the subscript k . Sectors can be analysed separately since the expenditure shares on each sector, μ_k , are constants.

4.2.2 Equilibrium

Firm profits in a sector are given by

$$\pi_h = \frac{\mu\beta}{\sigma} \gamma \kappa^{1-\sigma} \left(\frac{s}{\Delta_h} + \phi \frac{1-s}{\Delta_f} \right) t_h^{\alpha(1-\sigma)} - F \quad (4.2.13)$$

$$\pi_f = \frac{\mu\beta}{\sigma} \gamma \kappa^{1-\sigma} \left(\phi \frac{s}{\Delta_h} + \frac{1-s}{\Delta_f} \right) t_f^{\alpha(1-\sigma)} - F \quad (4.2.14)$$

where $\gamma \equiv \left(\frac{\sigma}{\sigma-1}\right)^{1-\sigma}$ and $\phi = \tau^{1-\sigma}$. $s \equiv \frac{L_h}{L_h+L_f}$ and $1-s \equiv \frac{L_f}{L_h+L_f}$ are the income and expenditure shares in home and foreign, respectively. Without loss of generality, we set $L_h + L_f = 1$. Finally,

$$\Delta_h \equiv n_h p_h^{1-\sigma} + n_f \phi p_f^{1-\sigma} \quad (4.2.15)$$

$$\Delta_f \equiv n_h \phi p_h^{1-\sigma} + n_f p_f^{1-\sigma}. \quad (4.2.16)$$

Assuming free entry ensures that the equilibrium firm profits are zero. The operating profit, $px - MC \cdot x$, must then equal the fixed cost F . Price is a constant mark-up on the marginal cost, which yields the equilibrium scale of a firm in country j

$$x_j^* = \frac{F(\sigma-1)}{\kappa t_j^\alpha}. \quad (4.2.17)$$

Substitute (4.2.10), (4.2.15), and (4.2.16) into to equations (4.2.13) and (4.2.14), at zero profit, to obtain the equilibrium values for n_j

$$n_h = \frac{\mu\beta \{((1-s)\phi^2 + s)T^{\alpha(\sigma-1)} - \phi\}}{\sigma F \{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}} \quad (4.2.18)$$

$$n_f = \frac{\mu\beta T^{\alpha(\sigma-1)} \{1 - (1-\phi^2)s - \phi T^{\alpha(\sigma-1)}\}}{\sigma F \{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}} \quad (4.2.19)$$

where $T \equiv \frac{t_f}{t_h}$. The global number of firms in each sector is constant

$$n^w = n_h + n_f = \frac{\gamma\kappa\mu\beta}{\sigma F}, \quad (4.2.20)$$

a customary result of Dixit-Stiglitz models.

The model displays what Helpman and Krugman (1985) call a 'home market effect' (HME). That is, firms disproportionately locate to the larger market. The reason for this is that firms save on transportation costs by locating production closer to centres of demand, i.e. in the larger market. The HME is amplified by trade liberalization and may lead to the concentration of all manufacturing firms in the larger market for sufficiently low trade costs. To illustrate the HME, consider a case where the emission taxes of the home and foreign country are symmetric, $t_h = t_f$ ($T = 1$). This gives the share of firms in the home country as a function of s and ϕ

$$s_n \equiv \frac{n_h}{n_f + n_h} = \frac{\{((1-s)\phi^2 + s) - \phi\}}{(1-\phi)^2}. \quad (4.2.21)$$

Differentiating (4.2.21) with respect to s yields

$$\frac{ds_n}{ds} = \frac{1+\phi}{1-\phi} > 1. \quad (4.2.22)$$

As the relative size of home increases, the share of firms locating in home increases more than proportionately; this is the HME. Furthermore, as seen from (4.2.22), the steepness of $\frac{ds_n}{ds}$ increases in ϕ . Trade liberalization magnifies the HME.

4.2.3 Emissions and emission intensity

In country j , a firm's demand for emissions (as input to production) is derived by applying Sheppard's lemma on the cost function:

$$e_j = \frac{\partial C_j}{\partial t_j} = \alpha \kappa t_j^{\alpha-1} x_j, \quad (4.2.23)$$

which yields the emission intensity

$$\frac{e_j}{x_j} = \frac{\alpha \kappa}{t_j^{1-\alpha}}. \quad (4.2.24)$$

Substituting the firm's equilibrium output from (4.2.17) gives firm-level emissions:

$$e_j = \frac{\alpha F(\sigma - 1)}{t_j}. \quad (4.2.25)$$

A higher emission tax and a more efficient abatement technology (lower α) decreases firms' emissions and emission intensity.⁵ Total emissions from a sector in the two countries are given by

$$E_h = n_h e_h = \frac{\alpha(\sigma - 1)\mu\beta}{\sigma t_h} \frac{\{((1 - s)\phi^2 + s)T^{\alpha(\sigma-1)} - \phi\}}{\{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}}, \quad (4.2.26)$$

$$E_f = n_f e_f = \frac{\alpha(\sigma - 1)\mu\beta}{\sigma t_f} \frac{T^{\alpha(\sigma-1)} \{1 - (1 - \phi^2)s - \phi T^{\alpha(\sigma-1)}\}}{\{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}}. \quad (4.2.27)$$

4.3 The effect of trade liberalization on emissions

The analysis juxtaposes the impact of a varying market size and asymmetric emission taxes. The size difference gives rise to an HME, while the difference in emissions taxes leads to a PHH effect. Before examining the interplay of these forces, we characterize the HME and the PHH separately. We continue to suppress the sector index, unless noted otherwise, because of the symmetry of sectors.

4.3.1 Symmetric taxes

In this section, we constrain emission taxes to be symmetric in the home and foreign country, $t_h = t_f = t$, which negates the PHH. Isolating the HME means that trade liberalization will lead to a relocation of firms to the larger market. At the same time, note that equation (4.2.25) suggests that firm emissions are unaffected by ϕ . It follows from this that emissions will increase in the large market and decrease in the small one, as trade is liberalized. More precisely, the shift of production to the larger market entails a proportionate shift of emissions. Substituting $t_h = t_f = t$ into equations

⁵Note that $\alpha \kappa = \alpha^{(1-\alpha)}(1 - \alpha)^{(1-\alpha)}$, which increases in α .

(4.2.26) and (4.2.27) yields

$$E_h|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t} \frac{\{s(\phi+1) - \phi\}}{\{1-\phi\}}, \quad (4.3.1)$$

$$E_f|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t} \frac{\{1 - (1+\phi)s\}}{\{1-\phi\}}. \quad (4.3.2)$$

All firms, and therefore all emissions, end up in the larger market for sufficiently open trade ($\phi \geq \frac{1-s}{s}$). Note also that no relocation takes place if countries are exactly equal in size ($s = 0.5$), in which case each country generates half of global emissions.

The sum of equations (4.3.1) and (4.3.2) yields global emissions from a single sector

$$E^w|_{t_j=t} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t}. \quad (4.3.3)$$

This suggests that when taxes are symmetric, global emissions from each sector decrease in the emission tax rate and abatement efficiency α . However, note that global emissions are independent of trade openness ϕ .

Proposition 4.1. *Trade liberalization leads to higher emissions in the larger market and lower emissions in the smaller market, but trade liberalization does not affect global emissions when environmental taxes are symmetric in the two countries.*

Proof. Differentiating the expressions (4.3.1) and (4.3.2) gives $\frac{\partial E_h}{\partial \phi} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t} \frac{2s-1}{(1-\phi)^2}$ and $\frac{\partial E_f}{\partial \phi} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t} \frac{1-2s}{(1-\phi)^2}$. It is seen from these expressions that $\frac{\partial E_h}{\partial \phi} > 0$ and $\frac{\partial E_f}{\partial \phi} < 0$ for $s > \frac{1}{2}$ and that $\frac{\partial E_h}{\partial \phi} < 0$ and $\frac{\partial E_f}{\partial \phi} > 0$ for $s < \frac{1}{2}$. Finally, it is seen directly from (4.3.3) that global emissions are unaffected by ϕ . \square

Intuitively, since the global mass of firms and emissions per firm are unaffected by trade liberalization, it must be the case that global emissions are constant in ϕ .

4.3.2 Symmetric markets

Next we constrain market sizes to be identical in home and foreign ($s = \frac{1}{2}$), while we allow environmental taxes to vary. The identical market sizes isolates effects related to the PHH but negates the HME.

The relative mass of firms in the two markets now depends on the relative tax rates and the level of trade costs. Combining equations (4.2.18) and (4.2.19) yields the relative mass of firms in the home and foreign country

$$\frac{n_h}{n_f} \Big|_{s=\frac{1}{2}} = \frac{(1+\phi^2)T^{\alpha(\sigma-1)} - 2\phi}{1+\phi^2 - 2\phi T^{\alpha(\sigma-1)}}. \quad (4.3.4)$$

Note first that when $T = 1$, i.e. a totally symmetric economy, the expression reduces to $\frac{n_h}{n_f} = 1$. From (4.3.4), the condition for there being manufacturing firms in both countries is

$$\frac{2\phi}{1+\phi^2} < T^{\alpha(\sigma-1)} < \frac{1+\phi^2}{2\phi}. \quad (4.3.5)$$

The range of relative taxes, T , for which there are firms in both countries varies with the level of trade costs. Firms are active in both countries for any $T > 0$ in autarky ($\phi = 0$), but the range shrinks as trade is liberalized. The range collapses to $T = 1$ for free trade ($\phi = 1$). Any tax difference would lead all firms to relocate to the low tax country when trade is free.

Differentiating (4.3.4) with respect to T yields the change in the location of production for a change in the relative tax rate

$$\left. \frac{\partial \left(\frac{n_h}{n_f} \right)}{\partial T} \right|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1) T^{\alpha(\sigma-1)-1} (1-\phi^2)^2}{(2\phi T^{\alpha(\sigma-1)} - 1 - \phi^2)^2} > 0. \quad (4.3.6)$$

Thus, a relative decrease in the tax rate of the home country leads to an increase in the share of firms in the home country. This identifies a pollution haven effect: firms are drawn to countries with low environmental standards.

The effect of trade liberalization on the location of production is obtained by differentiating (4.3.4) with respect to ϕ :

$$\left. \frac{\partial \left(\frac{n_h}{n_f} \right)}{\partial \phi} \right|_{s=\frac{1}{2}} = -\frac{(1-\phi^2)(1-T^{2\alpha(\sigma-1)})}{(2\phi T^{\alpha(\sigma-1)} - 1 - \phi^2)^2} > 0 \text{ for } T > 1. \quad (4.3.7)$$

This shows that trade liberalization leads more firms to locate in the low tax country (in this case the home country). This is the PHH.

Proposition 4.2. *The country with the lower tax rate has the larger share of firms when markets are symmetric.*

Proof. The proposition follows directly from (4.3.6). \square

Proposition 4.3. *Trade liberalization leads to a relocation of firms to the low tax country when markets are symmetric.*

Proof. Proof: The proposition follows directly from (4.3.7). \square

We now turn to analysing how the relocation of firms affects emissions. Emission levels in the home and the foreign country when markets are symmetric are obtained by setting $s = \frac{1}{2}$ in equations (4.2.26) and (4.2.27). This yields

$$E_h|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t_h} \frac{\left\{ \frac{1}{2}(\phi^2+1)T^{\alpha(\sigma-1)} - \phi \right\}}{\{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}}, \quad (4.3.8)$$

$$E_f|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\beta}{\sigma t_f} \frac{T^{\alpha(\sigma-1)} \left\{ 1 - \frac{1}{2}(1-\phi^2) - \phi T^{\alpha(\sigma-1)} \right\}}{\{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}}. \quad (4.3.9)$$

Emissions are higher in a low tax country when market sizes are symmetric. This is a consequence of firstly, firms migrating to the the country with a lower emission tax (the PHH), and secondly that firms pollutes more when the tax is lower (see equation (4.2.25)).

Global emissions E^w from the sector are found by summing (4.3.8) and (4.3.9). To characterize the change in global emissions with trade liberalization, we differentiate E^w with respect to ϕ :

$$\left. \frac{\partial E^w}{\partial \phi} \right|_{s=\frac{1}{2}} = \frac{\alpha(\sigma-1)\mu\beta}{2\sigma t_h t_f} \frac{T^{\alpha(\sigma-1)}(1-\phi^2)(T^{2\alpha(\sigma-1)}-1)(t_f-t_h)}{(\phi T^{\alpha(\sigma-1)}-1)^2(T^{\alpha(\sigma-1)}-\phi)^2} > 0. \quad (4.3.10)$$

The sign of this expression does not depend on the sector-specific parameters (α, σ, τ) , which means that trade liberalization increases emissions across all K manufacturing sectors.

Proposition 4.4. *Trade liberalization leads to higher global emissions if environmental taxes differ between countries and markets are symmetric.*

Proof. The proposition follows directly from (4.3.10). \square

Trade liberalization makes it easier for firms to concentrate in the low tax country, and since the global mass of varieties is always constant, it must be the case that trade liberalization leads to more emissions; that is, we have a pollution haven. This result is congruent with the neo-classical analysis (see Copeland and Taylor (2004)).

4.3.3 The general case

We now turn to the case where both market size and taxes differ between the two countries: both s and T are unconstrained. Global sector-level emissions are found by summing equations (4.2.26) and (4.2.27) to obtain

$$E^w = \frac{\alpha(\sigma-1)\mu\beta}{\sigma} \frac{1}{t_f} \frac{T \{((1-s)\phi^2 + s)T^{\alpha(\sigma-1)} - \phi\} + T^{\alpha(\sigma-1)} \{1 - (1-\phi^2)s - \phi T^{\alpha(\sigma-1)}\}}{\{1 - \phi T^{\alpha(\sigma-1)}\} \{T^{\alpha(\sigma-1)} - \phi\}}. \quad (4.3.11)$$

The change in global emissions from a change in trade openness is given by

$$\frac{\partial E^w}{\partial \phi} = \alpha(\sigma-1)\mu\beta T^{\alpha(\sigma-1)}(T-1) \frac{\left(s(T^{\alpha(\sigma-1)} - \phi)^2 - (1-s)(T^{\alpha(\sigma-1)}\phi - 1)^2 \right)}{\sigma t_f (1 - \phi T^{\alpha(\sigma-1)})^2 (T^{\alpha(\sigma-1)} - \phi)^2}. \quad (4.3.12)$$

The effect of trade liberalization on global emissions is in this case determined by the interplay of the two forces that have been discussed so far; the HME and the PHH.

Consider the case where the larger country has the lower emission tax ($s > \frac{1}{2}$ and $T > 1$). In this setting, trade liberalization induces firms to move to the large market (the HME) and so does the lower tax on emissions (the PHH). Trade liberalization will therefore lead to a larger share of firms in the large low tax country, and consequently to higher global emissions.

Proposition 4.5. *Trade liberalization leads to an increase in global emissions if the larger market has lower emission taxes.*

Proof. $(T^{\alpha(\sigma-1)} - \phi)^2 \geq (T^{\alpha(\sigma-1)}\phi - 1)^2$ for $T > 1$, and $s > (1 - s)$ for $s > \frac{1}{2}$. The numerator in (4.3.12) is therefore positive, which implies that $\frac{\partial E^w}{\partial \phi} > 0$. \square

However, the effect of trade liberalization is ambiguous when the larger country has the higher emission tax ($s > \frac{1}{2}$ and $T < 1$). In this case, the HME and the PHH counteract each other; firms would prefer to escape the higher tax in the large market (the PHH), but they are at the same time drawn to the larger market because of the HME. The effect of trade liberalization on the location of production and on global emissions therefore depends on the relative strength of the HME and PHH; trade liberalization will decrease global emissions when the HME outweighs the PHH effect. The dominant force is determined by relative country size, relative taxes and trade costs. For example, the HME is increasing in market size asymmetry. As an extreme case, evaluate equation (4.3.12) at $s = 1$ and $T < 1$. This yields $\frac{\partial E^w}{\partial \phi} < 0$, implying that trade liberalization decreases global emissions.

Figures 4.1 and 4.2 plot (4.3.11) and (4.2.18) in two cases, when the large home country has higher emission taxes,⁶ that is, when the HME and the PHH counteract each other.

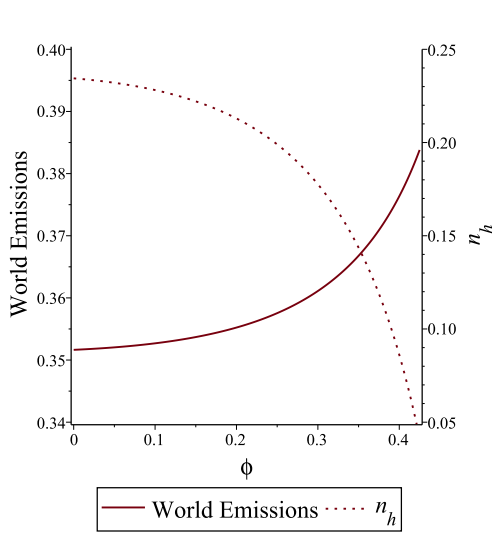


Figure 4.1: Trade liberalization increases global emissions

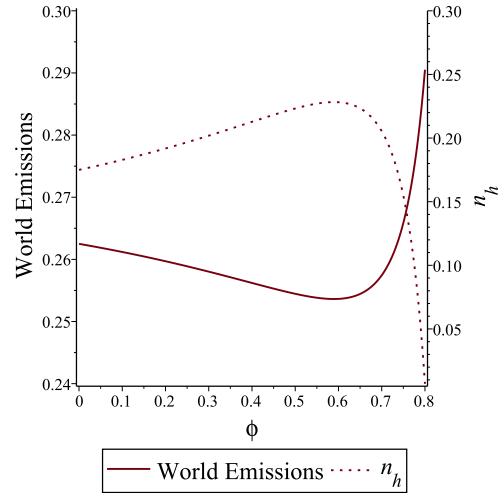


Figure 4.2: A U-shaped relationship between trade liberalization and global emissions

The HME is always dominated by the PHH in Figure 4.1, leading to a monotone increase in global emissions, as trade is liberalized. Firms continuously move to the lower tax country as trade is liberalized and this increases global emissions. Remember

⁶The parameters used to plot Figure 1 are $\sigma = 6, \mu = 0.5, \alpha = 0.7, t_h = 0.35, t_f = 0.3, s = 0.7, F = 0.1$ and likewise Figure 2 is plotted with $\sigma = 2, \mu = 0.5, \alpha = 0.7, t_h = 0.35, t_f = 0.3, s = 0.7, F = 0.5$.

that the global mass of firms is constant and that firm emissions are independent of ϕ . A movement of firms from the high tax home country is a sufficient condition for increased global emissions.

Figure 4.1 on the other hand illustrates a case where the HME dominates the PHH for a range of trade costs, although this dominance switches as trade costs fall sufficiently. Here, we have a U-shaped relationship between trade costs and global emissions. As trade is liberalized, starting from autarky, global emissions are reduced as firms are drawn to the larger high tax country. However, as trade is further liberalized, the pattern is reversed and global emissions then increase as we approach free trade. This effect follows from the well established property of the HME: the strength of the HME is increasing in trade costs and is strongest for intermediate trade costs. When trade costs are high, there is little trade and thus little incentive for firms to locate in the large market and export to the smaller market to save on trade costs. On the other hand, with low trade costs, firms have no incentive to avoid trade costs. Thus, the HME is U-shaped in ϕ . Trade liberalization therefore first leads to lower emissions as the HME grows stronger, and more firms are drawn to the high tax economy. However, when trade liberalization reaches the point where the HME weakens, further liberalization induces firms to move away from the large high tax country, which increases the emissions.

It is possible to distinguish the two cases by noting that E^w (by equation (4.3.11)) is a second-order polynomial in ϕ . We can determine if we are in the case shown by Figure 1 or in the case shown by Figure 2 by evaluating $\frac{\partial E^w}{\partial \phi}$ at $\phi = 0$. Trade liberalization increases global sector level emissions, as in Figure 1, if the derivative evaluated at $\phi = 0$ is positive. Likewise, a negative derivative implies that global emissions are U-shaped in ϕ . The condition that distinguishes the cases is given by the following proposition:

Proposition 4.6. *Global sector level emissions are U-shaped in trade freeness when $T^{2\alpha(\sigma-1)} < \frac{1-s}{s}$, and increase monotonically in trade freeness when $T^{2\alpha(\sigma-1)} > \frac{1-s}{s}$.*

Proof. The proposition follows from substituting $\phi = 0$ in (4.3.12). \square

Trade liberalization decreases emissions when the home country is sufficiently large relative to the tax difference. The threshold between the U-shaped and monotonically increasing global emissions is a function of the sector-specific parameters σ and α . Trade liberalization is more likely to increase emissions in sectors with a high σ , since a higher σ implies that goods are closer substitutes, which decreases the importance of the HME. Second, a higher α (a less efficient abatement technology) increases the likelihood that trade liberalization increases emissions, since it makes firms more sensitive to the emission tax, which implies that a larger difference in size is needed to compensate firms for the higher tax in the larger market.

Our results have several implications for empirical studies of the PHH. In particular, they suggest that relative market size, trade costs, ease of abatement, and the substitutability of goods may need to be considered in the design of the estimated equation.

4.4 Concluding remarks

This paper uses a monopolistic competitive framework with many sectors to study the impact of trade liberalization on local and global emissions. We focus on effects stemming from tax differences (PHH) and the differences in market size (HME) and exclude comparative advantage effects derived from differences in factor intensities; our model only has one factor of production.

We begin the analysis by examining the home market effect and the effect of asymmetric emission taxes separately. We find that trade liberalization does not affect global emissions if taxes are identical in the two countries. In this setting, the home market effect induces firms to locate to the larger market which, in turn, implies higher emissions in the larger market and lower emissions in the small market; however, global emissions remain constant. On the other hand, when countries are symmetric in size but emission taxes differ, trade liberalization increases global emissions. This result is driven by the pollution haven effect.

We then analyse the general case, relaxing the constraints on market size and emission taxes. Trade liberalization increases emissions when the HME and the PHH reinforce each other. This is the case when the larger country has a lower emission tax. As trade is liberalized, both the HME and the PHH draw firms to the larger market which results in higher global emission. However, trade liberalization may not result in increased global emissions when the HME and the PHH work against each other. This happens when the larger country has a higher emission tax. If the HME dominates the PHH, then trade liberalization will result in a decrease in global emissions as firms are drawn to the large, high tax economy. It is not uncommon that a large country liberalizes trade with a smaller market with a laxer environmental standard. The fact that some studies fail to identify PHH effects, could be due to the fact that the market under study is large enough to overcome the PHH.

Generally, our results suggest that the relative market size, the level of trade costs, the ease of abatement, and the degree of product differentiation at the sectoral level are relevant variables for empirical studies on trade and pollution.

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Chapter 5

What's holding it back? A study in organic retail coffee purchases¹

5.1 Introduction

Many people claim to be willing to buy environmentally friendly and ethically labeled products, even if such products are more expensive. For instance Eurobarometer (2011, p 76) reported that 72 percent of respondents are ready to buy environmentally friendly products even if they cost more (this result was based on face-to-face interviews with more than 26,000 respondents across the 27 EU member states). Hertel et al. (2009) reported that 75 percent of a random sample of US coffee buyers would be willing to pay at least 50 cent more per pound to buy Fairtrade-labeled coffee (which can be related to the average price per pound of 3 dollars). Despite these stated intentions the market for environmental and ethically-labeled (EE-labelled) products remains relatively small. The estimated market share of organic coffee in Germany and Italy (Europe's largest and second largest coffee markets) is 3 percent and around 0.5 percent respectively.² In the USA, organic coffee had an estimated market share of around 3.5 percent (by value) in 2009. Shares for ethically labeled coffee (e.g. Fairtrade) are lower.³

Why are market shares of organic and Fairtrade-labeled products not higher given the stated intentions of consumers? There are several potential explanations. Are EE-labeled products only available in a small fraction of stores, such that it is a lack of access that limits purchases? Or are prices for these products simply too high? Or is the breadth of choice too limited? Or is it the consumers themselves who, consciously or not, exaggerate the extent to which they are willing to buy organic and Fairtrade-labeled products? These questions motivate the present article. We use a consumer scan panel of Swedish households' coffee purchases, and stated behavior of these same

¹This paper is co-authored with Richard Friberg, Stockholm School of Economics and CEPR

²Tropical Commodity Coalition (2012).

³Organic Trade Association, 2010 *Organic coffee market tops \$1.4 billion in North America, new survey shows*. Press release, 15 June 2010.

households, to examine the propensity to buy organic products. Firstly, we relate the stated behavior of a household to the same household's actual shopping choices. We observe the coffee varieties that households buy at the bar-code level as well as a number of demographic variables such as area of residence, household income and the number of people in the household. We also observe the age and level of education of the household's primary shopper. The source of data is the market research firm GfK. Once a year participating households fill in a questionnaire and answer whether they, to the extent feasible, try to buy organic products when shopping.⁴ We find that even households that say they do their utmost to purchase organic products in fact buy mostly conventional coffee.⁵ Over the three years that we examine, only 22 percent of the coffee bought was organic for the group that were in total agreement with the statement that 'When I buy groceries I try to the extent feasible to buy organic.'

To systematically investigate coffee choice we combine revealed and stated behavior and apply a discrete-choice, conditional logit, model of demand. We establish that survey responses have important predictive power for household organic coffee purchases. Furthermore, household willingness to pay is in line with their survey responses. I.e., households that said they try buy organic products have, as demonstrated through the shopping choices they made in the market, higher choice probabilities for organic labels. Thus, we establish that stated behavior is indeed informative, but also that even the most keen organic households buy mostly conventional coffee. The last year included in the data set a corresponding question was introduced for Fairtrade products. While the qualitative results of interactions between choice of Fairtrade coffee and stated behavior are similar as for organic coffee, the significance is lower, reflecting less observations. In the paper we therefore focus on the choice of organic coffee.

While a tendency to verbally profess pro-social behavior is well documented,⁶ we note several other explanations that could explain low market shares for EE-labeled products. We use the demand estimates to examine how the choice probabilities of organic coffee would be affected by changes in availability or prices. We consider three counterfactual scenarios. Firstly, a household might not buy any organic products because these products are simply not available in nearby stores, suggesting lack of access as an explanation for the discrepancy. When there are fixed costs of supplying a particular product, sufficiently many consumers need to share your preferences if that product is to be offered (for an early formalization of this problem see Spence (1976) and for empirical evidence of this mechanism see for instance George and Waldfogel (2003). Secondly, for the same reason, there may be a limited overlap of organic labeling with other characteristics that consumers value. A household could very well value organic, but also value a particular brand that is not available as an organic coffee. The

⁴The subjects surveyed answer the questions by ticking a box that corresponds to one of five responses that vary from 'Totally Agree' to 'Totally Disagree.'

⁵'Conventional coffee' in this context refers to non-organic and non-Fairtrade labeled coffee.

⁶See for instance Harrison and Rutstrom (2005).

value associated with a brand may trump the value associated with organic. Again, with fixed costs of retailing a particular product, sufficient numbers of consumers need to demand a combination of characteristics for the product to be offered. Finally we examine the effect of lowering prices - a household might sincerely try to buy organic or Fairtrade products but find them too expensive relative to the next-best alternative.

Around 11 percent of the coffee purchases of consumers who state that they 'agree' or 'totally agree' to the organic statement are organic. To examine the importance of lack of access per se we introduce a synthetic counterfactual organic product that is made available in all stores. We equalize the fixed effect for this product to the median fixed effect across all products. The introduction of such a product increases the share of organic purchases only marginally. Our results thus indicate that lack of access to organic coffee per se is not an important constraint on household purchases. In contrast, when we introduce a synthetic brand where the fixed effect has been set at the 75th percentile at the distribution of fixed effects we predict a market share among the stated organic shoppers of some 40 percent. This suggests that a limited overlap between organic and other coffee characteristics is an important constraint facing self-reported organic households. The high price of organic coffee is also an important constraint. We predict that a halving of the organic price premium is associated with a doubling of organic purchases among the self-professed organic households.

These counterfactuals provide insight on why the share of organic products is not higher. In a second step one could examine if, under the status quo, producers and retailers are 'leaving money on the table' - calculations such as these are highly relevant to coffee producers contemplating pricing policy or product assortment. If we could observe the cost of developing and distributing additional products, and were willing to make behavioral assumptions on competitor responses, it would be possible to calculate the profitability of changes in strategy.⁷ However, absent such information, any suggestion to further increase producer profits would be speculative. We therefore contend ourselves with an examination of consumer responses to a relaxing of potential constraints for organic market penetration.

Let us briefly clarify how our paper relates to the literature. First and foremost we relate to a large number of articles that examine the impact of the introduction of EE-labeled products and that try to estimate the willingness to pay for EE-labels. A number of different approaches have been used. One set of studies use market data, similar to ours, but without complementing the data with stated preferences. For example Bjorner et al. (2004) use a discrete choice model to establish that the introduction of an organic label in Denmark had a significant impact on brand choices for toilet paper and

⁷How straightforward this is of course depends on what one is willing to assume, back-of-the-envelope calculations are easy enough to make under different scenarios by simply using the estimated demand system. If we are to more rigorously model strategic interactions the complexity increases substantially, see for instance Dubé et al. (2005) for an overview.

washing detergents (but less so for paper towels). Kiesel and Villas-Boas (2007) find that the appearance of a government sponsored label on organic milk increased consumer valuation of organic milk and Teisl et al. (2002a) document substantial consumer responses to the appearance of dolphin-safe labels in the USA. Willingness to pay for environmental and ethical labels has also been estimated using stated preference methods and choice experiments across a range of products. Overall these studies also tend to find positive willingness to pay for such labels. For example, on coffee in particular, Loureiro et al. (2003) use face-to-face interviews to study willingness to pay for EE-labeled coffee and find that consumers in the USA were on average willing to pay a premium of 3-4 percent for Fairtrade coffee. Their corresponding estimate for organic coffee was 2.5 percent. Hainmueller et al. (2011) conduct labeling experiments in stores and find that sales of two popular brands of coffee increased by almost 10 percent when they were labeled as being Fairtrade products. Likewise a study by De Pelsmacker et al. (2005) found willingness to pay premiums for Fairtrade coffee at 10 percent amongst Belgian test subjects.⁸ Thus, a positive willingness to pay for EE-labels is a feature in many studies and serves as a motivation for our examination of why the market share for EE-labeled products is not higher, despite an important fraction of consumers appearing to have a positive willingness to pay for such products.

As noted a part of the above literature relies on stated preferences. Asking about willingness to pay for organic products can be problematic. A desire to conform to social norms can bias responses. Indeed a rather large set of papers analyze the discrepancy between answers to questionnaires (typically involving contingent valuation) and observed actions in a lab or field experiment. Many such studies find evidence of what Harrison and Rutstrom (2005) refer to as hypothetical bias: a systematic difference between values that are elicited in a hypothetical context, such as a questionnaire, and those elicited in a real context, such as a market where decisions are economically binding (see for instance Blumenschein et al. (2008), Cummings and Harrison (1995), and Seip and Strand (1992)). Test subjects in many of the studies on hypothetical bias are likely to make the connection between the questions being asked and the behavior being tracked. In these settings, anchoring and other behavioral biases can affect findings. We see our contribution to this literature as small, but not irrelevant. We use responses to a questionnaire that asks whether people, to the extent feasible, purchase organic products when they visit grocery stores but only track one product category. Thus our data cannot yield a precise estimate of hypothetical bias.⁹ However, the questions we use are but two of a total of 35 questions asked in the annual survey and the market data tracks consumer choice across a regular assortment and prices of coffee

⁸Several studies have also found considerably higher willingness to pay estimates. Rotaris and Danielis (2011) survey Italian coffee consumers and Hertel et al. (2009) surveys US consumers. They both find that a majority of test subjects would be willing to pay premiums of around 50 percent.

⁹The reason is that a subject could purchase organic varieties of all products apart from coffee, and still be seen as answering truthfully. On the other hand, as we show below, coffee is one of the foremost categories of organic and Fairtrade products.

during a year. Thus we believe that anchoring, or the need to keep one's word, is likely to be weak in our setting. In this way the results of our study provide support for the hypothesis that stated behavior is informative of actual behavior regarding organic and Fairtrade-labeled products, a finding that should prove valuable to works that for instance use survey data such as the Eurobarometer (as in Koos (2011) discussed below).

A final strand in the literature estimate willingness to pay for EE-labels using a combination of detailed data on household purchases (tracked over years or months), and stated preference or choice experiment data performed by the same households. A recent example of such a study is Brooks and Lusk (2010), wherein a multinomial-logit model was used to estimate consumer response to milk from cloned cows in the USA. They gauged the social-welfare benefits of labeling initiatives. Their results indicate that consumers are willing to pay large premiums to avoid milk from cloned cows. They also show that predictive power is improved by combining revealed and stated preferences.¹⁰ In a related study Griffith and Nesheim (2010) deploy revealed preference methods to estimate bounds on the willingness to pay for product characteristics, they extend work by Blow et al. (2008), to accommodate a basket of goods and examine consumer response to the organic label. The consumer scan panel they use also includes questionnaires that are similar to those included in our data set. They show that the lower bound on willingness to pay for organic products is higher for households that agree strongly/agree to the statement that 'I try to buy environmentally friendly products.' (Griffith and Nesheim (2010), Table 9).

We are not aware of any previous studies that apply, as we do, supply-side counterfactual exercises to examine the role of product availability and prices as a constraint on expansion of organic purchases.¹¹ An interesting comparison can be made with Koos (2011) who uses responses from the 2007 edition of Eurobarometer (a survey of some 17000 individuals across 18 European countries) to provide a cross-sectional account of the probability that a consumer purchases environmental-labeled products. As explanatory variables he uses individual-level demographic characteristics as well as a number of country-level variables intended to capture supply side factors; such as whether there exist state-backed environmental labels, the number of competing environmental labels, the share of retailers that have less than ten employees and a measure of the supply of environmentally labeled products.¹² Interestingly, the supply of environmentally-

¹⁰Other studies that combine revealed and stated preferences include Hensher and Bradley (1993), Adamowicz et al. (1994) and Brownstone et al. (2000).

¹¹The application of structural models to predict market shares under various counterfactuals is not new however; see for instance Hausman (1996) or Petrin (2002) for ex-post examinations of the welfare effects of new product introductions (breakfast cereal and the Chrysler minivan, respectively). Other factors, that we are unable to investigate with our data, can also affect the effectiveness of eco-labeling. Teisl et al. (2002b) for instance report results from three experiments on the informational content in eco-labels.

¹²This latter measure was calculated by combining the national share of farm land used for organic production with measures of the number of non-food environmental-labeled products available.

labeled products is the only variable, apart from individual-level demographics, that has a robust positive influence on the probability that environmental-labeled products are purchased. A concern that one may have in interpreting this result is that supply and demand should in theory be determined jointly and the significance of supply may be partly reflecting its endogeneity. The result from our counterfactual experiments, that broadening the overlap between organic coffee and brands on offer increases organic market shares, lends support to Koos' findings.

Our use of coffee purchases to investigate the relationship between stated and actual behavior is motivated in part by the importance of coffee as a commodity (by value), and in part because the coffee market is characterized by a large number of differentiated products. These factors taken together, in combination with a transparent production technology, arguably make the coffee market fertile ground for studies pertaining to the field of industrial organization.¹³ We were also attracted to the fact that coffee is mainly produced in developing countries. Because environmental and labor regulations are weak in several coffee-producing countries, environmental and ethical labeling may provide particularly useful information.

5.2 The data and the links between stated and actual behavior

In our analysis, we use a dataset collected by GfK, a German-based market-research consultant with an affiliate in Sweden. GfK has assembled a consumer scan panel that follows grocery-shopping choices of 3,000 families across Sweden. We use observations from January 2007 to January 2010. The data was collected with an electronic scanner and web-based diary entries. Not all participating households buy coffee. The data set that we use consists of an unbalanced panel of 2,782 households.

The participating households are chosen as a representative sample of the Swedish population, but were sampled using non-probabilistic methods typical for this type of market research data.¹⁴ We observe household characteristics such as the age and level of education of the reference shopper, household annual income, and postal code of residence. The top panel in Table 5.1 compares the household characteristics of the sample with national averages in Sweden.

There are only small differences compared to the national averages. The average reference shopper is slightly older than the average age of the population: 50.6 versus 48.9 years, respectively (the average age of those 18 years and older, since the reference persons in the panel were all 18 or older). The share of households with a university education is lower in the sample than the national average: 33 versus 36 percent,

¹³See, for example: Nakamura and Zerom (2009) on cost pass-through; Draganska et al. (2010) on the distribution of profits in the vertical chain, and; Mason (2009) for a study of Environmental and/or ethical labeled coffee.

¹⁴Lusk and Brooks (2010) provide a critical evaluation of the representativeness of such samples, finding that participants in two US household scanning surveys were slightly more price sensitive than a random sample.

Table 5.1: Household summary statistics

Variable	Mean	Std. Dev.	National mean ²
Household characteristics	372	182	350
Average annual income ¹ (thousand Swedish crowns)	372	182	350
Age in years (above 18)	50.60	14.19	48.9
Have university	0.33	0.47	0.36
Household size ¹	2.28	1.19	1.97
Urbanization (4 most urban)	2.88	0.94	
Purchasing behavior			
Shopping trips per household per year	7.06	6.78	
Purchases per household per year (Swedish crowns)	325.29	329.76	
Purchases per household per year (grams)	7104.40	7206.81	
Purchases per capita per year (grams)	3929.02	4366.96	4500 ³

¹ Number of observations for income (2678) and for household size (2781). All other variables 2782 observations.

² Figures on national means from Statistics Sweden, data for 2008.

³ Source: <http://www.kaffeinformation.se/>

respectively. The average size of the sampled household is 2.28, compared to the national average of 1.97. We used the postal area in which the households resided to map households into four types of municipalities:¹⁵ 1) sparsely-inhabited municipalities and other municipalities with less than 25,000 inhabitants; 2) municipalities with more than 25,000 inhabitants but not major centers; 3) major regional centers, and; 4) the largest three municipalities in Sweden and their suburbs. The mean of this measure in our data was 2.88, indicating that our sample reflects Swedish urbanization levels.

On the product side, the data was matched to European Article Numbers (EANs), providing a description of each coffee product bought by the household, including the package size, brand name, whether it was labeled organic, Fairtrade, as well as other product characteristics. We use data on purchases of all ground and bean coffee. Instant coffee was excluded. The data on households and the data on product varieties are linked via a database of market transactions. These market transactions describe the price and quantity purchased for each variety of coffee on a particular date at a particular store by a particular household. The combined dataset, therefore, includes household statistics, coffee-product descriptions and a record of market transactions. In the lower panel of Table 5.1 we report some descriptive statistics on household purchasing behavior. On average, households purchased coffee in retail stores on 7.1 occasions per year, and the average annual household expenditure on retail coffee was 325 Swedish crowns (approximately 36 Euro using July 2008 exchange rates).

The households in our dataset appear to have diligently reported their retail coffee purchases. In 2008, average coffee consumption in Sweden was 9.4 kg/capita/year.¹⁶ Of this, roughly 60 percent was bought through retail channels for household consumption. The remaining 40 percent was consumed at work or in restaurants and cafes. Around 12 percent of the total consumption was instant coffee, which is almost exclusively sold retail. This means that, if our sample was representative and fully diligent in reporting all purchases, we would expect them to consume approximately 4.5 kg/capita/year. As seen on the bottom row of Table 5.1, our sample of households purchased an average of 3.9 kg/capita/year, which is close to the expected level of consumption. As with any Homescan data, some degree of under reporting is expected. Einav et al. (2010) compared the recorded purchasing behavior of US households in the Homescan data administered by AC Nielsen, with the purchasing behavior reported by stores. Overall, the authors found evidence that households are diligent and that Homescan data are a valuable source of information.¹⁷

¹⁵Swedish Association of Local Authorities and Regions, www.skl.se.

¹⁶This figure includes children. Source of this and the following statistics: <http://www.kaffeinformation.se/>

¹⁷One important discrepancy that they found is that around 20 percent of purchases on a given shopping trip are not recorded. As seen, this does not appear to be a significant concern with respect to our data. Secondly, they found that consumers who use loyalty cards to receive discounts often fail to report the discounts. In Sweden, the use of such rebates and coupons to achieve discounts is less prevalent than in the US; we do not expect any such misreporting to have had an important impact

GfK questionnaires are completed by households when they join the consumer panel and then again every January, and cover a range of issues related to household shopping preferences. There are 35 questions in the questionnaire, and many questions have multiple alternative responses. One subset of questions relates to household choices of different types of products. We made use of one question regarding organic labeled products. The question was: 'When I buy groceries I try, to the extent feasible, to buy organic products'. The respondent can tick one of six boxes; box 1 indicates 'Totally Disagree,' box 5 indicates 'Totally Agree,' and box 6 indicates 'Don't Know.'¹⁸

To what extent do households that say that they try to buy organic products actually do so? As a first examination of this question we detail the share of expenditures on organic coffee across survey responses (see Table 5.2). Households that answered 'Totally Agree' or 'Agree' had a higher expenditure share of organic coffee products subsequent to answering the questionnaire. However, even among the set of households that answered 'Totally Agree,' we observe that only 22 percent of actual retail coffee purchases were organic. In other words, these households still primarily purchased conventional coffee.¹⁹

Households sometimes change their answers from one year to another, which explains why the number of observations in Table 5.2 sums to more than the number of households (2,782). As seen, the largest share of households answered 'Neither Agree nor Disagree.' However, there is considerable variance across survey responses, with substantial numbers of participants responding more or less affirmatively.

5.3 Choice Constraints

Why are even those households that say they try, to the extent feasible, to buy organic products not buying more organic coffee? Let us examine a number of possible explanations which guide the subsequent analysis. A first observation is that we track coffee purchases, whereas the questionnaire asks about grocery purchases.²⁰ This difference between what is asked and what is tracked precludes the data in Table 5.2 from providing a direct test of whether people's stated and revealed behaviors coincide. On the other hand, we expect that consumers who really try hard to purchase organic products

on our results.

¹⁸These surveys are conducted in Swedish. The Swedish survey question is: 'När jag/vi köper daglivsvaror försöker vi i möjligaste mån köpa ekologiska produkter'. The responses range from 'instämmer absolut inte' to 'instämmer helt' and 'vet ej.'

¹⁹We also calculate shares of organic and Fairtrade coffee during the year preceding the survey response, and observe only minor differences with respect to Table 5.2. We further examine the share of purchases in terms of volume and in terms of the share of shopping trips when coffee was purchased. We find that the patterns observed are not sensitive to the timing of the questionnaire or whether purchases are measured by volume or by the share of shopping trips in which organic or Fairtrade coffee was bought.

²⁰Or, more precisely, about goods purchased in grocery stores: 'daglivsvaror' is the Swedish term used.

Table 5.2: Share of expenditures on organic coffee, by answers to question on purchasing habits

Q: When I buy groceries I try, to the extent feasible, to buy organic	Percent share of organic purchases ¹	Standard Deviation	t-stat ²	Number of survey responses
Don't know	7.41	21.29		113
Totally disagree	1.14	8.27		436
Disagree	1.82	9.31	1.42	1181
Neither agree/disagree	3.81***	14.00	4.05	1248
Agree	07.99***	21.94	4.48	678
Totally Agree	21.73***	33.7	5.18	179
Total	4.57	16.51		3835

¹ Percent share of organic purchases is the mean over households.

² The t-tests are tests of the hypothesis that the mean response for a group is equal to the mean for the response above under the assumption of unequal variances. For example, 5.18 indicates that the t-statistic for the hypothesis that the mean share of Organic purchases for households that respond Totally Agree is the same as for households that respond Agree. This difference is significant from zero at the 1% level, which we denote with ***

would do so in the case of coffee as well.²¹ Organic coffee is one of the top categories of organic products in Sweden by value, after organic dairy and organic eggs.²² Thus, we do not see the difference between what was asked and what was tracked as a satisfactory explanation for why the self-professed organic shoppers did not have a higher share of organic coffee purchases.

A second potential explanation for the relatively low share of organic coffee purchases is that buying such products can be seen as a pro-social behavior. Respondents may wish to give the appearance of conforming to such norms and hypothetical bias (as defined by Harrison and Rutstrom (2005)) could be driving results.²³ We cannot rule

²¹ An example of another product may clarify our point. Say that we instead used data on a really marginal product in terms of environmental labeling, such as carbonated soft drinks. In such a case introspection suggests a quite weak link between stated purchasing habits in grocery stores in general and the propensity to purchase organic carbonated soft drinks.

²² Source: www.krav.se, ÅI Marknadsstatistik 2010. In total, 3.4 percent of grocery expenditures in 2008 were made on organic products. Around 7 percent of milk purchases were made on organic products (total value around 500 million Swedish crowns). The total value of sales of organic eggs was around 300 million Swedish crowns, of fermented milk 280 million and coffee 200 million. The next category was juice, with a total of some 100 million Swedish crowns.

²³ Note however that we are not able to distinguish between an agent having an accurate view of her/his behavior but not reporting it accurately, and an agent having a distorted perception of what s/he does but reporting this distorted view truthfully.

out hypothetical bias as a contributing factor. However, we are able to examine the extent to which stated preferences provide valuable information as opposed to being uninformative talk. If stated preferences were uninformative, self-reported purchasing habits would have no additional explanatory power once we control for prices, income and other household characteristics.

The data also allows us to investigate other potential constraints to higher sales of organic coffee. Our investigation relies on demand estimated at the household level, and then uses these demand estimates to study consumer response to counterfactual settings. Consider then a third potential explanation where household choices of organic products are constrained by lack of access; a household that responds 'Totally Agree' or 'Agree' might not buy any organic coffee because such products are simply not available in nearby stores. The potential for bias exerted by a lack of product availability has recently been explored in the literature on estimating demand systems using market-level data (see Bruno and Vilcassim (2008)). In a counterfactual simulation we introduced an organic coffee variety, making it available in all household choice sets. We then studied the impact this had on organic market shares. If limited access per se kept organic shares low, then introducing an additional organic brand should lead to a marked increase in the share of organic coffee purchased by the keener households.

A fourth possibility is the limited overlap of organic products with other coffee characteristics valued by consumers. Consider a household that values organic coffee, but also has a strong preference for a particular brand, a particular roast or East African beans. The household may sincerely try to buy organic coffee but be unable to find an organic product that overlaps with the other product characteristics that they also highly value. To investigate the quantitative effect of this mechanism we introduce a highly valued organic product, letting its price reflect the organic premium, and let it be available in all choice sets.

A fifth potential explanation focuses on price effects. A household might sincerely try to buy organic coffee but find it too expensive relative to the next-best alternative. As seen in Figure 5.1 below, the price of organic coffee has fluctuated relative to regular coffee. Clearly, large increases in the relative prices of organic coffee could lead consumers to purchase regular coffee even if they would not have done so at the prices that prevailed when they responded to the questionnaire. In a counterfactual scenario we halve the organic price premium and consider the effects on market shares of organic coffee.

The extent to which these mechanisms constrain sales of organic coffee is an empirical issue that is discussed in the next sections. But first we describe the determination the dependent variable for the regressions - the choice sets; the choice of coffee varieties facing each household on their shopping trips.

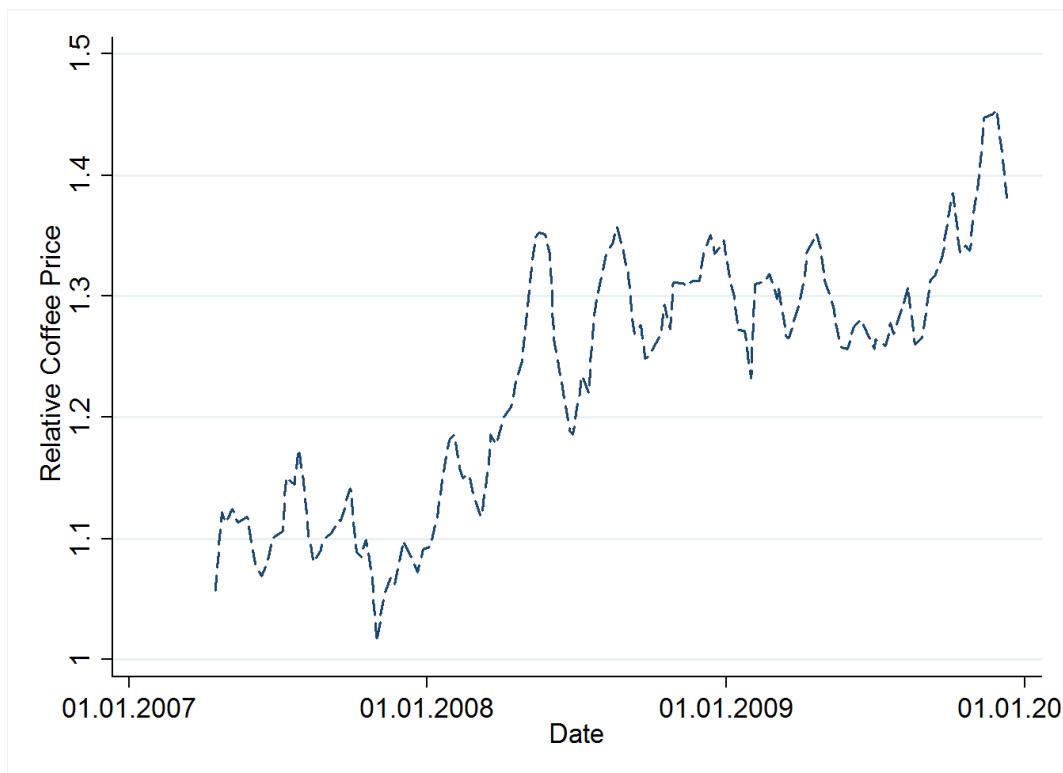


Figure 5.1: Price of organic coffee relative to conventional coffee

5.4 Identifying household choice sets

Homescan data provides observations of actual choices, but does not provide observations of choices that are not made. Therefore, we cannot directly observe the choice set facing a household on any given shopping trip. We have derived the choice sets from observations of coffee varieties that were purchased by other households from the same chain and store format²⁴ (44 combinations in all) for a given type of municipality (4 types) within a three month window. A manual comparison with the assortment in some selected stores pointed to our generated choice sets as giving a generally accurate representation of the assortment.

A total of 43,252 shopping trips were observed in our data. However, the construction of choice sets expanded the size of the dataset to a total of 1,260,081 observations. Table 5.3 provides descriptive statistics on the coffees in the expanded sample. Since we only observed the actual price when there was a purchase, we used a hedonic regression to generate prices for all of the products in the choice set. The regression was run on the 43,252 observations on price. We regressed price on bar-code-level fixed effect by product (238 in all), store effects (by chain and store format: 44 in all), monthly

²⁴There are four store formats over eleven chains. Thus an ICA convenience store would be one of the 44 possible combinations.

fixed effects (1 for each of the 36 months in the data) and municipal-type fixed effects (4 in all). The adjusted R² of this regression is 0.58 and the F-statistic for the joint significance of all variables is 184.28.

Table 5.3: Summary statistics for the sample¹

Variable	Mean	Std. Dev.	Min	Max
Price (Swedish crowns/Kg)	51.66	15.93	15.7	266.0
Organic	0.0702	0.2555	0	1
Fairtrade	0.0330	0.1786	0	1
Number of products in choice set	35.17	11.48	1	60
Number of organic coffees in choice set	2.50	1.522	0	7
Number of Fairtrade coffees in choice set	1.25	1.269	0	6

¹ Number of observations in sample: 1,260,081

The mean hedonic price is around 52 Swedish crowns per kg, with considerable dispersion between the highest and lowest prices. We also present descriptive statistics for the sample on a number of dummy variables that capture characteristics of the product and the choice set. Around seven percent of the available choices were organic, and three percent were Fairtrade.

As noted, a potential reason for the low share of organic coffee purchases could be the lack of availability of products carrying these labels. If no organic coffees were available in a respondent's store, then there is not much of a puzzle as to why they were not chosen. There are indeed some choice sets in our data that do not include any organic coffee, but the majority do. For example, at the 10th percentile of observations in the sample there was one organic coffee in the choice set. At the median, a household faced 2.5 organic coffee varieties in their choice set. This suggests that, while organic coffee is widely available in Sweden, only a narrow range of these coffees make their way into household choice sets. We return to this issue in the regression work that follows.

5.5 Empirical specification

We use a discrete-choice model of demand and assume a conditional logit specification (McFadden (1974), Cameron and Trivedi (2009)). Consider household i facing the choice of a product j among a set of J available products on shopping trip s . The household derives utility U_{ijs} from its choice j and chooses the alternative that provides the greatest utility. The behavioral model is therefore: household i chooses alternative j if $U_{ijs} > U_{iks} \forall j \neq k$. We express utility as:

$$U_{ijs} = X_j\beta + HH_{ijs}\gamma + p_{js}\alpha + \epsilon_{ijs} \quad (5.5.1)$$

where X_j is a vector of product attributes and β is a vector of coefficients. HH_{ijs} is a vector of product characteristics that interact with household characteristics and γ is the vector of associated coefficients. p_{js} is the log of the price of coffee j on shopping trip s , and α is the sensitivity to price. In the main specification we assume that ϵ_{ijts} is a logit error term: an individual and product specific error term that follows a type II extreme value distribution. We thus estimate the parameters in equation (5.5.1) with a conditional logit specification.

$$Prob(choice_{ijs} = 1 | X_j, HH_{ijs}, \alpha) = \frac{e^{(X_j\beta + HH_{ijs}\gamma + p_{js}\alpha)}}{\sum_{k=1}^{J_s} e^{(X_k\beta + HH_{ijs}\gamma + p_{js}\alpha)}}. \quad (5.5.2)$$

In the estimation we group the data by household and use heteroskedasticity-consistent standard errors that are clustered at the level of the household. As a first pass at describing the data we also use a linear probability model which makes for easy interpretation of interaction effects.

Let us now describe the variables in turn. The dependent variable is 'choice' which is equal to one if the household chooses variety j and equal to zero if the variety is not chosen. To capture the characteristics of the product we use two different specifications. The first specification aims at understanding the effect of an organic label on demand. In the first specification the variables included in X_j are fixed effects defined at the brand level (36 brands), a measure of roast (dark roast and other roast, medium roast is the omitted category), and dummy variables for different national origins of single origin coffee (Columbia, other Latin America, Ethiopia/Kenya and Indonesia). Finally we include dummy variables to capture if good j carries an organic or Fairtrade label. While this specification allows us a clear view of the effect of an organic dummy on demand the predictive ability of what product that consumers choose is limited with this specification. For the counterfactuals we instead rely on a specification that includes product fixed effects that are defined at the EAN-level (238 products). We also expect consumers to have preferences for certain brands and therefore include a dummy to capture if a particular brand (44 brands) was purchased on the last shopping trip. Thus, while this latter specification provides a good predictive fit some of the valuation of organic characteristics will be absorbed by product level fixed effects and purchase history.

HH_{ijs} is a vector of household characteristics, interacted with dummy variables that capture organic and Fairtrade labels. 'Old' households indicate a primary shopper over the age of 55 years. Likewise 'University' for those with a University degree and 'high income' for households with a combined annual pre-tax income of at least 500,000 Swedish crowns (SEK) (approximately 53,300 euro in July 2008). These household characteristics are interacted with dummy variables that capture the set of possible household responses to the survey questions. The omitted category is households that answered 'neither agree nor disagree'.

Our attention focuses particularly on the interaction between the organic label and household survey responses. For example, we are interested in estimating the impact

of a household answering 'Totally Agree' in the survey on the probability of choosing an organic coffee. By including survey responses one might fear that we are in essence regressing outcome on outcome. Note however that the question asks about whether the households tries to buy organic when shopping for grocery, as opposed to asking if organic coffee was bought on the shopping trip in question. Our preferred interpretation is therefore that this variable should be seen as capturing preferences.

Finally, the natural log of the price for each product, p_{js} , is also included (we use predicted values from the hedonic regression as explained in Section 3). We make two restrictions on the data: Firstly, for clarity of comparison we drop the observations where households had not responded or answered 'don't know' which leads us to loose 65 households, from 2785 to 2717. Secondly we exclude shopping trips where we estimate that consumers are faced with at three coffee products or less. This mainly excludes a handful of shopping trips to pharmacies.

5.6 Estimation results

In Table 5.4 we report the coefficients of interest from the estimation of equation (2) in columns (3)-(5). For ease of interpretation we first report the results using a linear probability model in columns (1) and (2).

We see in column (1) that the estimates for the interaction between survey response and organic provide statistically-significant coefficients and indicate that respondents indeed value organic products when they say they do, and don't value them when they say they don't. The omitted category is households that answered 'Neither Agree nor Disagree' to the question on their purchasing habits. The interactions between stated behavior and organic labeling are quantitatively important. For example, answering 'Totally Agree' raises the probability that the household purchases an organic coffee by 9.6 percent relative to the indifferent household. The estimates dovetail with the finding presented in Table 2 and provide support for the hypothesis that survey responses do provide useful information on attitudes.

The interactions between observable household characteristics and the choice of organic coffee are small in magnitude and not significant. Income does not significantly explain the choice of organic or Fairtrade coffee. This is in contrast to Kiesel and Villas-Boas (2007), who find that income is a significant predictor of organic milk purchases in the USA, and Griffith and Nesheim (2010), who find a similar result in the UK. The Swedish income distribution is compressed relative to these countries, which may explain part of the reason for the difference. The point estimates indicate that older households are less likely to purchase organic or Fairtrade products, but the effects are small and only in the case of Fairtrade is the coefficient significant. University education raises the probability of purchasing a Fairtrade product but the effect on the choice of organic is low and not significant. In column (2) we report a regression where the stated behavior variables are excluded. As seen, most coefficients are stable

Table 5.4: Brand-level demand for coffee, 2,717 Swedish households, 2007-2009

Dependent Variable: Choice	(1)	(2)	(3)	(4)	(5)
Estimation	Linear probability	Linear probability	Conditional logit	Conditional logit	Conditional logit
Coefficient					
Ln(Price)	-0.019 (0.002)**	-0.018 (0.002)**	-1.854 (0.239)**	-2.820 (1.830)	-2.509 (1.809)
Organic x totally disagree	-0.011 (0.004)*		-1.033 (0.542)		
Organic x disagree	-0.010 (0.003)**		-0.908 (0.221)**		-0.725 (0.200)**
Organic x agree	0.023 (0.005)**		0.914 (0.177)**		1.238 (0.154)**
Organic x totally agree	0.099 (0.018)**		2.149 (0.271)**		
Organic x high income	-0.004 (0.004)	-0.006 (0.004)	-0.232 (0.231)	-0.015 (0.197)	-0.063 (0.197)
Organic x university	0.007 (0.005)	0.012 (0.005)*	0.385 (0.212)	0.700 (0.188)**	0.604 (0.181)**
Organic x old	-0.003 (0.004)	-0.003 (0.004)	-0.214 (0.197)	-0.066 (0.173)	-0.098 (0.165)
Fairtrade x high income	0.001 (0.005)	0.001 (0.005)	0.091 (0.393)	0.000 (0.239)	-0.008 (0.240)
Fairtrade x university	0.015 (0.006)**	0.015 (0.006)**	1.136 (0.286)**	0.908 (0.204)**	0.916 (0.203)**
Fair trade x old	-0.007 (0.003)*	-0.007 (0.003)*	-0.756 (0.253)**	-0.578 (0.201)**	-0.547 (0.198)**
Organic	-0.021 (0.004)**	-0.018 (0.004)**	-0.522 (0.212)*		
Fairtrade	-0.004 (0.003)	-0.004 (0.003)	-0.204 (0.210)		
Observations	1225715	1225715	1225715	1225715	1225715
R- squared	0.01	0.01			
Log-likelihood			-128504	-48450	-48244
Pseudo R2			0.05	0.64	0.64

¹ Columns (1) - (3) include product dummy variables for product brand (44). Column (4) includes dummy variables for region of origin for single-origin coffees and column three also includes dummy variables for bean roast type. Column (4) and (5) include product fixed effects (238). Number of households: 2,717. Heteroskedasticity consistent standard errors clustered by household. ** Denotes significance at 1%, * at 5%.

across these two specifications but in column (2) the interaction between organic and university implies an increase in the probability of choosing an organic product of about 1 percent, which is significant at the 5 percent level. This points to that the lack of significance for university education on organic choice in column (1) is partly due to a positive correlation between university education and the degree to which households say they try to buy organic.²⁵ The price coefficient is negative and significant in both specifications, as expected.

Column (3) reports the results from an estimation of the specification in column (1) but instead using conditional logit. Signs and significance of variables are similar as in (1) but note that given the nonlinear nature of probabilities the magnitude of coefficients can not be interpreted without being specific at what point we interpret them. As stressed by Ai and Norton (2003) particular caution is warranted for models with interaction effects and estimates of marginal effects from statistical programs can be misleading. In the next subsection we therefore provide an in depth look at the interaction between the organic dummy and the stated behavior variables.

Before doing so note that the regressions in columns (1)-(3) are well suited for understanding the qualitative impact of stated behavior on choice probabilities and the pattern that we document is robust to other estimation routines such as probit and mixed logit with a random coefficient on price. However the ability to predict which coffee variety a household will choose is limited, as evidenced by the low (pseudo) R-square in specifications (1)-(3).²⁶ The counterfactual experiments that we wish to explore require that we are able to predict product choice well. To improve predictive ability we include fixed effects at the product level in columns (4) and (5). This captures product characteristics more fully than we are able to do with the brand level dummies and other observable characteristics.²⁷ We also know that many households exhibit brand loyalty, and we therefore include a dummy for the products of a particular brand that was purchased on the previous shopping trip. With the full set of behavioral interaction effects, such a specification somewhat overpredicts the propensity of the households that answer 'totally agree' to purchase organic and somewhat

²⁵Using Kendall's tau, the association is 0.04; statistically significant at the 1 percent level.

²⁶Three concerns are often raised in connection with the use of linear probability models: 1) that predictions may be outside the [0,1] interval; 2) that constant marginal effects are assumed, and; 3) that the error term is heteroskedastic. The first issue is a minor concern in our data: only 0.3% of the predicted probability choices in the benchmark regression are outside the unit interval. Constant marginal effects are also a minor concern if we only use dummy variables on the right-hand side of the equation. If, for instance, income were a continuous measure, we could easily predict implausible patterns for very high and very low incomes. Our use of heteroskedasticity consistent standard errors correct for the last concern. In the past, linear probability models have sometimes been discarded because of a perception that they cannot be derived from a random-utility model. However Heckman and Snyder (1997) show that this can indeed be done.

²⁷Our motivation is thus similar as in the literature that uses market level data to estimate demand and where product fixed effects are often seen as the preferred way to include product characteristics, see for instance Nevo (2000).

underpredicts the propensity of the households that answer 'agree' to purchase organic. Extensive specification searches have not come up with an ideal way to treat this and, noting that the effects partly cancel, we pool households into three groups, the disagreeers (households who answer 'totally disagree' or 'disagree'), neutrals (answering 'neither agree nor disagree') and agreeers (answering 'agree' or 'totally agree'). As seen in columns (4) and (5) the explanatory power of these regressions is considerably higher and we use them for our counterfactual analysis. Before turning to that let us first examine the marginal effects of a product acquiring an organic label. Note that to be able to do this we want a separate estimate of how an organic label affects the probability of purchase rather than have the valuation of organic products absorbed in the product fixed effects. We therefore examine the marginal effects of the specification in column (3).

5.6.1 Marginal effects of organic on coffee choice probabilities

The main coefficients of interest from the regressions are the interactions between the survey responses and the dummy variables for organically-labeled coffee and the associated marginal effects. To illustrate the marginal effect we choose a particular variety and study the impact of changing the organic dummy from 0 to 1. The particular variety chosen for this exercise is a 'Zoegas Skånerost,' 500 gram package; a popular coffee that does not offer organic varieties. A graphical presentation of the effect of said marginal change on choice probabilities is a useful way to illustrate the marginal effect. In Figure 5.2 we have graphed the change in choice probabilities resulting from the introduction of this counterfactual organic variety against the factual predicted choice probabilities, across the different survey responses.

Each point in the figure represents an instance in our dataset where 'Zoegas Skånerost' appeared in a household choice set. The horizontal axis of each graph denotes the estimated choice probabilities, ' p ' in the factual data. The vertical axis denotes the change in that probability, ' Δp ' for the counterfactual organic 'Zoegas Skånerost.' 'Totally Agree' and 'Agree' households would be more likely to choose 'Zoegas Skånerost' if it carried an organic label. Likewise, 'Totally Disagree' and 'Disagree' households would be less likely to choose Zoegas if it were organic. The marginal effect of the organic characteristic is, as derived from our regression in Table 4 column (3), with few exceptions positive for households that are keen organic households and negative for households that are not keen organic households. We note that effects are quite strong; the choice probability for positive households frequently doubles when we confront consumers with this counterfactual organic variety. The fan-shaped pattern seen most clearly in Panel B reflects the interaction of the organic dummy with the dummies for education, age and high income. These differences across household characteristics generate discrete jumps in the choice probability. The qualitative pattern that we see is similar when we repeat this exercise for other coffee varieties.

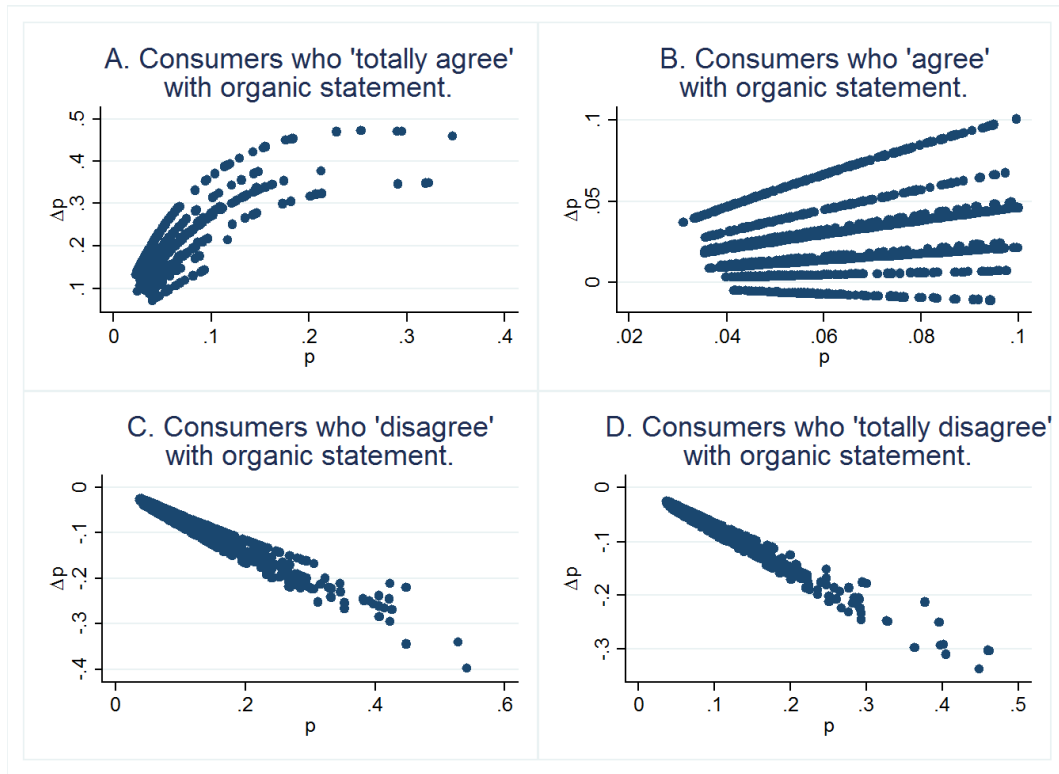


Figure 5.2: The marginal effect on choice probabilities for changing 'Zoegas Skånerost' to a counterfactual organic 'Zoegas Skånerost' by survey response. The horizontal axes denote the estimated factual choice probabilities ' p .' The vertical axes denote the change in the choice probability ' Δp ' under the counterfactual.

5.7 Using the estimates to consider counterfactual choice

Why do self-professed organically-minded households not have a higher share of coffee purchases that carry an organic label? We use our estimated demand model to study counterfactual settings to explore the contribution of the different behavioral responses identified in Section 3. The results from the simulations are presented in Table 5.5.

The actual share of organic coffee in our data for the different responses to the stated behavior question is presented in column (1).²⁸ Taking observed values and combining with our estimates yields a predicted choice probability for each product on each shopping trip. In a discrete choice setting the product with the highest predicted probability will be chosen. Summing over all the choices we present the predicted share of these choices that are organic in column (2). As seen the model predictions are rather close to the actual data but for the counterfactuals column (2) should be seen as the baseline comparison.

²⁸These numbers differ from those reported in Table 5.2. The difference is due to the fact that households that did not respond are omitted from the demand estimates and Table 5.2 reports means across households, whereas Table 5.5 reports the aggregate share.

Table 5.5: Counterfactual shares (in percent) of organic coffee purchases by survey response.

Q: When I buy groceries I try to the extent feasible to buy organic						
		Counterfactuals ³				
Survey response	Factual purchases observed in data	Factual logit predictions using benchmark regression ¹	Factual logit predictions without stated behavior ²	One more organic coffee of average quality available on all shopping trips ⁴	One more organic coffee of high quality available on all shopping trips ⁵	Halved organic price premium
	(1)	(2)	(3)	(4)	(5)	(6)
Totally disagree and disagree	1.43	0.82	0.84	0.86	0.94	0.87
Neutral	3.55	2.27	2.29	2.45	2.75	2.33
Agree and						
Totally agree	12.12	11.15	7.15	19.22	49.02	22.10
Total	4.42	3.50	2.68	5.26	11.63	5.83

¹ Based on estimates reported in Table 4, column (5).
² Based on estimates reported in Table 4, column (4).
³ The counterfactuals are based on estimates from Table 4, column (5).
⁴ Predicted market share with organic supply increased by introducing one additional synthetic organic-coffee variety with average quality characteristics (product fixed effect set equal to mean of all brands and hedonic price) to all household choice sets.
⁵ Predicted market share with organic supply increased by introducing one additional synthetic organic-coffee variety with high quality characteristics (product fixed effect set equal to 75th percentile of all brands and hedonic price) to all household choice sets.

In terms of pseudo-R² or the value of the log-likelihood function there were small differences between the specification where stated preferences were included (Table 4, column (5)) and the one where they were not (Table 4, column (4)). Even so, including stated preferences helps us predict shopping behavior of organically minded households as seen by comparing the predicted values from the specification without stated behavior (column (3)) with actual data and the predictions in column (2). It is also worthwhile noting that the results in column (3) indicate that also when excluding stated preferences, the observable household characteristics such as university education, age and income describe and past shopping behavior are useful in predicting choice of organic coffee. Relating back to our guiding research question, this also indicates that household statements are not just uninformative talk; stated behavior is useful in predicting actual behavior.

5.7.1 Counterfactual choice settings

We now turn to the analysis of three counterfactual choice settings. In a first counterfactual setting we examined the effect of ensuring access to at least one organic choice on every shopping trip through the sample. Households may not buy organic products because these products are simply not available in nearby stores. Adding one more organic coffee variety to all shopping choice sets would relax this constraint. In order to avoid the confounding effects with other coffee qualities we introduce a 'synthetic' average organic coffee variety. This synthetic variety has an average coefficient on the product fixed effect (as estimated in Table 4, column (5)). The product is a medium roast, sold in a 500 gram package with no specified region of origin sold under the brand name 'Gevalia'. We generate a price for this synthetic variety is generated using predicted values from the same hedonic regression that we used to generate counterfactual prices in the construction of the choice sets. We introduce this synthetic variety to all choice sets, changing predicted choice probabilities as per equation (2). These new choice probabilities provide the basis for the counterfactual market shares for organic coffee presented in column (4) of Table 5.5.

If lack of access to organic varieties at nearby stores is an important restriction this counterfactual would generate higher shares of organic for the agreeing households. Indeed, the share of organic products goes up to 19 percent under this counterfactual scenario. This suggests that limited access to organic coffee per se is part of the explanation why not more organic coffee is purchased.

In a second counterfactual setting we examine the effect of relaxing the limited overlap of organic with other coffee characteristics valued by households. To illustrate the quantitative impact of this mechanism we again introduce a synthetic product that is available in all stores, but now let it have a product fixed effect that comes higher in the distribution of fixed effects, from the 75th percentile. The product is a medium roast, sold in a 500 gram package with no specified region of origin sold under the brand

name 'Löffbergs Lila'. The counterfactual setting pursued here assigns an organic label to this coffee and as before uses a hedonic regression to generate the counterfactual price. Introducing this new variety changes the choice probabilities across households and these new choice probabilities form the basis for the counterfactual market shares for organic presented in column (5) of Table 5.5. The introduction of a more attractive organic product has a large effect on the choice probabilities for the self-professed organic-purchasing households and the share of organic coffee approaches 50 percent. While this may seem like an implausibly large effect let us note that at the median there were only 2.5 organic coffees in the choice set. Adding an attractive organic product thus is an important increase of choice and for a consumer that values organic products the interaction between a high product valuation and a valuation of organic makes for this product being ranked number 1 on many shopping trips. More broadly this suggests that the limited overlap of the organic label with other valuable coffee characteristics (in this case a desired brand) is an important contributing factor to the limited organic expenditures among households that say they try to buy organic. The quantitative impact of this mechanism is clearly dependent on precisely how one specifies the counterfactual.

In a final counterfactual setting we examine the price effect; a high price may deter households from purchasing organic coffee. The organic premium from our hedonic regression is 14 percent. In the counterfactual reported in column (6) of Table 5.5 we discount this premium to seven percent for all coffee carrying the organic label. We see small effects for the households and the households who disagree with the organic statements. This is not surprising, even if the premium is lowered these products are still more expensive than a comparable non-organic product and only in few instances does the lower price push an organic position into the top position for such a household on a shopping trip. In contrast, the lower price has a substantial impact on shopping behavior by households that agree. The market share of organic for the latter group doubles from 11 percent to 22 percent. For these households, with a positive valuation of organic, the lower price is effective in placing an organic product with the highest purchase probability on a given shopping trip. We should note that the price sensitivity of demand was not very precisely estimated in Table 5.4, column (5). We therefore do not want to overemphasize the quantitative result but rather note that the estimated model points to a potentially important role for the price premium in explaining the low share of organic coffee purchases.

5.8 Concluding remarks

Our paper presents research that examines why households are not buying more organic labeled coffee despite many surveys that express a wish to do so. We find that even households that say they try hard to purchase organic coffee products in fact buy mostly conventional coffee. We have identified several behavioral responses that are consistent with the survey question responses and the shopping choices made, and

apply a discrete-choice conditional logit model of demand to study these behavioral responses. We have established that survey responses have important predictive power for the retail coffee purchases made by these households. There is also evidence that the limited overlap between organic and other coffee characteristics is the most important factor limiting organic purchases amongst organic households. Lesser, but still non-trivial roles can be given high organic price premia and limited access to organic products per se. These results are particularly pertinent given recent announcements by the major coffee brands to significantly expand their offering of EE-labelled products. For example, Nestle has announced plans to source all of its Nescafe products from EE-producers within the next 5 years. Likewise Kraft has made a commitment that 100% of its European coffee brands will source EE-coffee by 2015.²⁹

Let us end with a few observations on external validity. Levitt and List (2007) identify the following factors as important for the external validity of (experimental) results: 1) the potential influence of moral and ethical considerations; 2) the way and extent to which one's actions are scrutinized by others; 3) the context in which the decision is embedded; 4) self-selection of the study subjects into the experiments, and; 5) the stakes of the game. The first factor raised by Levitt and List (2007), the potential influence of moral and ethical considerations on answers, is a key motivation for our study. It is often suggested that to purchase organic or Fairtrade products is a form of pro-social behavior. Thus, there may be an expectation that respondents attempt to conform to such norms.

The other concerns raised by Levitt and List (2007) are unusually minor in our data. The level of scrutiny perceived by subjects participating in the GfK panel are likely to be minimal; we focus on two out of 35 questions answered once a year, but track purchases over the full year. On sample selection, we concede that any group of households that agrees to have their purchases tracked is unlikely to be representative of a true random selection of Swedish households. However, GfK's purpose for tracking these households is not specifically linked to organic or Fairtrade consumption. Thus, while sample selection may be an issue, we have no strong prior belief for what effect, if any, it would have on our results. It is also noteworthy that on observable characteristics, the sample is representative. Finally, the stakes of the game are economically significant and concern consumer choice across a regular assortment and prices of coffee during a year.

²⁹Nestle, 2011. Nestle invests CHF 500 million in coffee projects, doubling direct purchases. Press release, 27 August 2011. See also Kraft, 2011. Kraft Foods Expands Sustainability Goals to Build on Success. Press release, 12 May 2011.

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