Climate policy and international trade:
Impacts of EU carbon tariffs on the Finnish economy

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Abstract

The incomplete global coverage of current emissions trading schemes has raised concerns about free-riding and carbon leakage. EU ETS, the first and currently the biggest carbon market, is at the fore of such fears. Carbon-based import tariffs have thereby been proposed to compensate domestic industries for the cost disadvantage against their rivals in non-regulating countries.

This thesis uses an applied general equilibrium (AGE) model to assess the impacts of a hypothetical EU carbon tariff on the Finnish economy. The carbon content of imported goods is first estimated with an environmentally extended input-output analysis, and the tariff is levied according to the anticipated price of EU emission allowances. To examine the sensitivity of the results, five additional scenarios are then constructed by altering the key simulation parameters. The tariff is imposed on the most energy-intensive and trade-exposed industries in 2016 and simulated until 2030.

The results suggest that carbon tariffs are detrimental to the Finnish economy. The negative outcome is determined by high material intensity and a growing dependence on imported materials throughout the industry sector. As a result, the tariff-induced increase in import prices adds up to a notable growth in total production costs. Moreover, the negative impact is most pronounced within the export-oriented heavy manufacturing sector that the tariff was designed to shelter in the first place. The few sectors that gain from the tariff were not directly subject to it, but utilize the secondary impacts as the economy adapts to the shock. The findings imply that due to the deeper integration of global value chains, the appeal of protective tariffs, even if environmentally motivated, can be harmfully over-simplistic.

Keywords
carbon tariff, CGE, computable general equilibrium, modelling, EU, climate, policy

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Tiivistelmä

Päästökauppajärjestelmien alueellisesti rajallinen kattavuus on herättänyt huolta vapaamatkustamisen ja hiilivuodon riskeistä. Teollisuuden kansainvälisen kilpailukyvyn heikentymistä pelätään erityisesti EU:ssa, joka on ollut edelläkävijä päästökaupan käyttöönotossa. Hiilipäästöjen hinnoittelusta aiheutuvien kustannusten kompensoimiseksi onkin ehdotettu hiilitullia löyhemmän ilmastopolitiikan maita vastaan.

Tässä tutkielmassa arvioidaan EU:n mahdollisen hiilitullijärjestelmän vaikutuksia Suomen kansantalouteen laskennallisen yleisen tasapainon mallin avulla. Tuonnin hiilisisältö määritetään aluksi päästötiedoilla laajennetulla panos-tuotos -mallilla, minkä jälkeen tulli lasketaan hyödykekohtaisesti EU:ssa vallitsevan päästöoikeuden hinnan mukaan. Herkkyystarkastelu suoritetaan laatimalla viisi vaihtoehtoista kehitysuraa, joissa keskeisiä mallinnusparametreja muutetaan. Tulli asetetaan ainoastaan energiaintensiivisille ja hiilivuotoalttiille toimialoille. Simulointi alkaa vuodesta 2016 ja päättyy vuoteen 2030.

Tulosten perusteella hiilitullin vaikutus Suomen kansantalouteen on haitallinen. Vaikutus johtuu pääasiassa teollisuuden materiaali-intensiivisyydestä ja tuontiriippuvuudesta, joiden myötä pienikin tuontihintojen nousu ilmenee tuntuvana lisäyksenä tuotantokustannuksiin. Erityisesti hiilitullista näyttäisivät kärsivän ne vientivetoiset prosessiteollisuuden alat, joiden kilpailukyvyn suojaamiseksi tulleja alun perin esitetään. Ne harvat toimialat jotka hiilitullista hyötyvät eivät sen sijaan suoraan kuulu tullin piiriin, vaan hyötyvät sen epäsuorista vaikutuksista talouden sopeutuessa aiheutuneeseen shokkiin. Tulokset osoittavat, että Suomen yhä tiiviimpi integroituminen osaksi kansainvälisiä arvoketjuja monimutkaistaa suojatullien vaikutuksia merkittävästi, eikä tullijärjestelmän ympäristöperusteisuus olennaisesti vähennä sen aiheuttamaa taloudellista haittaa.

Avainsanat
hiilitulli, YTP, laskennallinen yleinen tasapaino, mallinnus, EU, ilmasto, politiikka

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Abbreviations and Acronyms

AGE	Applied General Equilibrium
BAT	Best Available Technology
BCA	Border Carbon Adjustment
BOTE	Back-Of-The-Envelope
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CO_2	Carbon dioxide
EITE	Emission-Intensive and Trade-Exposed
ETS	Emissions Trading System
EU	European Union
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IO	Input-Output
ISIC	International Standard Industrial Classification
OECD	Organisation for Economic Co-operation and Development
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WTO	World Trade Organisation

1 Introduction

Limiting climate change to well below 2 °C requires a swift reduction in global greenhouse gas (GHG) emissions. A cost-effective option is to set a price on CO_2 either with an emissions trading system or an emissions tax. Some regions already have a pricing mechanism in place (e.g. EU ETS and California Cap-and-Trade), but a global system is currently unavailable under the varying political and economic circumstances. Therefore, it is likely for individual countries, or coalitions of countries, to continue with stringent unilateral carbon pricing while others show only a limited interest in climate action.

The sub-global carbon price has raised concerns about free-riding and carbon leakage. Especially the emission-intensive and trade-exposed (EITE) industries, such as iron and steel, cement, pulp and paper and chemicals, are feared to suffer competitiveness losses against their rivals in non-acting countries, resulting only in emission relocation instead of actual reductions. EU ETS, the first and currently the biggest carbon market, is at the fore of such fears. To avoid leakage, carbon-based trade restrictions have been proposed against countries that lack a comparable pricing scheme. One alternative is carbon tariffs — more generally, border carbon adjustments (BCA) — where goods entering the customs territory of EU are taxed according to their carbon content and the prevailing price of EU emission allowances. Never tested and possibly harmful for trade relations, the concept was included in the revised ETS directive with a delicate phrasing. It states that the EU *could apply requirements to importers...for example by requiring the surrender of allowances*, as long as the requirements are not *less favourable* than what they are for European producers (European Commission, 2009).

Border carbon adjustment is appealing for several reasons. First, it would curb carbon leakage. Heavy industry groups, particularly in the metals sector, have welcomed tariffs as a means to level the global playing field skewed by emissions trading (European Parliament, 2014, 2015). Linking together trade and climate policies could also address the shortcomings in CO_2 accounting methodology. Currently, each country only reports emissions that are produced within its national borders. The imported share of EU's consumption is thereby excluded from the EU emissions inventory and the EU's GHG reduction targets. As a result of growing international trade, however, emission transfers have increased considerably — mainly from developing to developed countries (Peters et al., 2011). Imposing a carbon tariff would take the entire consumption into consideration, as the increasing price of carbon-intensive goods steers consumption to cleaner substitutes.

In addition, the post-2020 reform of EU ETS is focused on leakage issues and updated rules of free allocation (Erbach, 2016), both of which could be tackled with border carbon adjustment. During ETS Phase 3 (2013-2020), nearly one billion free allowances are being allocated annually to industries that are deemed at risk of carbon leakage (EUTL, 2016). The generous allocation method has caused unwanted side-effects, including excess production in order to secure a maximum amount of future permits (Branger et al., 2015) and substantial heavy industry windfall profits (Laing et al., 2014). Introducing a BCA system would be a leap towards full auctioning as simultaneous free allocation and border adjusting could hardly be justified (Monjon and Quirion, 2011). Last, as Condon and Ignaciuk (2013) point out, trade restrictions can even be used to pressure non-acting countries to a more active contribution in future climate agreements.

There are also drawbacks aplenty. A detailed approximation of emissions embodied in trade is extremely data-intensive. Take for example aluminium, which in 2014 was imported to the EU from over 100 different countries (UN Comtrade, 2015). Acquiring verifiable emission data for each country, not to mention each production facility, is simply impractical. It is also unclear whether a border adjustment policy can be fine-tuned to comply with international trade agreements. A protectionist attempt would be overturned by the WTO dispute settlement body. Even after an approval from the WTO, if considered unjust by other countries, any form of tariffs might provoke trade retaliation.

Besides, not all businesses benefit from a new trade barrier. The consequent increase in domestic prices could be detrimental to those manufacturing industries that rely on a high share of imported intermediate goods. Moreover, a unilateral carbon tariff only protects industries within the internal market. Globally exporting European firms would still face the uneven playing field outside the EU, only this time with the soaring price of inputs (Böhringer et al., 2014). Last, no empirical evidence of carbon leakage has yet been discovered in the EU (Bolscher et al., 2013). It doesn't necessarily make the border adjustment policy any less useful, but suggests that it is often supported with tenuous arguments.

In this thesis, the FINAGE applied general equilibrium (AGE) model of the Finnish economy is used to estimate the impacts of a hypothetical EU carbon tariff. The main questions are whether a globally integrated small economy can benefit from a climate-motivated tariff, and if not, does the magnitude of environmental gains still justify its use?

A tariff reflecting the EU ETS allowance price is imposed in 2016 on all non-European emission-intensive imports and simulated until 2030. Results are presented with a top-down approach, from macroeconomic indicators to a sector-specific analysis. The underlying mechanisms behind the results are explained both through the immediate tariff impacts and the more gradual wage adaptation that follows the shock. This is in contrast to the vast majority of existing BCA literature, typically covering more regions, but focusing merely on carbon leakage and competitiveness issues. This thesis is also the first in-depth quantitative modelling study of BCA impacts in Finland.

The rest of this study is structured as follows: a brief literature review and the theoretical framework are presented in Chapter 2. Chapter 3 presents the FINAGE model, and Chapter 4 the additional data that are required to quantify the carbon tariff. Chapter 5 shows the results, and their robustness is tested in Chapter 6. The results are further discussed in Chapter 7. Chapter 8 concludes.

2 Literature

2.1 Theory

This study builds on an extensive literature on using tariffs to tackle transboundary pollution stemming from foreign production processes. Markusen (1975) presented a simple general equilibrium model of two countries that produce and trade two goods. The negative production externalities were addressed by a tax either on production, consumption or trade. Markusen showed that in a case of foreign pollution, welfare is maximized with a policy mix that consists of a domestic production tax and an import tariff. Markusen also presented a numeric illustration of several second-best scenarios where only one tax alternative is available due to political constraints. Ranking of the second-best optimums is highly sensitive to the actual product mix, but tariffs still yielded a higher welfare relative to the reference scenario that had no government intervention. Copeland (1996) has a very similar approach with a simple two-country model. He further specifies that a pollution content tariff that reflects the actual foreign process emissions should be used. Copeland also highlights the strategic use of tariffs by arguing that the tariff-induced increase in environmental regulation abroad creates more demand for environmental services, which can then be exploited by the home country.

Hoel (1996) uses a more generalized model of several countries. He maximizes a domestic welfare function that consists of utility from consumption of goods, but also environmental degradation from production-related use of fossil fuels. The study includes two alternative methods to tackle carbon leakage: carbon tariffs on imports and tax exemptions for trade-exposed domestic industries. Similarly to Markusen, also Hoel concluded that an optimal domestic policy combines a carbon tax on production with an import tariff. Furthermore, he argued that domestic carbon tax exemptions should only be available in a special case where tariffs are for some reason unavailable. His explanation was that solving the optimal combination of a uniform carbon tax and a tariff is more straightforward than reaching the same level of welfare by using only differentiated domestic taxes. High data requirements should thereby not be used as an argument against tariffs and to justify tax exemptions for domestic industries.

Many authors suggest that an environmentally motivated trade policy is beneficial also from the global point of view. According to a partial equilibrium study by Maestad (1998), both import tariffs and export rebates should be available. The optimal instrument depends on whether the environmental harm is local or global, and whether it originates from consumption (ozone depletion) or production activities (acid rain). Again, the underlying assumption throughout his work is that a Pigouvian tax is set on all domestic production externalities. Gros (2009), also using a partial equilibrium model, narrowed the scope of global welfare analysis explicitly on carbon tariffs. He found that the welfare losses from lower consumption at home were outweighed by an increase in global social welfare. The positive net impact was driven by diminishing foreign production that also caused the associated negative production externalities to decrease.

2.2 Tariff impacts

Recent numeric studies are less unanimous about the overall desirability of border carbon adjustments. The main impacts are clear, but the distributional effects and the extent of foreign counter-measures remain much debated. This section presents the relevant literature regarding these issues. Virtually all use multi-regional computable general equilibrium (CGE) models, which are the established method for studying international trade policies.

Many authors conclude that border carbon adjustments tackle carbon leakage effectively. Böhringer et al. (2012a) and Winchester et al. (2011) estimate that a BCA on emission-intensive industries reduces carbon leakage on average by a third. A meta-analysis of 25 BCA studies by Branger and Quirion (2014) shows even higher figures: leakage rate more than halved from an average of 14 percent to an average of 6 percent. Manders and Veenendaal (2008) focused explicitly on the EU, and found that leakage rate fell from

3,3 percent to 0,5 percent when border measures were introduced.

All industries, however, will not benefit equally. Steel (Mathiesen and Maestad, 2004) and cement (Demailly and Quirion, 2008) sectors have a lot to gain in terms of leakage protection, whereas the leakage rate in minerals sector is hardly affected at all (Kuik and Hofkes, 2010). This is because carbon leakage occurs through different channels. The competitiveness channel — that is, additional costs to firms from domestic climate policy — can be directly compensated with border carbon adjustments. Leakage through the energy market channel means that falling domestic demand for fossil fuels lowers their global market price and thereby encourages consumption abroad. This channel is beyond the reach of border adjustments (Schinko et al., 2014).

The overall economic impacts of BCA are typically estimated to be small and unevenly distributed between different countries. Babiker and Rutherford (2005) and Lanzi et al. (2012) found that border carbon adjusting is beneficial for domestic competitiveness, but causes substantial welfare losses outside the tariff area. Mattoo et al. (2009) studied the impacts of BCA using the World Bank ENVISAGE model, designed particularly to analyse the distributional impacts of climate policy. They concluded more generally that rich countries will benefit from border adjustment at the expense of the poor. Fouré et al. (2016) drew similar conclusions in a modelling study that focused only on Europe. Imports to the EU decreased — as predicted — causing a slight boost in domestic production. Goods originally destined for EU markets, however, were re-routed to other destinations. It caused increased competition and production losses elsewhere.

The magnitude of impacts mainly depends on the structure of domestic industry. According to Böhringer et al. (2014), the US non-ferrous metal sector was able to increase its production when the unilateral emission pricing scheme was supplemented with a carbon tariff on imports. A similar policy applied in Switzerland, on the other hand, caused the output to deteriorate. This is because the Swiss industry uses a higher share of imported intermediates and is more oriented to global markets. It is therefore more vulnerable to trade shocks. Also Winchester et al. (2011) and Dissou and Eyland (2011) found that carbon tariffs have negative impacts on domestic production due to the increase in material costs. Burniaux et al. (2013) and Monjon and Quirion (2010) showed that the increase in general price level and the following decrease in domestic demand can even outweigh the gains from a protective tariff.

Border carbon adjustment has only a minor impact on emissions. Winchester et al. (2011) estimated that emissions inside the tariff area fall by 0,8 percent and the global emissions by 0,6 percent. In their study, the acting coalition was responsible for a relatively small share of global emissions. Therefore, even a big drop in leakage rate translates only to a small reduction in absolute emissions. Dong and Whalley (2009) studied the changes in energy-related emissions when the EU imposes border measures against the US and China. EU emissions fell by 0,1 - 0,8 percent, depending on the carbon price. However, a simultaneous increase in foreign energy use cancelled out the impact on total global emissions.

In the absence of empirical evidence, the political consequences of border carbon adjustment remain unclear. Helm et al. (2012) viewed BCA from a game theoretic point of view, and concluded that they are able to reduce trade distortions and to build a larger climate coalition. A Nash equilibrium game constructed by Böhringer et al. (2016b), however, pointed out that this leverage might not be strong enough to engage big countries like Russia and China to regulate their emissions. Some authors suggest that a border adjustment policy might even provoke a trade war (Fouré et al., 2016; Dröge et al., 2009).

2.3 The legality of trade restrictions

Another major issue impeding the introduction of border carbon adjustments is the possible inconsistency with international trade agreements. In the World Trade Organization, any of the more than 150 member countries can file a formal complaint against unfavourable trade measures adopted by another member. If a bilateral round of consultations fails to resolve the issue, a wider dispute settlement panel is formed (WTO, 2015b). China and India, for instance, have already threatened to trigger a WTO dispute if carbon tariffs are used against them (ICTSD, 2010; Voituriez and Wang, 2011). However, several recent studies conclude that when carefully planned, border carbon adjustment is likely to turn out WTO-compatible (Horn and Mavroidis, 2011; Pauwelyn, 2012; Ismer and Neuhoff, 2007; Monjon and Quirion, 2010).

The requirements for legitimate border measures are documented in The General Agreement on Tariffs and Trade. It forbids all discrimination between *like products* from different importing countries and *charges of any kind in excess of those applied to like domestic products* (GATT, 1986). However, the likeness of a domestic product and its physically identical but more polluting foreign substitute is open to interpretation. The ruling is made case-by-case in accordance to their tariff classifications, cross-price elasticities, and end-use purposes (Horn and Mavroidis, 2011). In cases like border carbon adjustment, the interpretation is likely to favour the appellant and prohibit the *different* tax treatment of otherwise similar products based on mere process-related differences (Low et al., 2012). This conclusion is supported by a previous case law, where the WTO panel blocked the US-established import requirements on Venezuelan and Brazilian gasoline (WTO, 1996).

Even after proving the likeness of two rival goods, challenging a dispute is extremely laborious for the appellant. Next, it should be able to prove that the treatment of imports is *less favourable* compared to domestic goods. However, as long as the emission pricing and the estimation of embodied carbon are consistent with the EU ETS, no rules are being violated (Horn and Mavroidis, 2011). Furthermore, the GATT article XX allows deviating from the rules if the measures are either *necessary to protect human, animal or planet life or health* or *relating to the conservation of exhaustible natural resources* (GATT, 1986). The necessity of border measures is uncertain (Ismer and Neuhoff, 2007), but clean air was actually declared as an exhaustible resource during the US gasoline dispute (WTO, 1996). Moreover, the previous WTO review processes have taken a more considerate approach for policies that relate to protecting public health (Horn and Mavroidis, 2011). The environmental exceptions thus seem like a solid last resort to justify the use of BCA, if needed.

Only a handful of previous dispute settlement outcomes can be directly applied to assess the legality of carbon-based trade measures. In the US-Superfund case (WTO, 1987), the US was allowed to extend its list of domestically banned chemicals with a tax on imports that contain those same chemicals. The Superfund case is significant for border carbon adjustment because it wasn't necessary for the chemicals to be physically in the imported product, as long as they were used as process inputs (Pauwelyn, 2007). The environmental exceptions in Article XX were for the first time successfully invoked in the EC-Asbestos case, where the WTO panel approved the French ban on Canadian asbestos-containing construction materials, highlighting the health attributes of otherwise perfectly competitive products (Sander, 2015).

Importantly, those foreign exporters that can prove their production to be cleaner than the European standard should be exempted from the tariff. In 1994, the Finnish government imposed a uniform excise tax on all imported electricity (Law on excise duty on certain sources of energy, 1473/1994). The law was challenged by Outokumpu, an electricity-importing steel manufacturer, claiming that a flat rate on all imports is discriminatory in comparison with the more detailed rates that are applied to domestic production. The European Court of Justice followed this argument and blocked the law that even in some cases could lead to an unjust treatment of imports (CJEU, 1998).

It is also worth noting that while border carbon adjustments have never been used, the EU is not the first to attempt. The closest so far is the American Clean Energy and Security Act, which would have required foreign exporters to surrender emission allowances for goods that enter the US customs territory (US Congress, 2009). The bill was eventually rejected by the Senate. More successfully, the US used an import tariff to enforce Montreal Protocol, the agreement prohibiting the use of ozone-depleting substances. The legality of this measure was never challenged to a WTO dispute settlement (Winchester et al., 2011).

Last, as Low et al. (2012) conclude, the GATT text was compiled well before the mainstream awareness of climate change. Some authors have therefore argued that the trade agreements should be updated according to a more recent scientific outlook (Wiers, 2008). The current WTO stance is approving for *carefully crafted* border adjustments for climate motives (Tamiotti et al., 2009). Firger and Gerrard (2011) remark that currently the main causes for WTO disputes are clean technology subsidies, not protectionist trade measures.

2.4 Tariff design issues

This section reviews alternative carbon tariff designs from the previous literature. The focus here is to deal with the simplifying assumptions that are necessary to conduct this study and to implement the actual tariff.

A detailed estimation of embodied carbon for every imported commodity is virtually impossible. Ismer and Neuhoff (2007) and Godard (2007) suggest the use of a best available technology (BAT) benchmark. It leads to an inevitable underestimation of the carbon content, but it also has two major advantages. First, it would be much simpler to implement, which improves the feasibility of BCA significantly. Second, it would reduce the risk of trade retaliation by treating foreign export sectors more gently. For instance, a

US carbon tariff based on actual emissions is estimated to cut Chinese manufacturing exports by 20 percent (Mattoo et al., 2009), more than enough to provoke counter-measures. A possible version of the BAT approach for the EU is to tax imported carbon according to domestic process standards. This is a likely alternative as the free allocation of emission allowances under the EU ETS is already based on a benchmark of the most efficient domestic installations (European Commission, 2011).

Whether the amount of imported carbon is estimated using a domestic benchmark or the actual process emissions has only a small impact on BCA results (Burniaux et al., 2013; Demailly and Quirion, 2008; Mattoo et al., 2009). The downside of domestic benchmarks is that setting the tariff according to an EU reference hardly offers an incentive for foreign producers to cut their emissions. Ismer and Neuhoff (2007) remind that it might also passivate the EU producers, as making substantial energy efficiency improvements would decrease the taxation of their foreign rivals. A global benchmark would overcome this issue. According to Balistreri et al. (2014) and Böhringer et al. (2016a) the optimal tariff rate is in any case smaller than what the domestic carbon price would imply, because the redirection of polluting imports encourages consumption outside the tariff area.

A tariff on imports is not the only possible form of border carbon adjustment. BCA can also be used as an export rebate, an obligation for importers to surrender emission allowances, or a combination of these (Kuik and Hofkes, 2010). According to Monjon and Quirion (2010), the most suitable option for the EU is a system that covers both imports and exports, as it would be the most efficient in reducing carbon leakage and global emissions in a WTO-compatible manner. However, many authors disregard the export compensation as either inefficient (Gros, 2009), illegal subsidies (Böhringer et al., 2014), restraint on domestic emission reductions (Dröge et al., 2009), or irrelevant to the tariff outcome (Steininger et al., 2012).

The next design question is the proper use of tariff revenue. Many recent studies suggest that all revenue should be recycled back to the exporting country either directly or in a form of international clean development funds (Branger and Quirion, 2014; Taylor and Grubb, 2011; Springmann, 2012; Eckersley, 2010; Steininger et al., 2014). It would leave the targeted countries with fewer arguments to engage in trade retaliation, but also compensate for the possible losses in global welfare. Knopf et al. (2014) even suggest that the EU could negotiate its trading partners to implement an export tax themselves. It would have an identical outcome to a revenue recycling import tariff, only with less administration for the EU. Export taxes are already in place in many developing countries. They are used to shift economic activity from exporting natural resources towards manufacturing of higher value-added goods (OECD, 2010; Voituriez and Wang, 2011).

This study supplements the previous literature on carbon tariffs by using a single-country general equilibrium model. Rest of the world is treated exogenously, which means that some feedback effects from changing international trade patterns will unavoidably go unnoticed. On the other hand, the single-country approach enables a substantially more detailed examination of tariff impacts on the domestic economy. As the data availability is less of a problem, industries and other economic actors can be described more extensively. Having more detailed data means that the model can also produce more detailed simulation results. Therefore, the results presented in this thesis will mainly be focused on how the tariff shock affects the economy as a whole, whereas the previous literature has mainly studied the tariff impacts on global competitiveness and carbon leakage.

In summary, the following definitions will be used in this study based on the previous literature. The carbon content of imports is estimated using a benchmark of average EU production emissions. Export rebates are excluded, and the border carbon adjustment policy only includes a tariff on imports. Hence, BCA and carbon tariffs are used as synonyms. The collected tariff revenue is recycled back to the country of origin in full.

3 Model

3.1 Overview

The tariff impacts are modelled using FINAGE , an applied general equilibrium (AGE) model of the Finnish economy based on Honkatukia (2009) and Honkatukia and Dixon (2015). AGE models (also referred as Computable General Equilibrium, CGE) are an increasingly popular instrument for the quantitative analysis of different policy proposals, what if -questions and economic shocks. They are especially useful in situations where the proposed policy has a divergent impact on different actors — industries, regions, or household types — and winners and losers are difficult to tell apart with other methods.

AGE models are an aggregate of economic theory, behavioural assumptions and statistical data. The structure of FINAGE is illustrated in Figure 3.1. By default, each economic agent acts rationally according to a number of supply and demand functions. The observed real and financial transactions quantify these conditions, and link the theoretical approach to real world data. A detailed representation of the public sector is an essential feature of the model. It enables the assessment of virtually all forms of government intervention, as all taxes, tariffs, income transfers and public expenditure can be modified. Rest of the world is included in the model through international trade, which is further divided into EU and non-EU components. All variables are based on real data, which makes the model computable but also highly data-intensive. The data are obtained mainly from input-output tables and various other national datasets.

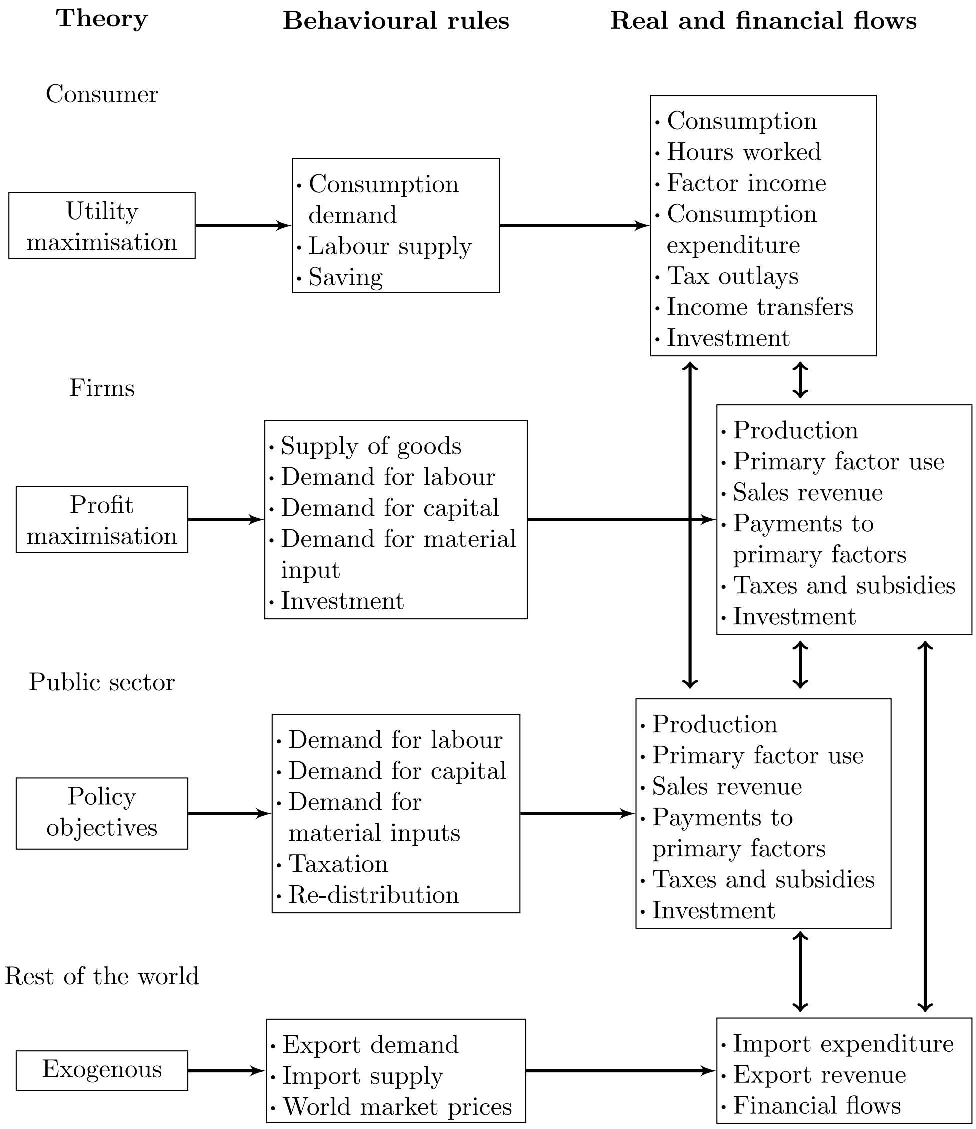


Figure 3.1: The structure of an AGE model (Honkatukia, 2009).

3.2 AGE Theory

This section offers a brief introduction to the underlying theoretical features that are relevant for this study. These include the demand structures for a profit-maximising firm and a utility-maximising household as well as a description of labour market dynamics. A more detailed summary of the model, including the TABLO code syntax, is available by Honkatukia (2009).

Firms operate in a perfectly competitive market, where the level of output is determined by the equality of marginal costs and the market price. The model also takes into account taxes, transportation costs and retail trade profits that add up to actual consumer prices. The economy is aggregated to 97 industries and 144 commodities according to the Standard Industrial Classification TOL 2008. One industry typically produces a multitude of goods, and the model allows the change in relative prices also to change the structure of output. This is especially useful for the energy commodities that in many cases are either side streams or by-products from outside the actual energy sector.

The model is based on a nested structure of functions. Figures 3.2 - 3.4 illustrate the decision-making process of a cost-minimising firm. The top-level nest in Figure 3.2 depicts how production costs in each sector are divided between intermediate goods, primary factors and other costs. The latter includes all costs not specified elsewhere, for example the costs of holding inventories. The Leontief production function indicates that all these inputs are perfect complements and always used in a fixed proportion.

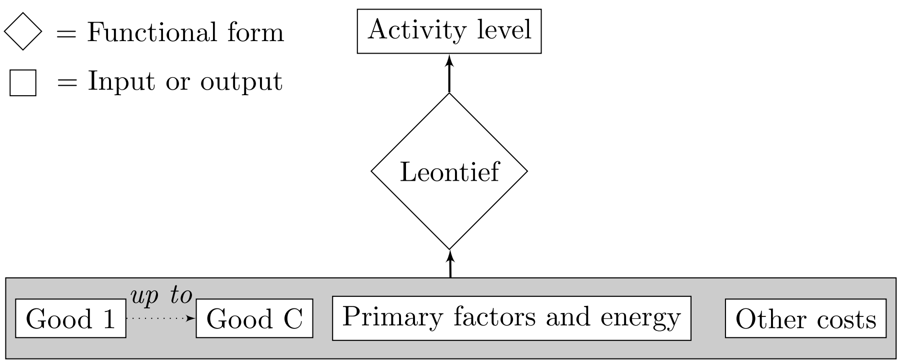


Figure 3.2: Top-level production nest (Honkatukia, 2009).

Figure 3.3 specifies the firm's demand for intermediate goods. They can be acquired either from domestic, European or non-European sources. This nest is also referred to as the Armington nest, for the constant elasticity of substitution (CES) is set according to the Armington assumption (Armington, 1969). Many trade models assume all goods to be perfectly homogeneous regardless of their country of origin. This is hardly the case in real life, but as Armington stated, domestic and imported goods are actually imperfect substitutes. It makes a crucial difference in trade analysis. For instance, if there is a strong bias to favour domestic goods over imports, the lack of an Armington parameter could lead to overestimating the volume of international trade (Blonigen and Wilson, 1999). Also in more general, elasticities are the key behavioural parameters in AGE modelling, and even the slightest changes in their values can have radical impacts on the simulation results. Estimates for different substitution elasticities are readily available from econometric literature both on the national and international level. In FINAGE, the Armington value is specified separately for each commodity, and it can also be differentiated between consumption, investment and intermediate goods.

The lowest set of nests in Figure 3.4 shows the demand for primary factors (land, labour and capital) and energy inputs. They can also be substituted according to a CES parameter. Last, the demand for labour is further specified between different skill types following the Classification of Occupations by Statistics Finland.

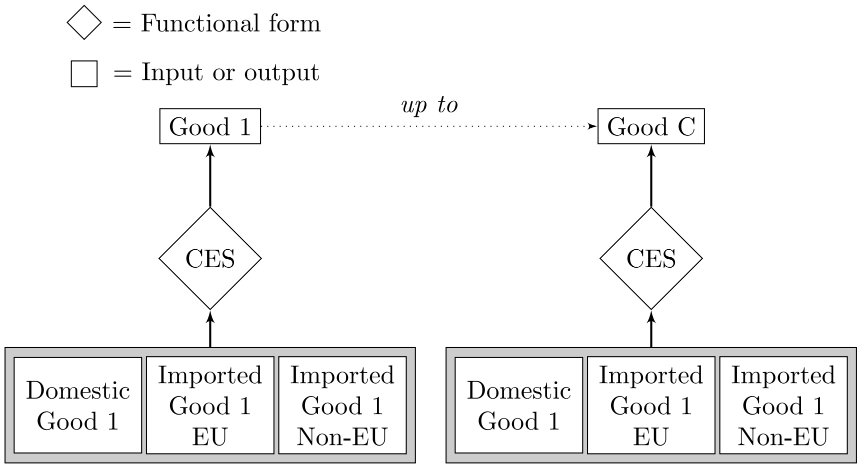


Figure 3.3: Intermediate sourcing nest (Honkatukia, 2009).

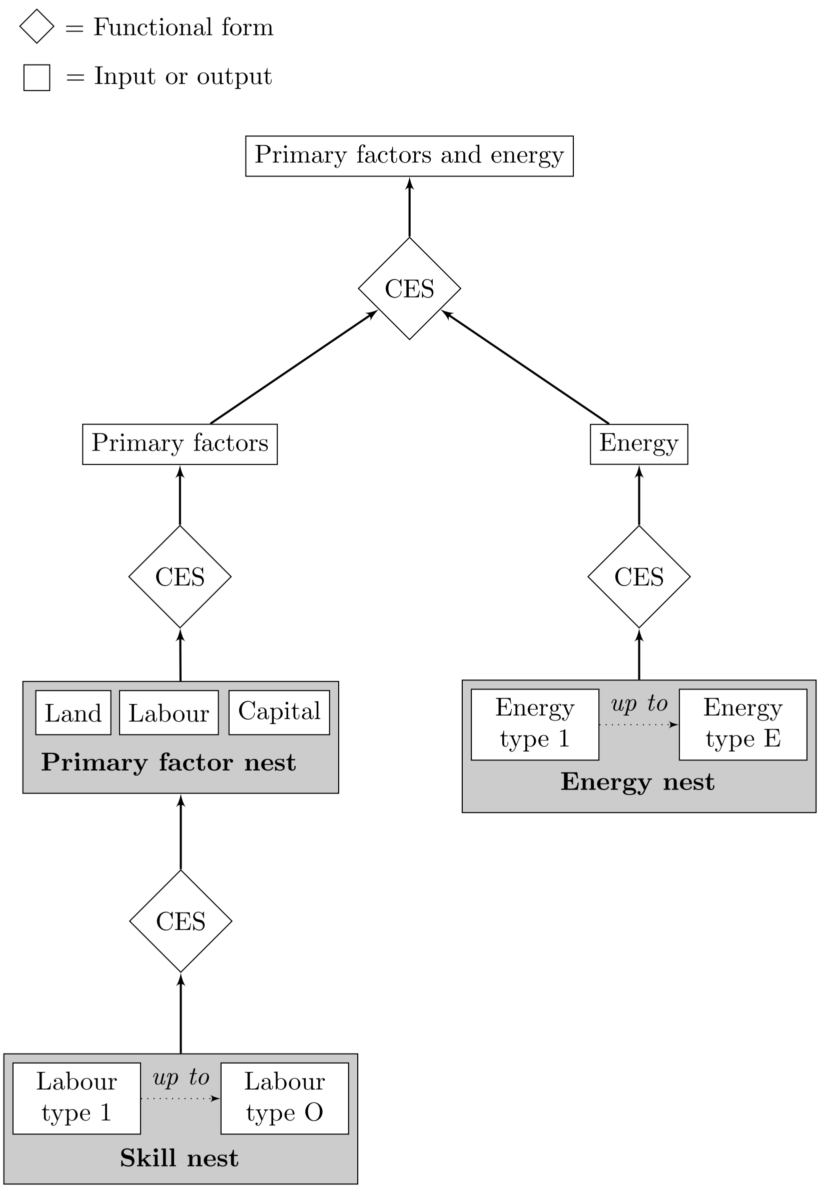


Figure 3.4: Primary factor and energy nest (Honkatukia, 2009).

Households maximize their utility through consumption. They face constraints determined by the primary factor income and the public income transfers they receive and the taxes they pay. As illustrated in Figure 3.5, the selection between different goods is very similar to the intermediate sourcing by firms. As a distinction, however, the decision-making process is modelled using a non-homothetic Klein-Rubin utility function. It allows the budget shares spent on different goods to change as the household income changes. A typical example of this is that the share of income used on food and housing tends to be bigger in lower income households, but gradually decrease when moving to higher income classes.

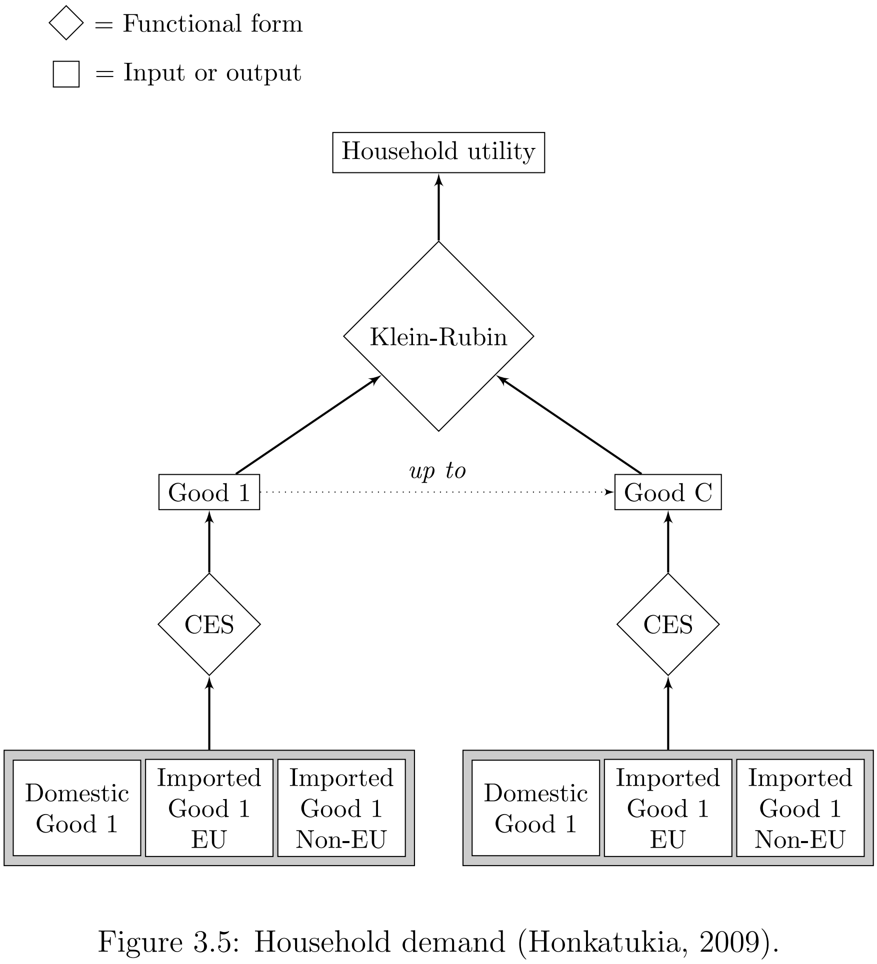


Figure 3.5: Household demand (Honkatukia, 2009).

Both households and firms make investments, guided by the expected rate of return on capital. The main trend is that the capital-labour ratio K/L remains constant in the long-run. Investments are always sector-specific, and cannot be transferred between sectors without new investments taking place.

The FINAGE model is solved using the GEMPACK (General Equilibrium Modelling Package) software (Harrison and Pearson, 2002). The modelling begins by creating a baseline scenario for the simulation period. This forecast compiles both historic data, future growth expectations, and industry-specific expert estimates to capture the development and trends in the economy for the coming years. The studied policy proposal is introduced as a shock to this baseline reference. The simulation is then repeated, and results are presented as a deviation between the baseline and the policy re-run. This study uses FINAGE in its dynamic mode, which means that the simulation is performed over time and for each year the database is updated. The solution of one year works as the starting point for the subsequent one. The economy adapts to shocks by changes in relative prices, which balances the supply and demand for each of the solutions. The dynamic approach, however, multiplies the computational workload. It can be lightened in the model closure, where the split between exogenous variables (predetermined by user) and endogenous variables (solved by the model) can be customised for each study application individually.

The reaction of labour markets is a key determinant in the way different shocks are being passed through the economy. The basic approach in AGE modelling is that the adjustment of wages clears the labour market after the shock has been introduced. In this study, it is further assumed that due to a somewhat centralized wage setting, the adjustment of wages is sluggish. It means that real wages are fixed in the short-run and the wage adjustment only takes place in the long-run, causing short-run changes in employment. The assumption of wage rigidities is modelled in the policy simulation with the following equation:

$$(\frac{W_t}{W_{t,base}} - 1) = (\frac{W_{t-1}}{W_{t-1,base}} - 1) + \alpha_1[\frac{E_t}{E_{t,base}} - (\frac{W_{t-1}}{W_{t-1,base}})^{\alpha_2}] \tag{3.1}$$

where the numerators W_t and E_t denote the real wage and employment rate in year t of the policy scenario. The denominator subscript *base* refers to same variables in the baseline forecast without the shock.

The above equation can be interpreted as follows: if the proposed policy drives employment E_t above (below) the baseline level, the deviation in year-to-year real wages will also increase (decrese). The wage response can be modified by positive parameters α_1 and α_2. The former controls the speed of adjustment — that is, the time it takes for the impact on employment to be fully transformed to changes in real wages. A non-zero value for α_2 deviates employment permanently from its forecast path. In that case, wages in year t are determined by both the prevailing level of employment in year t and the labour supply that was available at the wages of t-1. Now, if the policy proposal drives wages high (low) enough in year t-1, workers will continue to supply an above (below) baseline level of labour also in year t.

3.3 Back-of-the-envelope notation

The FINAGE model is based on the work of Centre of Policy Studies in Victoria University, particularly the VU-National dynamic model of the Australian economy (Dixon and Rimmer, 2001). An essential part of their CGE modelling fashion is explaining the results with a stylized back-of-the-envelope (BOTE) version of the full-scale model. It outlines both the key mechanisms behind the results and the interactions that take place within the economy. Furthermore, it offers the reader a convincing validation that the complex full-scale model performs the calculations correctly, is consistent with economic theory, and is based on a sound set of data. In the FINAGE model, the short-run production function of the economy is determined by:

$$Y = A * F(K, L) \tag{3.2}$$

According to equation (3.2), GDP is defined by a technology parameter A and a function of capital K and effective labour L. Following the BOTE model by Dixon and Rimmer (2002), the economy is next assumed to consist only of two goods: Good X that is domestically produced and exported and Good M that is imported. The only tax considered here is a tariff on imports. It is also assumed that the labour input by workers is compensated according to the value of its marginal product. This gives:

$$W = P_X * A * F_L \tag{3.3}$$

where W is the nominal wage rate, P_X the price of Good X and F_L the marginal product of labour. Next, a deflator indicating the price changes is defined as:

$$P_c = P_X^{\delta} * P_M^{(1-\delta)} * T_c \tag{3.4}$$

where P_c is the price deflator for consumption, P_M is the price of Good M, T_c is the power (1 + ad valorem rate) of tariff and δ is a positive parameter that shows the proportion in which Good X and Good M are being consumed. Dividing the nominal wage rate in equation (3.3) with the price deflator in equation (3.4) gives the real wage rate W_r:

$$W_r = \frac{1}{T_c} * (\frac{P_X}{P_M})^{(1-\delta)} * A * F_l(\frac{K}{L}) \tag{3.5}$$

Equation (3.5) can then be used to anticipate the direction and magnitude of the main tariff impacts. As the real wage level is fixed in the short-run, all changes can be isolated to the right-hand-side of the equation. Introducing a new tariff leads to a certain drop in $1/T_c$ as the ad valorem rate increases. The price of exports P_X relative to the price of imports P_M is the terms of trade component. It is of central interest when assessing a tariff policy. It is determined by several variables such as export and import demand elasticities, exchange rates, and relative market powers. A large coalition like the EU can draw substantial terms of trade improvements from erecting trade barriers as the diminishing demand for imports lowers their world market price. On the other hand, tariffs will hamper the efficient allocation of global resources and cause technology coefficient A to decrease. Now, if the increase in terms of trade is not large enough to compensate for the reductions in $1/T_c$ and A, there needs to be an increase in $F_l(\frac{K}{L})$. As the short-run level of capital K is also fixed, the only way for F_l to increase is through a temporary drop in labour L.

4 Data

4.1 Trade volume

Some additional information is required to quantify the tariff. The main data source for this study is the OECD inter-country input-output database (OECD, 2015). Input-output (IO) tables are used to evaluate the interdependencies between different industrial sectors and end users, either within a country or between countries through international trade. A stylized representation is available in Table 4.1. Columns specify the intermediate cost structure: each cell x_{ij} tells how many units from sector i, domestic or imported, is needed in sector j in order to produce the total output X_j. The basic unit is millions of US dollars. Rows specify the total income for each sector from delivering its output either to satisfy the final demand Y or the intermediate demand from other sectors. The sum of elements in a column is always equal to the sum of elements in its respective row, creating a balanced, one-year representation of the economy.

The OECD database was selected due to good compatibility with the FINAGE industry aggregation and a high level of country detail compared to many other available sources. The OECD trade data is aggregated to 34 industries and 61 countries, listed in Appendix A. Rest of the world is included as a single component (RoW) for a better global coverage. From the IO data, the total value of imports from all non-EU countries to Finland is extracted separately for each sector. The base year is 2011, which at the time of writing is the newest data set available.

	Intermediate demand				Final demand	
	Sector 1	Sector 2	...	Sector N	C+I+G+X	Output
Sector 1	x_{11}	x_{12}	...	x_{1n}	Y_1	$= X_1$
Sector 2	x_{21}	x_{22}	...	x_{2n}	Y_2	$= X_2$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
Sector N	x_{n1}	x_{n2}	...	x_{nn}	Y_n	$= X_n$
Value added	W_1	W_2	...	W_n		
	$\parallel$	$\parallel$		$\parallel$		
Output	X_1	X_2	...	X_n		

Table 4.1: A stylized input-output table.

4.2 Carbon content

The amount of CO_2 embodied in trade is computed following the environmentally extended input-output model by Koskela et al. (2011). The emission intensity per (monetary) unit of output is first determined for each industry, and multiplied by the volume of trade between Finland and non-EU regions. The total climate impact is the sum of direct and indirect emissions. The direct emissions stem from the burning of fossil fuels during the production process, whereas the indirect emissions are embodied in intermediate goods.

Koskela et al. make a simplifying assumption that all imports are produced with the same environmental impacts and an identical composition of intermediate products as equivalent domestic goods. The authors conclude that it leads to an underestimation of foreign emission intensities. This shortcoming, in fact, is well suited for the assessment of EU carbon tariffs. If the tariffs are introduced, they are most likely based on some general EU benchmark value below the actual emissions. This is in order to minimize the administrative burden and the protectionist appearance of the policy. Therefore, this study follows the simplification but calculates the industry-specific emission intensities as averages for the entire EU, whereas Koskela et al. only use the Finnish production technology as a reference.

First, a coefficient for the direct emissions from each sector is calculated by dividing total process emissions by total sector output:

$$E = \frac{CO_2\ (tonnes)}{Output\ (millions\ of\ USD)} \tag{4.1}$$

where E forms a vector of 34 elements, one for each of the OECD industries. The required emission data are obtained from the Eurostat Air Emission Accounts (Eurostat, 2016).

The indirect emissions are traced along the supply chain by applying the input-output analysis of Leontief (1970). A structural matrix of the economy is first constructed from the OECD data by dividing each input in a column by the corresponding total output:

$$a_{ij} = \frac{x_{ij}}{X_j} \tag{4.2}$$

where a_{ij} is a technical input coefficient. It determines the amount of goods from industry i needed to produce a single unit — one dollars' worth — of output in industry j. The obtained 34x34 matrix is illustrated in Table 4.2. It needs to be constructed separately for the domestic and imported intermediates, which are then summed together for the total material requirement.

$$\text{From} \begin{cases} \text{Sector 1} \\ \text{Sector 2} \\ \vdots \\ \text{Sector N} \end{cases} \overset{\overbrace{\begin{matrix} \text{Sector 1} & \text{Sector 2} & \cdots & \text{Sector N} \end{matrix}}^{\text{Into}}}{\begin{bmatrix} a_{12} & a_{12} & \cdots & a_{1n} \\ a_{22} & a_{12} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n2} & a_{12} & \cdots & a_{nn} \end{bmatrix}}$$

Table 4.2: The structural matrix of the economy.

The supply chain is still only partially covered. The structural matrix merely compiles the direct input requirements from each industry. However, producing the intermediate product a_{ij} also needs inputs, which requires inputs, and so forth. The structural matrix can be re-written as a set of linear equations:

$$\begin{matrix} X_1 - a_{11}X_1 - a_{12}X_2 \cdots - a_{1n}X_n = Y_1 \\ X_2 - a_{21}X_1 - a_{22}X_2 \cdots - a_{2n}X_n = Y_2 \\ \vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots \\ X_n - a_{n1}X_1 - a_{n2}X_2 \cdots - a_{nn}X_n = Y_n \end{matrix} \tag{4.3}$$

And in a general form as:

$$X_i = \sum_j a_{ij} X_j + Y_i, i = 1 \dots n \tag{4.4}$$

Equations (4.3) and (4.4) present the circular connections within the economy. The total output X_i in each sector 1 ... n must satisfy both the corresponding final demand Y_i and the intermediate requirements from all producing sectors. The intermediate demand from other sectors is always in a fixed proportion to their total level of output X_j. Transforming equation (4.4) to matrix notation gives:

$$X = AX + Y \tag{4.5}$$

Which in a stylized and rearranged form can be written as:

$$X = Y(I - A)^{-1} \tag{4.6}$$

where I is an identity matrix. The $(I - A)^{-1}$ is also known as the Leontief inverse or the total requirement matrix. It is an expansion of the technical coefficient matrix: each element in a row is a multiplier that specifies the requirement from that sector in order to produce one unit of final demand in every sector. Similarly, and more importantly for this study, each column now specifies the input requirements from all other sectors that are needed to produce one unit of final demand in that specific sector. The inverse matrix can then be multiplied by the emission intensity vector E, in order to determine the total climate impact per unit of output. The results are presented in Table 4.3 below.

Finally, the extended input-output model can be written out in its entirety as:

$$f^{tot} = E(I - A)^{-1} e_{rs} \tag{4.7}$$

where f^{tot} denotes the total amount of direct and indirect emissions embodied in imports, $E(I - A)^{-1}$ forms the carbon content coefficients, and e_{rs} is the value of trade extracted from the OECD data.

Industry	CO_2 content, kg/$
Agriculture, hunting, forestry and fishing	0,49
Mining and quarrying	0,57
Food products, beverages and tobacco	0,39
Wood and products of wood and cork	0,38
Pulp, paper, paper products and printing	0,49
Coke, refined petroleum and nuclear fuel	0,79
Chemicals and chemical products	0,67
Rubber and plastics products	0,42
Other non-metallic mineral products	1,50
Basic metals	0,98
Fabricated metal products	0,42
Machinery and equipment	0,33
Electricity, gas and water supply	2,28
Computer and electronic equipment	0,28
Transport and storage	0,63

Table 4.3: Embodied carbon in relevant sectors.

4.3 Quantifying the shock

In order to determine the size of the carbon tariff, the amount of imported CO_2 needs to be multiplied by the price of European emission allowances. The estimate for EU ETS allowance price is taken from a model comparison study by Knopf et al. (2014). They approximated the price level that is required to bring an emissions reduction of 80 percent by 2050. The price development and associated uncertainties are illustrated in Figure 4.1. Starting from less than €20 in 2015, the price exceeds €50 by 2030. This is a reasonable estimate in the light of the previous carbon tariff literature, with carbon prices ranging from $20 (Kuik and Hofkes, 2010; McKibbin and Wilcoxen, 2009) to $63 (Burniaux et al., 2013) and everything in between (Atkinson et al., 2011; Sakai and Barrett, 2016). A static allowance price, however, was not considered to be plausible for the simulation in this study.

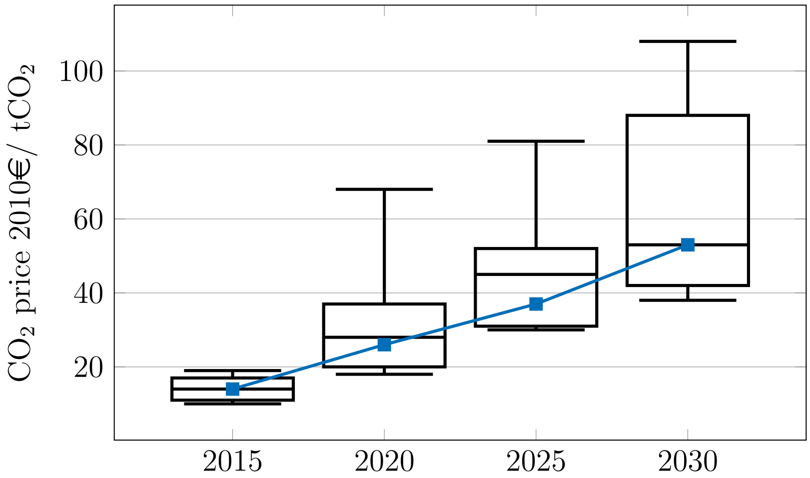


Figure 4.1: EU ETS allowance price development (Knopf et al., 2014).

To translate the obtained carbon tariff levy into the TABLO code format, it needs to be expressed as a *power* of tariff, that is, 1 + the ad valorem rate. The commodity-specific baseline tariffs are readily available from the FINAGE database. The actual economic shock is then determined as the necessary percentage increase to include the carbon component to the baseline tariffs. Only modest increases are required, ranging from 1 percent to 18 percent during the entire simulation period. A new shock needs to be introduced each year in order to capture the ascending price of emission allowances. For the purpose of this study, all administrative costs from the implementation of a new tariff are ignored.

Last, the OECD classification of 34 industries needs to be mapped to match the 97 industries and 144 commodities in FINAGE dataset. For convenience in reporting, the FINAGE industries are later compiled to 15 sectoral aggregates. The mappings are specified in Appendix A. Both datasets follow the ISIC rev. 3 classification, which makes the aggregation straightforward. The tariff is only imposed on the emission-intensive and trade-exposed sectors. It includes pulp, paper and prints, coke, refined petroleum, nuclear fuels, chemicals, rubber and plastic products, non-metallic minerals, basic metals, and fabricated metal products. This imitates the typical industry classification from previous BCA literature (Böhringer et al., 2012b; Winchester et al., 2011). The tariff is introduced in 2016 and modelled until 2030.

5 Results

5.1 Macroeconomic effects

The macroeconomic impacts of the carbon tariff policy are presented in Figure 5.1. Two main mechanisms drive the results. The immediate effect is the increase in general price level, which hikes up the costs of living and appears as a steady decline in household consumption. The second driver is the sluggish wage adjustment. The soaring price level also tends to drag down real wages, which — along with capital — are fixed in the short-run. It channels the shock into a temporary drop in employment instead, as explained earlier in equation (3.5). The drop begins to even out as soon as real wages have had time to adapt. However, employment remains below its initial level during the entire simulation period, because the annual tariff increase outweighs the effect from wage adjustment. Higher unemployment in turn causes nominal wages to fall as there are now more people willing to accept jobs.

The carbon tariff boosts intra-EU trade but cuts the exchange with other regions even more. This leaves total imports well below the baseline level. Strikingly — and contrary to the tariff argument for better global competitiveness — the pattern for exports is almost identical. During the first four years of simulation, the slump in exports is even bigger than in imports. Three explanations arise. First, when it comes to sourcing of intermediate goods, the Finnish exporting sector is highly import-dependent. Thus even a moderate increase in import prices adds up to a notable growth in total production costs. Moreover, the exporting sector is an intensive user of particularly those high-carbon imports that were targeted by the tariff. A relatively clean production process coupled with an emission-intensive global supply chain can turn out to be unfavourable for the domestic manufactur-

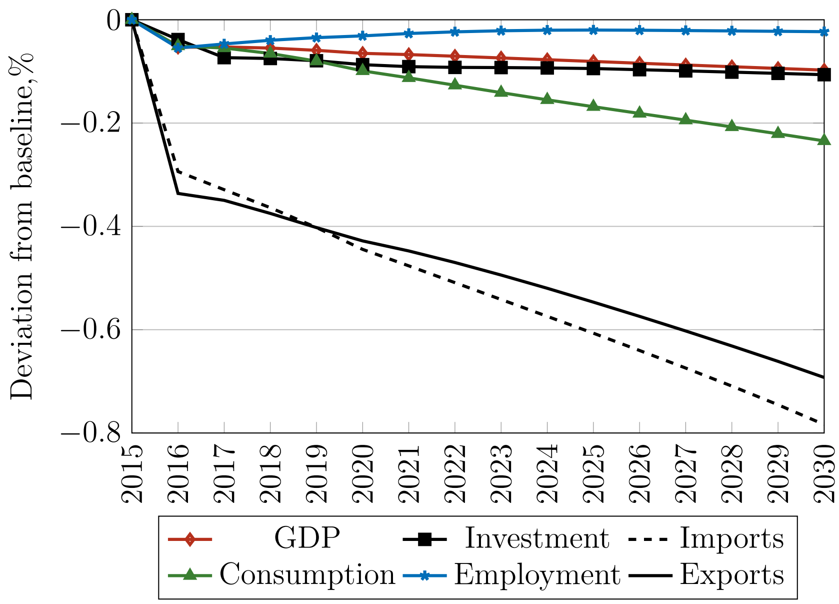


Figure 5.1: Macroeconomic effects.

ing sector if carbon tariffs are introduced. Last, exports face notably higher price elasticities than domestic demand, which leaves the export-oriented industries more sensitive to changes in relative prices.

Aggregate investment diminishes as well, mainly because of decreasing economic activity. Moreover, the increase in general price level weakens the return on capital, which also contributes to falling investment. The fall, however, stabilizes quickly as more investments are used to compensate for the shrinking imports.

The total long-run impact on real GDP is -0,1 percent. Figure 5.2 decomposes the relative importance of different expenditure-side aggregates. Clearly, the main impacts stem from the fall in exports and imports, but their opposite contribution to GDP cancels out their effect almost entirely. Apart from the changes in international trade, GDP is driven down by decreasing household consumption and a minor fall in investment. Government demand is not assumed to be affected by the tariff policy. Instead, it is set to follow official public expenditure estimates exogenously. This is in order to isolate the examination of results only on immediate tariff impacts.

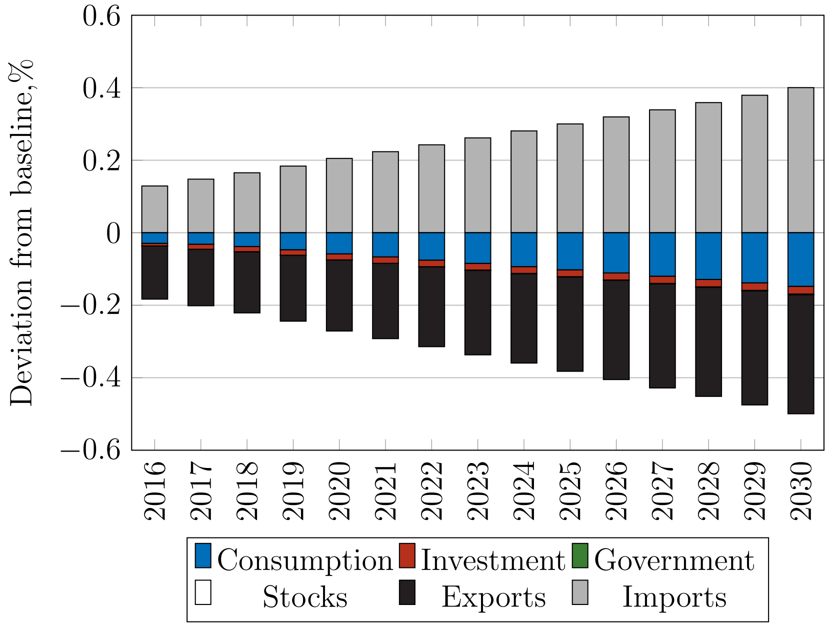


Figure 5.2: Contributions of real GDP expenditure aggregates.

5.2 Sector effects

Tariff impacts are unevenly distributed within the economy. All industry sectors are indirectly affected, despite the tariff is only imposed on sectors that are considered to be the most carbon-intensive and trade-exposed. Figure 5.3 illustrates the sector-specific contributions to real GDP. Consumption falls in each sector, following the diminishing real income. The impact is most pronounced within the private services and the *other manufacturing* sectors. The latter includes all major consumer goods such as food, wearing apparel, furniture and vehicles, and is therefore more sensitive to changes in income. These sectors also bear the most notable decline in investment. Export losses are concentrated to those manufacturing industries that were subject to the tariff, and indirectly to the transport sector. Apart from the general downturn in imports, the only positive GDP contribution stems from a small fillip in service exports.

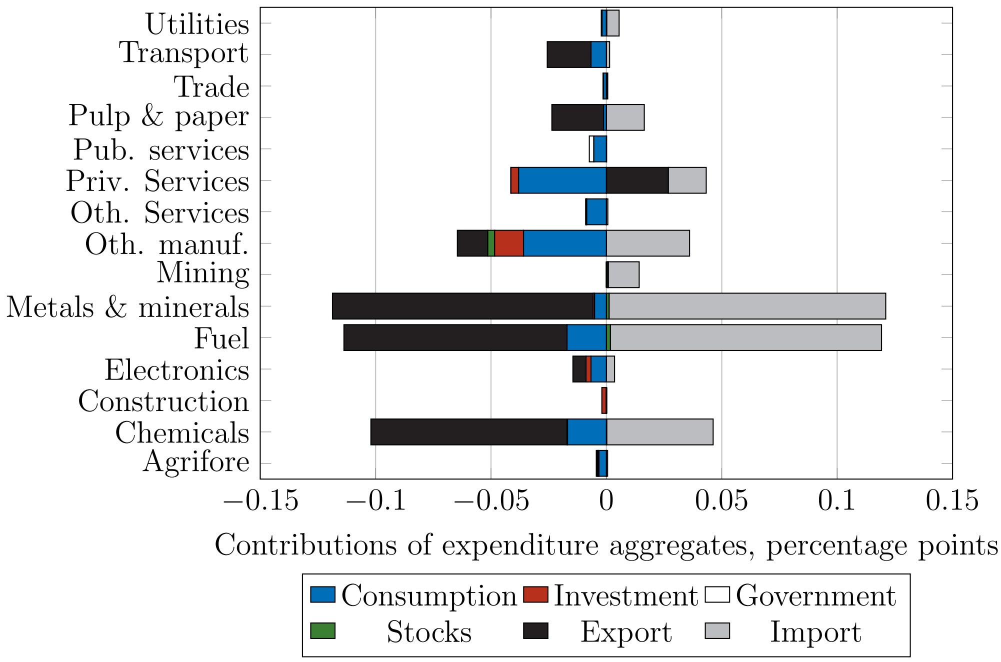


Figure 5.3: Industry contributions to real GDP in 2030.

Figure 5.4 compares the distribution of impacts in terms of value added, that is, the difference between the value of output and the value of goods and services that are used during production process. Surprisingly, the only winners — private services, electronic manufacturing and the utilities sector — were not directly targeted by the tariff, but benefit from the secondary impacts as the shock works its way through the economy. All other sectors fall below the baseline level and are unable to recover during the simulation period.

The magnitude of the tariff impact is mainly determined by the structure of intermediate demand. Systematically, all losing industry sectors are highly material-intensive and dependent on imported goods, which makes them vulnerable to the tariff-induced cost increases. Moreover, the share of value added in total manufacturing output is relatively small, meaning that there is only a thin buffer to receive the tariff shock.

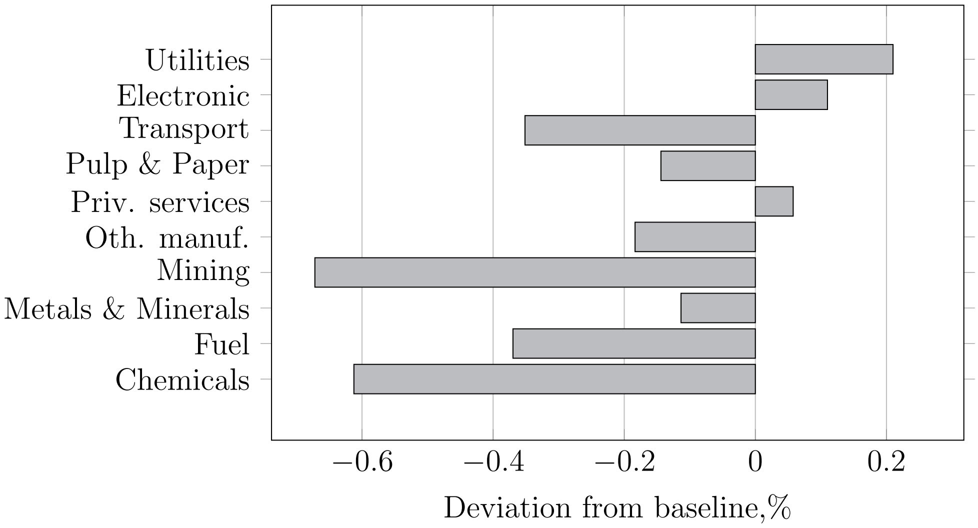


Figure 5.4: Change in value added for relevant sectors in 2030.

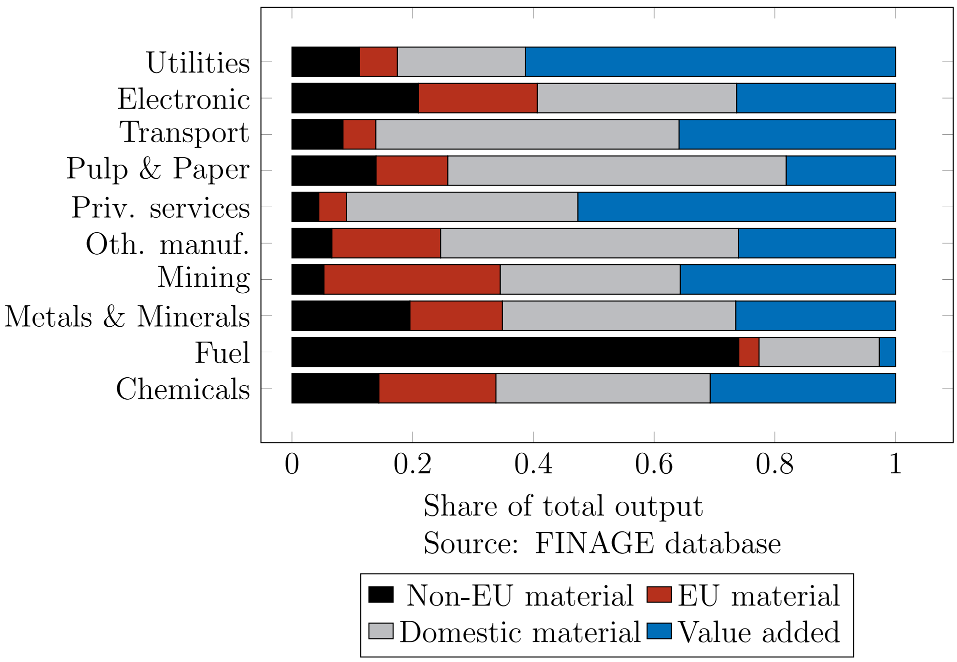


Figure 5.5: Structure of total output, initial pre-tariff level.

A summary for key industry characteristics is available in Figure 5.5, where the total output is broken down to shares of value added and intermediate consumption by region of origin. Particularly the fuel manufacturing sector stands out with a heavy reliance on non-EU materials and a small share of value added. However, the proportion of imported goods alone gives only a partial explanation for the uneven distribution of tariff impacts. Even a seemingly small share of foreign intermediates can turn out to be disadvantageous if it consists merely of carbon-intensive goods. The pulp and paper sector, for instance, is a traditionally domestic industry. However, it requires many tariff-covered inputs such as chemicals, fuel, and a growing share of imported pulp, which is mainly sourced from Latin America (Finnish Customs, 2015).

The wage-decreasing labour market reaction is beneficial for all industries. However, throughout the manufacturing sector, the share of labour costs is insignificantly small compared to the use of intermediate goods. The wage reduction is thereby unable to spur any positive outcomes alongside the soaring material costs. The service and electronic manufacturing sectors, on the other hand, manage to avoid major cost increases. The service sector is notably more labour-intensive, whereas the electronics sector — although an intensive user of intermediate goods — mainly imports components that are not subject to carbon tariffs. Despite a short-run drop, both sectors are able to ramp up their output as the wage adaptation brings down labour costs.

Another key determinant in adapting to the tariff shock is the ability to transfer the increasing production costs to consumer prices. The utilities sector consists of generation and distribution of heat and power, water supply, and sewerage. Being virtually unexposed to global competition, it can pass through the increasing material costs without notable changes in consumption patterns. Combined with decreasing wages, it takes a clear advantage of the carbon tariff policy.

The sectoral analysis verifies that carbon tariffs are not only detrimental to the Finnish economy in general, but particularly inadvisable for those globally-competing heavy manufacturing industries that they were designed to shelter in the first place. Domestic substitutive production will gain some market share at home, but the benefits from import replacement are not large enough to compensate for the losses from soaring material costs, decreasing household consumption, and diminishing export demand.

5.3 Regional effects and revenue distribution

Also regional impacts are unevenly distributed, following the industry structure in different parts of Finland. Changes in the gross region product are illustrated in Figure 5.6. All regions do worse, but the negative impacts are especially emphasized in Lappi, Itä-Uusimaa and Ahvenanmaa. In Lappi, the drop is mainly caused by the damage to iron and steel sector, which in terms of revenue is by far the biggest industry in the region (Regional council of Lapland, 2011). Finnish oil refining, on the other hand, is mainly concentrated in Itä-Uusimaa, explaining the considerable drop both in local fuel and chemical manufacturing sectors. In Ahvenanmaa, an autonomous archipelago, the general downturn in consumption and trade accumulates the negative tariff impacts to water transport sector.

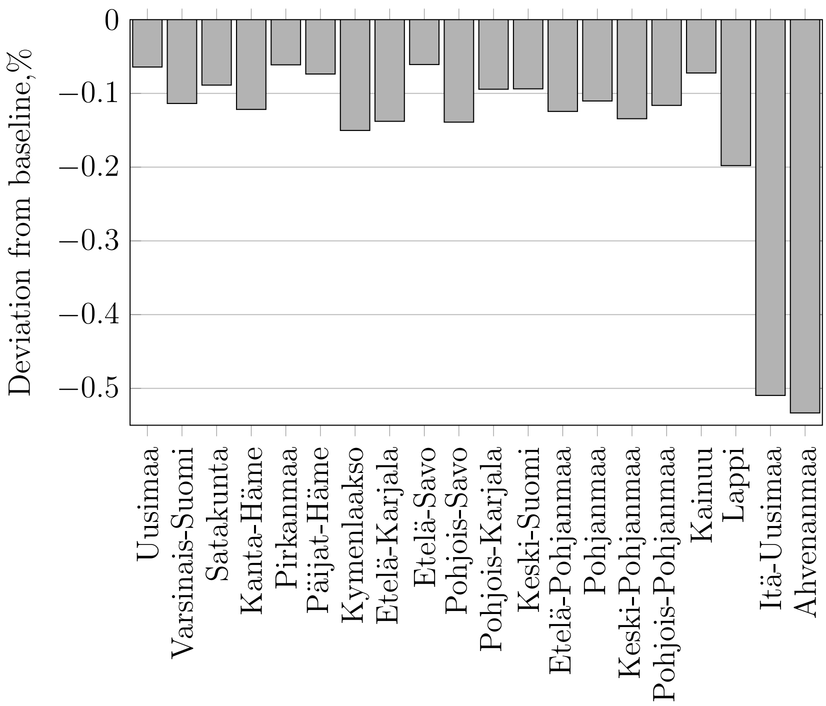


Figure 5.6: Changes in gross region product in 2030.

Beyond these three regions the losses are less dramatic. The decreasing activity in pulp and paper sectors is notable in Kymenlaakso and Etelä-Karjala. Service-oriented regions such as the metropolitan area Uusimaa and the second-biggest urban area Pirkanmaa are amongst the least affected areas.

When assessing the viability of carbon tariffs, the allocation of tariff revenue is by no means indifferent. Alternatives for compensating the negative tariff impacts include, for instance, unburdening the tax on labour, allocating money to emerging clean technologies, and steering funds to other general government revenue. In this thesis, however, these options were all disregarded as either inconsistent with the previous literature or as industry subventions beyond the scope of this study. Instead, all revenue is assumed to be recycled back to the countries of origin through international clean development funds, and hence modelled as net transfers.

The development of tariff revenue is presented in Figure 5.7. Starting from €173 million in 2016, the annual revenue reaches €700 million by 2030, following the anticipated increase in EU ETS allowance prices. For reference, the annual EU ETS auction revenue for Finland has varied between €60 million and €90 million during recent years (Energy Authority, 2017).

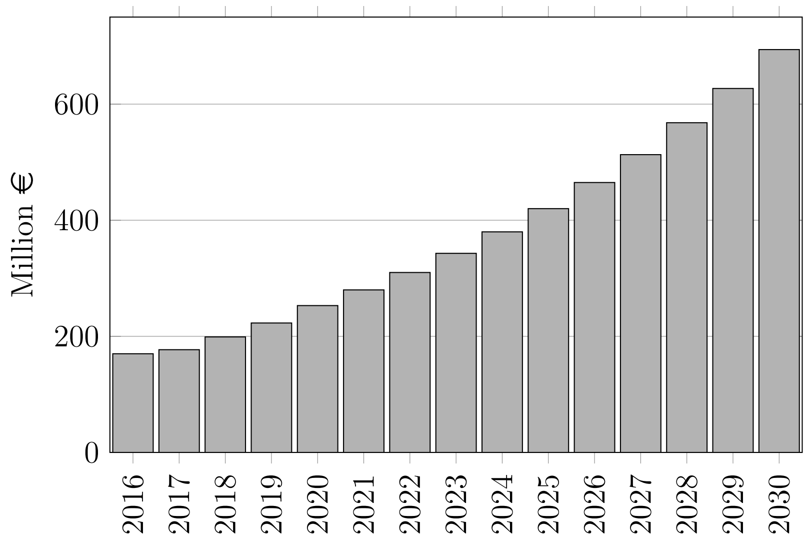


Figure 5.7: Annual tariff revenue.

5.4 Emissions reductions in Finland

Carbon tariff cuts both domestic and imported emissions but the impact is relatively small. By 2030, the total domestic emissions decrease by 1,1 percent. The only energy carriers subject to tariffs are coke and refined petroleum products. Their emissions fall by more than two percent because of direct price increases. The tariff-inflicted general economic inactivity also reduces emissions, yet with an even smaller impact. Emissions from coal, natural gas and peat only fall by 0,21, 0,31 and 0,75 percent, respectively.

The imported emissions fall for two reasons: the drop in import volume and the transition to cleaner substitute products. However, there are some uncertainties regarding changes in imported emissions. The domestic emissions reduction can be directly computed from the changes in fossil fuel use, whereas the imported emissions are estimated using the average EU carbon content as a reference. Furthermore, as the goods that were previously imported to the EU are now destined to other regions, not just left unproduced, the impact on actual foreign production emissions remains unclear.

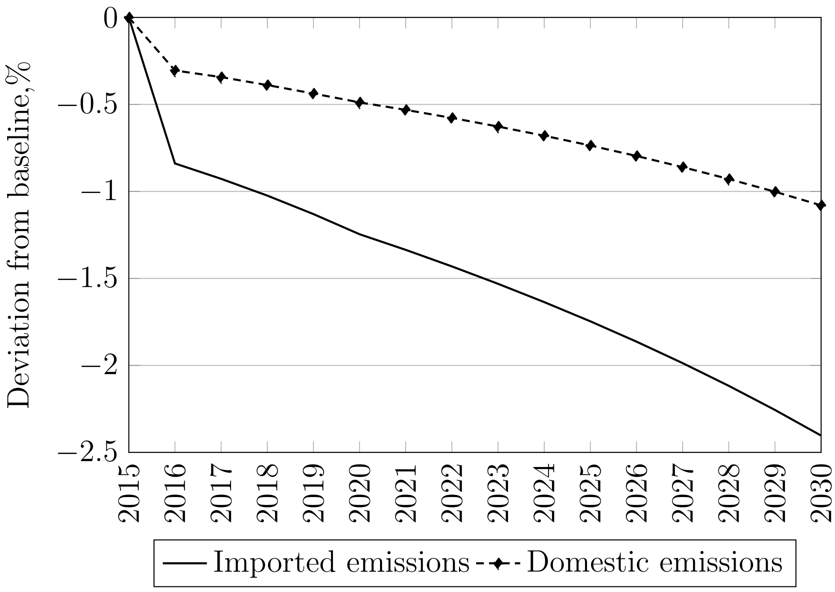


Figure 5.8: Emission reductions.

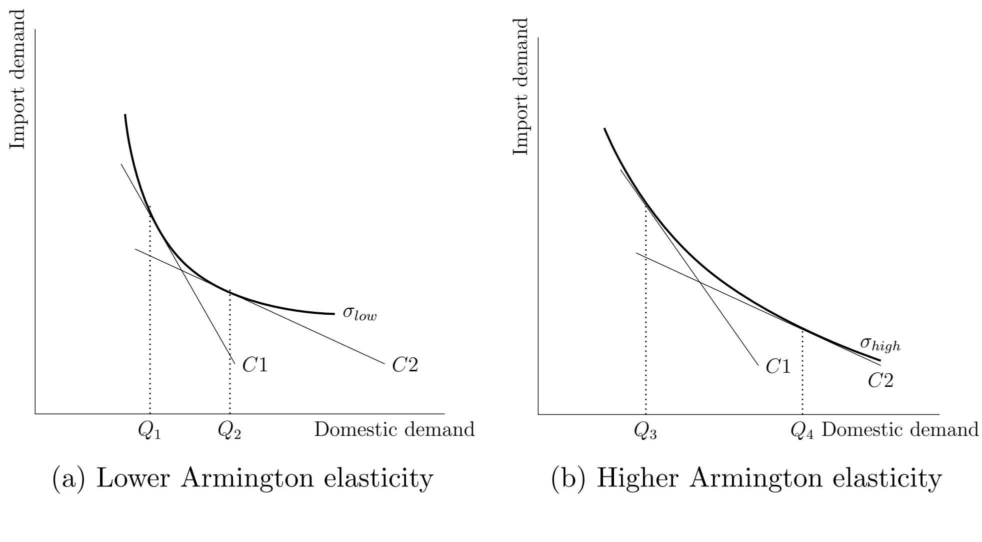
6 Sensitivity

This section tests the robustness of the results. In addition to the core simulation *(TARIFF)*, five sensitivity scenarios have been constructed by altering the key simulation parameters. First, Armington elasticity — the tendency to substitute between domestic goods and imports — is increased *(ARMI-high)* and decreased *(ARMI-low)* by 30 per cent. Similar treatment for export demand elasticity is performed in scenarios *EXDE-high* and *EXDE-low*. Last, the parameters controlling the rate of wage adaptation are altered in the *WAGE* scenario. Some short-run fluctuations occurred, but the long-run impacts remain robust in all of the five sensitivity scenarios. Results for main macroeconomic indicators are reported in Appendix B Figure B.1 for Armington elasticity, in Figure B.2 for export demand elasticity and in Figure B.3 for labour market dynamics.

The most profound differences arise from increasing the Armington elasticity. Higher elasticity indicates more homogeneity between domestic and foreign goods. This amplifies the trade response as consumers are now more prone to replace tariff-imposed imports with relatively cheaper domestic substitutes. As a result, there is a sharp upturn in domestic production during the first years of simulation. As the level of capital is fixed in the short-run, the higher demand for domestic goods also gives a strong boost for domestic employment. Due to the real wage rigidity, however, this can only happen through a drop in nominal wages. Yet simultaneously, there is a temporary increase in household consumption. This is possible because the more pronounced shift away from the increasingly expensive imports lowers the price of the entire consumption basket. Consequently, there is also less pressure for domestic real wages to diminish. As a result, consumer prices decrease more than the disposable household income, leaving consumption above the initial level. Eventually, wage adaptation cuts the boom, and the overall performance of the economy continues to fall below the core simulation levels.

Lowering the Armington elasticity has a smaller and more anticipated impact on the results. It attenuates the trade response slightly, but hardly affects any other indicators. Because the volume of imports now falls less, the compensatory increase in investment is also smaller.

Figure 6.1 illustrates the Armington elasticity effect. C_1 is the original isocost line where each combination of domestic goods and imports generates the same total cost for the consumer. The slope of the line is determined as the ratio between domestic and import prices. C_2 represents the isocost line after the tariff policy has been implemented. It is slightly kinked, as the price of imports has now increased. σ represents the Armington CES curve. The curved shape indicates that in the case of a higher elasticity, a smaller change in relative prices makes the consumer switch between domestic goods and imports. After imposing the tariff, the shift towards domestic goods under the higher elasticities Q4-Q3 is notably bigger than the core simulation values Q2-Q1.



(a) Lower Armington elasticity (b) Higher Armington elasticity

Figure 6.1: Armington CES curves.

In terms of export demand elasticity, the results remain very robust. Increasing the elasticity boosts the negative tariff impacts whereas lowering the elasticity dampens them. This can be explained by recalling the back-of-the-envelope real wage model from equation (3.5):

$$W_r = \frac{1}{T_c} * (\frac{P_X}{P_M})^{(1-\alpha)} * A * F_l(\frac{K}{L})$$

A lower export demand elasticity means that a bigger share of the increased production costs can now be transferred to export prices. This keeps export prices higher and holds up the terms of trade component P_X/P_M. Now, a bigger share of the negative tariff impacts to $\frac{1}{T_c}$ and A are compensated by higher terms of trade. It means that there is less pressure to increase $F_l(\frac{K}{L})$ by reductions in labour L, which can now remain more stable. For higher levels of export demand elasticity, the mechanism is completely opposite. This slightly emphasizes the negative tariff impacts.

Scenario *WAGE* alters the parameters α_1 and α_2 in equation (3.1). In the core simulation, their values are set to 0,7 and 0, respectively. Under this assumption, employment eventually recovers to its long-run forecast level. In the sensitivity simulation, the parameter values are increased to 1,1 and 0,4 following Honkatukia and Tamminen (2011). Adding up to α_1 makes the wage adaptation slower whereas the non-zero value for α_2 drives a lasting wedge between employment levels in the forecast and the policy simulation. Overall, the tariff impact remains very similar but slightly more pronounced. The extended slump in employment diminishes investment, as the K/L ratio tends towards long-run stability. The export curve begins to diverge from the core simulation values because wages now fall more slowly, bringing less cost reductions to export sector. Eventually, also GDP continues to decline below the core simulation level.

$$(\frac{W_t}{W_{t,base}} - 1) = (\frac{W_{t-1}}{W_{t-1,base}} - 1) + \alpha_1[\frac{E_t}{E_{t,base}} - (\frac{W_{t-1}}{W_{t-1,base}})^{\alpha_2}]$$

7 Discussion

There might still be a case for carbon tariffs. Despite the lacking empirical evidence of carbon leakage (Hokkanen and Ollikka, 2015; Bolscher et al., 2013), the outsourcing of emissions remains undisputed. EU en bloc imports annually nearly two gigatonnes of CO_2 embodied in goods and services, more than twice the emissions of Germany (Steen-Olsen et al., 2012; Eurostat, 2016). Finland is no exception: the import-related GHGs emitted abroad are equivalent to 70 – 80 percent of the total domestic emissions (Seppälä et al., 2011). The next question is, who is accountable for the climate impact — the producer or the consumer? A typical starting point in leakage-oriented BCA literature is that domestic manufacturing needs to be protected and less regulated foreign factories penalized. The assessment of global trade flows, on the other hand, emphasizes the role of consumers.

The current greenhouse gas accounting methodology under the UN Framework Convention on Climate Change (UNFCCC) is based solely on production-based emissions, where each country reports the emissions taking place within its territory during a certain period of time. A consumption-based approach would similarly include domestic activities, but add the imported emissions and exclude the production of goods that are destined for export. Advocates of the latter method argue that the current system distorts the fair allocation of reduction targets between regions and is the main cause for the whole concept of carbon leakage (Grasso and Roberts, 2013; Peters and Hertwich, 2008). Yet, neither approach is problem-free. Consumption-based accounting is arguably more complex both technically and politically. It is also inferior in building up the pressure on producers to clean their processes (Liu, 2015). Hence, a full shift in accounting methodology will be no panacea to fairer and more efficient emission reductions.

Carbon tariffs could be a reasonable compromise. Rather than reconstructing the entire accounting system, the key benefits of a consumption-based approach could be achieved with a relatively light — and only temporary, if need be — modifications. Emissions would still be measured at the point of production, but the responsibility would be shared between consumers and producers according to global trade patterns. This has two major advantages. First, the change in relative prices would steer consumers towards less polluting products, while maintaining the incentive for foreign exporters to cut their emissions in order to keep tariff costs down. Second, and perhaps more importantly, a bigger share of global emissions would be paid for. Currently, less than 15 percent of all emitted CO_2 is covered with a carbon market (World Bank, 2016). Carbon tariffs, or a requirement to surrender emission allowances at the border, would include imports to the system. As the increasing costs of trade are transferred to domestic market prices, also the consumer would pay for a fairer share of one's actual carbon footprint.

In practice, sharing the responsibility between producers and consumers boils down to balancing the roles between developing and developed countries. The debate is essentially a matter of historic emissions, but has more recent aspects to it as well. According to a global database constructed by Peters et al. (2011), the net emission transfers embodied in international trade from developing to developed (Annex B) countries quadrupled during 1990 – 2008. For some rich countries, imported emissions are growing faster than domestic emissions are being abated (Energy and Climate Change Committee, 2012). Therefore, even if the trade-related emissions are not directly included in the accounting methodology, their central role in climate debate is well-founded.

To fix the unequal incidence, the UNFCCC calls for *common but differentiated responsibilities and respective capabilities* (UN, 1992). In short, the main task in developing countries should be pursuing sustainable development while the developed world handles a bulk of the emission reductions. Carbon tariff doesn't automatically comply, and if poorly designed, it might even widen the gap. At worst, tariff cuts market access from those developing export sectors that are either in the middle of recovering from the recent economic downturn or even making their first-ever global appearance. The EU sources 60 percent of all imports from developing countries and is the main trading partner for 80 countries (European Commission, 2012a). Therefore, EU's influence in international trade is not easily overestimated. At best, however, carbon tariff contributes as a new source of climate finance, for which there is a crying need. During the historic climate convention COP21 in Paris, the collective goal of \$100 billion mobilized annually by developed countries was extended to 2025 and defined as a floor target for years thereafter (UN, 2015). In the EU, a carbon tariff merely on Chinese imports is estimated to yield over €14 billion each year (Gros, 2009). According to a modelling study by Springmann (2012), a carbon tariff between all Annex I and non-Annex I countries could raise an annual \$3,5 – 24,5 billion to clean development, even with a moderate carbon price of \$15 – 30/tCO_2.

Since its launch in 2005, the EU ETS has been the largest carbon market in the world, which has triggered the need to safeguard domestic industry competitiveness against rivals in non-acting countries. This might change sooner than expected. Most importantly China, the world's biggest exporter of both goods and carbon dioxide, is set to start its national emissions trading system during 2017 (Liu, 2016). The carbon price in the seven pilot markets that are already up and running has stabilized to around ¥40, matching the chronically low EU ETS allowance prices of €2-9 during recent years (Environomist, 2016; Marcu et al., 2016). In addition to China, many major emitters such as Russia, Brazil, Canada and Japan, have national emissions trading under consideration (ICAP, 2016).

The expanding carbon market changes the whole rationale behind carbon tariffs. Instead of a mere plug on carbon leakage, they could be used as a better aimed strategic tool against countries that are lagging behind in climate action. Moreover, the pressure should not be restricted only on developing nations. Carbon tariffs were first considered against the United States after the decision to leave the Kyoto Protocol unratified (Mrasek, 2006). More recently, the former French president Nicolas Sarkozy proposed similar trade restrictions if Donald Trump decides to withdraw the US from the Paris climate agreement (Davenport, 2016). Especially if the price of emission allowances in the EU ETS fails to take off and the generous cost compensation to heavy industries continues, there are hardly other but strategic reasons to bother with tariffs. Moreover, even the threat of EU having carbon tariffs at disposal might have a favourable outcome on global climate effort.

The political consequences of carbon tariffs remain unpredictable. A well-founded general view is that counter-measures are likely. The previous attempt to extend emission pricing beyond EU borders was by including international aviation. It was deferred after the *coalition of the unwilling*, led by the US and Russia, threatened to ban EU carriers from their airspace

(Elsworth and MacDonald, 2013). Yet, even if some retaliation occurs, the storm in trade relations is likely to relent before turning into a full-grown trade war. This is because tariffs are still a rather commonplace feature of global trade. The EU, for instance, has a wide variety of recent anti-dumping measures in place for Chinese imports, ranging from solar panels (European Commission, 2015) to 37 different tariffs on steel products (European Commission, 2016). The foreign reactions have varied from re-routing imports through proxy countries — as in the case of Chinese solar panels — to setting up counter-tariffs for European goods (WTO, 2015a).

Moreover, the EU itself is often inconsistent in responding to changes in foreign trade policy. For instance, the EU has imposed anti-dumping tariffs on Chinese goods for being too cheap (European Commission, 2007), but filed a WTO complaint about price manipulation when China used export duties to increase their prices (WTO, 2012). China's excuse for limiting resource exports was that it reduces environmental degradation. Therefore, it relied on the environmental exceptions in GATT — the very same Article XX that the EU is likely to defend its carbon tariffs with. Eventually, the EU rejoiced at the WTO ban on Chinese export duties by stating that *there are more effective environmental protection measures that do not discriminate against foreign industry* (European Commission, 2012b). It is obvious that carbon tariffs, or any other trade barriers alike, cannot be introduced without protectionist intentions and only as an environmental necessity.

As this study and many previous cases suggest, tariffs tend to backfire on especially those heavy industries that have been their most vocal supporters. Perhaps the most iconic example is the US 2002 steel tariff, where the soaring price of steel led to the loss of 200 000 American jobs, 50 000 of which from the steel sector itself (Francois and Baughman, 2003). Furthermore, even if trade restrictions do manage to repatriate some jobs, it usually comes with a high cost. Hufbauer and Lowry (2012) estimate that the 2009 US tariff on Chinese tires cost more than $1,1 billion to American consumers. However, the policy only managed to secure a maximum of 1200 jobs, valued almost one million dollars each. For many industries at home and abroad, the tariff-free flux of cheap imports is the precondition, not a restraint, on competitiveness.

Thus far, the European trade policy has embraced the benefits of free trade and globally intertwined supply chains. Over 70 percent of extra-EU imports enter the region without any or with lowered tariffs (European Commission, 2012a). Finland has indeed utilized this, and the share of imported manufacturing inputs has increased well above the average EU rate (Ali-

Yrkkö et al., 2016). But the deeper integration to global value chains also involves risks and makes the economy more vulnerable to exogenous trade shocks. The global economy has reached a level of complexity where the appeal of protective tariffs, even if environmentally motivated, can be harmfully over-simplistic.

Nonetheless, if the urgency of climate action makes carbon tariffs inevitable, the EU is an excellent location to start. First of all, having a well-established carbon market infrastructure also makes the use of supplementary tariff policies relatively easier. Useful data are already abundantly available, including the sector-specific emission benchmarks for the top EU manufacturers. Second, despite the last economic crisis, the EU has maintained its position both as the biggest market area in the world and as the top global importer of manufactured goods (European Commission, 2012a). It means that the EU actually has the leverage that is required to have an impact on global trade patterns. The timing for carbon tariffs has also substantially improved over the last few years. The recently ratified Paris climate agreement offers the WTO a legal foundation to update its trade regulations towards a more climate-emphasized direction. It is also a clear high-level mandate to use increasingly powerful policy measures in the fight against climate change.

On the validity of results

There are still some undiscussed caveats that might have an impact on the results. First, this study doesn't take into account the industrial energy efficiency improvements that are likely to take place during the simulation period and thereby reduce the carbon content of imports. From 2001 to 2011, energy intensity in the European manufacturing sector improved by nearly 19 percent (European Commission, 2014), although the lower energy consumption caused by economic downturn complicates the approximation. However, a sectoral assessment by Chan and Kantamaneni (2015) suggests that particularly for non-ferrous metals, iron and steel sectors and chemical manufacturing, the rate of future energy efficiency improvements will notably decelerate as the lowest-hanging fruits have already been picked. Thus, future energy efficiency potential in the manufacturing sector as a whole will be limited. Including energy efficiency improvements to the study would also play a greater role if the carbon content was approximated based on actual foreign process emissions. Here, the use of a European emission benchmark is likely to offset for energy efficiency improvements in production processes abroad.

Another missing element is the actual cost of foreign trade retaliation. The issue has only been covered in a small number of quantitative literature and is virtually still in the speculative level. A recent modelling study by Fouré et al. (2016) summarised the consequences of retaliation to three main features. If retaliation occurs, it is most likely started by the USA, China or India, targeted on the European agricultural sector and has only a marginal impact on the European GDP and other macroeconomic indicators. Hence, also the results presented in this study are expected to remain appropriately accurate, even if some form of trade retaliation is provoked.

Nonetheless, even under all these simplifying assumptions and future uncertainties, the underlying mechanism behind the results remains unchanged. A carbon tariff, big or small, will have an adverse impact on an open, material-intensive and import-dependent economy.

The results presented in this study are consistent with the existing literature. The obtained values for embodied carbon are very close to the previous EU estimates (Schenker et al., 2012) and predictably well below the global average levels (Nakano et al., 2009). Also the tariff-induced output losses have been widely documented (Burniaux et al., 2013; Böhringer et al., 2014). However, the industry structure varies considerably from country to country. It makes the generalization of aggregate EU-level results problematic and advocates for more country-specific research. Similarly, the results presented in this study should not be directly applied to estimate tariff impacts in other countries. In a more general context, however, the contracting economic activity reported here fits well with the statistical finding that the EU is poor in terms of raw materials, but highly dependent of manufacture exports (Moll and Remond-Tiedrez, 2011), and therefore sensitive to tariff policies.

This thesis diverges from previous literature as it uses a single-country AGE model in contrast to the multi-country models that are typically applied to study carbon tariffs. This has some clear limitations. Importantly, a tariff imposed by the EU will affect global market prices through various feedback effects more than what is captured by the model. This might also leave some impacts on intra-EU trade unobserved. If the EU demand for domestic exports increases substantially as the non-EU goods become more expensive, the tariff policy might be more worthwhile. However, if carbon tariffs turn out to be equally detrimental to the other EU economies as well, additional negative impacts may occur.

However, the FINAGE model stands out from the majority of single-country models as the rest of the world is not treated as a single component, but instead disaggregated between EU and non-EU data. Without this quality, a credible estimation of an EU trade policy would not be possible in the first place. Using a single-country model also revealed important mechanisms behind the results that are not usually covered in carbon tariff literature. For instance, labour market reactions are not typically available, but here they distinguished between winning and losing sectors.

Last, an in-depth discussion over the ability of AGE models to correctly represent the real economy and thereby forecast the policy impacts would require an entire study of its own. The AGE modelling convention is often criticized as a "black box", where the highly complex model merely conjures up figures without presenting any convincing validation for its audience. Another cause for suspicion is the level of industrial aggregation, which might blur some important linkages that exist in the real world economy. Without an access to full data and the algebraic notation, reproducing the study becomes virtually impossible and the lack of transparency undermines the credibility of results.

There are no simple answers to these questions. Broadly speaking, the power of AGE modelling lies not within the absolute accuracy of the results, but rather in the ability to capture the course and magnitude of impacts throughout the entire economy over long periods of time. Furthermore, Dixon and Rimmer (2009) compared earlier modelling results in the US with actual economic development. They were able to justify the use of computable general equilibrium models as *usefully accurate*, despite the unavoidable average errors. For opening the black box, Giesecke and Madden (2013) stress the importance of a thorough back-of-the-envelope analysis that strips the full model of its complexity. In this thesis, the BOTE analysis performed in Chapter 3 managed to anticipate the modelling outcomes accurately. It is first and foremost a validation for the user that the model is functioning without blind spots. Equally important, a credible explanation should be available also for any surprises in the sensitivity analysis, as the results are typically sensitive to changes in model parameters.

In sum, the critique on AGE modelling is often more correctly pointed to the way the results are presented. When appropriately analysed, general equilibrium models can indeed offer a valuable contribution to policy debate.

8 Conclusion

This study examined the economic impacts of a hypothetical EU-wide carbon tariff. The results were modelled using FINAGE, an applied general equilibrium model of the Finnish economy.

The main finding is that the current industry structure is not well-suited for the introduction of a carbon-motivated tariff. Particularly the manufacturing sector is highly dependent on imported materials and thereby poorly tolerant for exogenous trade shocks. As a result, the economy performed worse on all available macroeconomic indicators when the tariff was imposed. The few sectors that gain from the tariff were not directly subject to it, but either utilize the wage-decreasing labour market reaction, or are better capable of transferring the higher costs to consumer prices.

However, the discussion over carbon tariffs should not be limited to competitiveness issues. In addition, they have a potential role in sharing the burden of GHG reductions and as a strategic leverage against countries that are lagging behind in climate action. Nor should the planning of tariffs be stymied by the possible conflict with WTO regulation. The recently ratified Paris agreement lays the ground for increasingly powerful climate action. Furthermore, it provides justification for the WTO to review its rules that in the light of current climate policy seem outdated. The trade organization itself has already for long been compliant to an international climate agreement to *"send the WTO an appropriate signal on how its rules . . . should be employed in the fight against climate change"* (Lamy, 2007).

This leaves much room for further research. A possible extension to this study is to investigate how the optimal use of tariff revenue, whether at home or abroad, might spur clean substitutive production and thereby compensate for the economic detriment. The globally expanding emissions trading also shapes the future carbon tariff literature. The acting coalition might grow larger, but the targeted countries become more strategically selected. Also the roles might change, as China, the usual target for tariffs, is about to become the biggest carbon market in terms of global emissions covered (World Bank, 2016).

In sum, carbon tariffs would still be very burdensome to implement and politically flammable. Yet preconditions for their use, including the better-established link between climate change and international trade, have significantly improved during recent years. It advocates for keeping tariffs available in the climate policy toolbox at least for the foreseeable future. But as the findings in this study suggest, the argument for protective tariffs — even if environmentally motivated — is likely to adversely over-simplify their impact.

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A Regions and industry sectors

Table A.1: List of countries included in the OECD data.

ARG	Argentina	**HRV**	Croatia	**POL**	Poland
AUS	Australia	**HUN**	Hungary	**PRT**	Portugal
AUT	Austria	**IDN**	Indonesia	**ROU**	Romania
BEL	Belgium	**IND**	India	**RUS**	Russia
BGR	Bulgaria	**ISL**	Iceland	**SAU**	Saudi Arabia
BRA	Brazil	**IRL**	Ireland	**SGP**	Singapore
BRN	Brunei Darus.	**ISR**	Israel	**SVK**	Slovak Republic
CAN	Canada	**ITA**	Italy	**SVN**	Slovenia
CHL	Chile	**JPN**	Japan	**ESP**	Spain
CHN	China	**KHM**	Cambodia	**SWE**	Sweden
COL	Colombia	**KOR**	Korea	**CHE**	Switzerland
CRI	Costa Rica	**LVA**	Latvia	**THA**	Thailand
CYP	Cyprus	**LTU**	Lithuania	**TUN**	Tunisia
CZE	Czech Republic	**LUX**	Luxembourg	**TUR**	Turkey
DNK	Denmark	**MEX**	Mexico	**TWN**	Chinese Taipei
EST	Estonia	**MLT**	Malta	**GBR**	United Kingdom
FIN	Finland	**MYS**	Malaysia	**USA**	United States
FRA	France	**NLD**	Netherlands	**VNM**	Viet Nam
DEU	Germany	**NZL**	New Zealand	**ZAF**	South Africa
GRC	Greece	**NOR**	Norway	**RoW**	Rest of the world
HKG	Hong Kong	**PHL**	Philippines		

Table A.2: List of sectors included in the OECD data.

C01T05	Agriculture, hunting, forestry and fishing
C10T14	Mining and quarrying
C15T16	Food products, beverages and tobacco
C17T19	Textiles, textile products, leather and footwear
C20	Wood and products of wood and cork
C21T22	Pulp, paper, paper products, printing and publishing
C23	Coke, refined petroleum products and nuclear fuel
C24	Chemicals and chemical products
C25	Rubber and plastics products
C26	Other non-metallic mineral products
C27	Basic metals
C28	Fabricated metal products
C29	Machinery and equipment, nec
C30T33X	Computer, Electronic and optical equipment
C31	Electrical machinery and apparatus, nec
C34	Motor vehicles, trailers and semi-trailers
C35	Other transport equipment
C36T37	Manufacturing nec; recycling
C40T41	Electricity, gas and water supply
C45	Construction
C50T52	Wholesale and retail trade; repairs
C55	Hotels and restaurants
C60T63	Transport and storage
C64	Post and telecommunications
C65T67	Financial intermediation
C70	Real estate activities
C71	Renting of machinery and equipment
C72	Computer and related activities
C73T74	R&D and other business activities
C75	Public admin. and defence; compulsory social security
C80	Education
C85	Health and social work
C90T93	Other community, social and personal services
C95	Private households with employed persons

Table A.3: List of FINAGE sectors and aggregations.

ISIC code	Industry (shortened)	OECD	FINAGE-15
01	Crop and animal production	C01T05	Agrifore
021	Silviculture and other forestry	C01T05	Agrifore
022	Logging	C01T05	Agrifore
023_4	Gathering of non-wood products	C01T05	Agrifore
03	Fishing and aquaculture	C01T05	Agrifore
05	Mining of coal and lignite	C10T14	Mining
061	Extraction of crude petroleum	C10T14	Mining
062	Extraction of natural gas	C10T14	Mining
07	Mining of metal ores	C10T14	Mining
0892	Extraction of peat	C10T14	Mining
08_9	Other mining and support activities	C10T14	Mining
10_1	Mnf of food products and beverages	C15T16	Oth. manuf.
13_5	Mnf of textiles, wearing apparel	C17T19	Oth. manuf.
16	Mnf of wood and products of wood	C20	Oth. manuf.
171	Mnf of pulp, paper and paperboard	C21T22	Pulp & paper
172	Mnf of articles of paper	C21T22	Pulp & paper
18	Printing and recorded media	C21T22	Pulp & paper
19	Mnf of coke and refined petroleum	C23	Fuel
20	Mnf of chemicals	C24	Chemicals
21	Mnf of pharmaceutical products	C24	Chemicals
22	Mnf of rubber and plastic products	C25	Chemicals
231_4	Mnf of other non-metallic minerals	C26	Metals & minerals
235_9	Mnf of cement, lime and plaster	C26	Metals & minerals
241_3	Mnf of basic iron and steel	C27	Metals & minerals
244_9	Mnf of precious and non-ferrous met.	C27	Metals & minerals
251_9	Mnf of structural metal products	C28	Metals & minerals
253	Mnf of steam generators	C28	Metals & minerals
261_2	Mnf of electronic components	C30T33X	Electronics
263_4	Mnf of communication equipment	C30T33X	Electronics
265_8	Mnf of measuring instruments	C30T33X	Electronics
271	Mnf of electric motors	C31	Electronics
272_3	Mnf of batteries and accumulators	C31	Electronics
274_9	Mnf of electric lighting equipment	C31	Electronics
281	Mnf of general-purpose machinery	C29	Oth. manuf.
282	Mnf of other general machinery	C29	Oth. manuf.
283	Mnf of agricultural machinery	C29	Oth. manuf.
284_9	Mnf of metal forming machinery	C29	Oth. manuf.

ISIC code	Industry (shortened)	OECD	FINAGE-15
29	Mnf of motor vehicles	C34	Oth. manuf.
301	Building of ships and boats	C35	Oth. manuf.
302_9	Mnf of railway locomotives	C35	Oth. manuf.
31	Mnf of furniture	C36T37	Oth. manuf.
32	Other manufacturing	C36T37	Oth. manuf.
331	Repair of fabricated metal products	C36T37	Oth. manuf.
332	Installation of industrial machinery	C36T37	Oth. manuf.
351	Electric power generation	C40T41	Utilities
352	Mnf of gas	C40T41	Utilities
353	Steam and air conditioning supply	C40T41	Utilities
36	Water collection, treatment and supply	C40T41	Utilities
37_39	Sewerage	C40T41	Utilities
411	Development of building projects	C45	Construction
412p432_9	Construction of residential buildings	C45	Construction
42p431	Construction of roads and railways	C45	Construction
45	Trade and repair of motor vehicles	C50T52	Trade
46	Wholesale trade	C50T52	Trade
47	Retail trade	C50T52	Trade
491_2	Land transport	C60T63	Transport
493	Other passenger land transport	C60T63	Transport
494_5	Freight transport by road	C60T63	Transport
50	Water transport	C60T63	Transport
51	Air transport	C60T63	Transport
52	Warehousing and support activities	C60T63	Transport
53	Postal and courier activities	C60T63	Transport
55	Accommodation	C55	Priv. Services
56	Food and beverage service	C55	Priv. Services
58	Publishing activities	C64	Priv. Services
59_60	Motion picture, video and television	C64	Priv. Services
61	Telecommunications	C64	Priv. Services
62_3	Computer programming	C64	Priv. Services
64	Financial service activities	C65T67	Priv. Services
65	Insurance	C65T67	Priv. Services
66	Activities auxiliary to financial serv.	C65T67	Priv. Services
681	Buying and selling of own real estate	C70	Priv. Services
68201	Letting of dwellings	C70	Priv. Services
68202	Operation of dwellings	C70	Priv. Services

ISIC code	Industry (shortened)	OECD	FINAGE-15
683	Real estate activities	C70	Priv. Services
69_70	Legal and accounting activities	C73T74	Priv. Services
71	Architectural and engineering activities	C73T74	Priv. Services
72	Scientific research	C73T74	Priv. Services
73	Advertising and market research	C73T74	Priv. Services
74_5	Other professional activities	C71	Priv. Services
77	Rental and leasing activities	C71	Priv. Services
78	Employment activities	C75	Priv. Services
79	Travel agency and related activities	C75	Priv. Services
80_2	Security and investigation activities	C75	Priv. Services
841_3	Administration of the State	C75	Pub. services
844	Defence equipment and conscripts	C75	Pub. services
845	Maintaining of railways	C75	Pub. services
846	Maintaining of roads and streets	C75	Pub. services
85	Education	C80	Pub. services
86	Human health activities	C85	Pub. services
87_8	Residential care activities	C85	Pub. services
90_1	Creative, arts and entertainment	C90T93	Oth. Services
92	Gambling and betting activities	C90T93	Oth. Services
93	Sports activities	C90T93	Oth. Services
94	Activities of membership organisations	C90T93	Oth. Services
95	Repair of personal and household goods	C90T93	Oth. Services
96_8	Activities of households as employers	C95	Oth. Services

B Sensitivity results

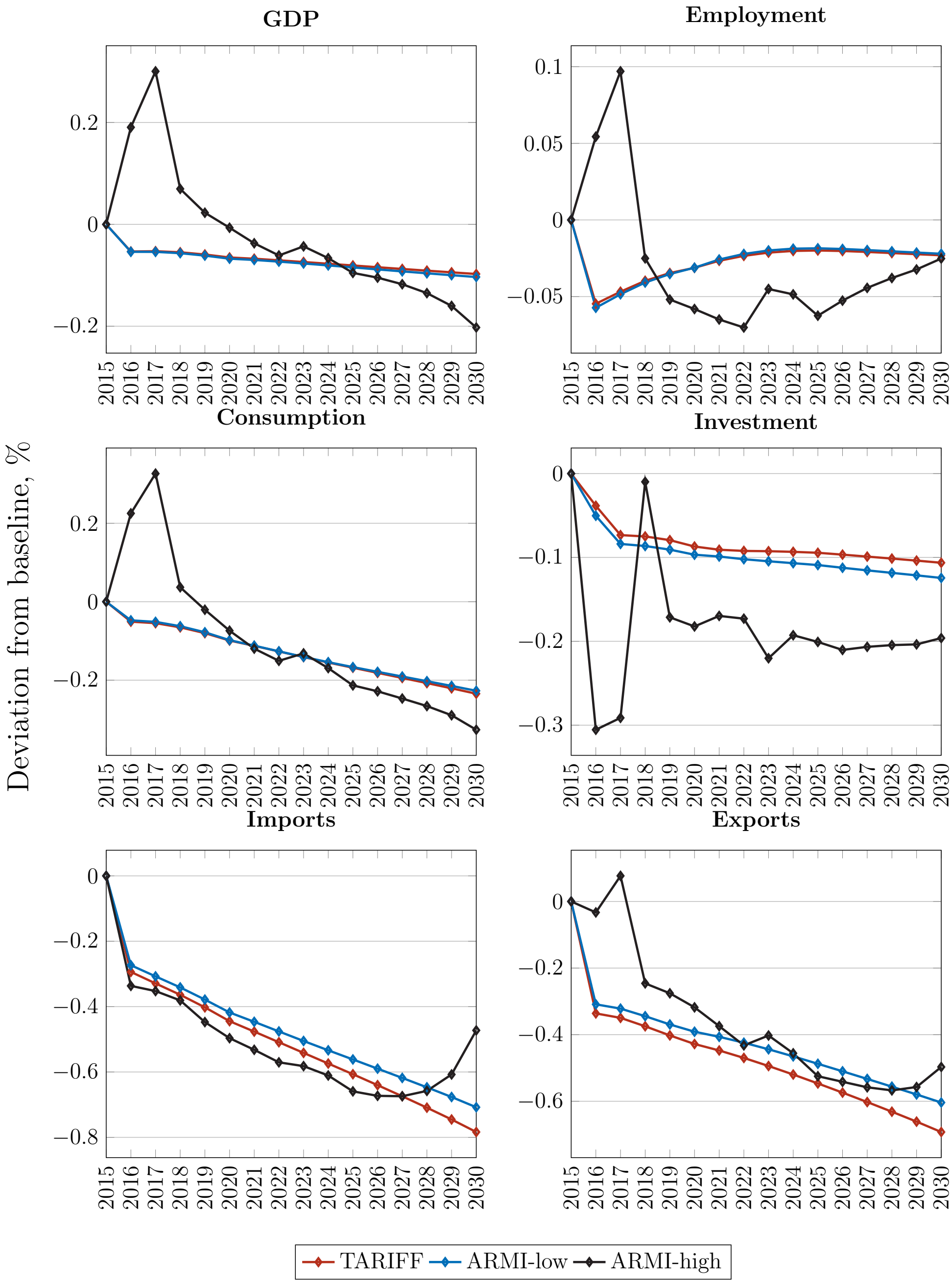

Figure B.1: Sensitivity analysis for Armington elasticity.

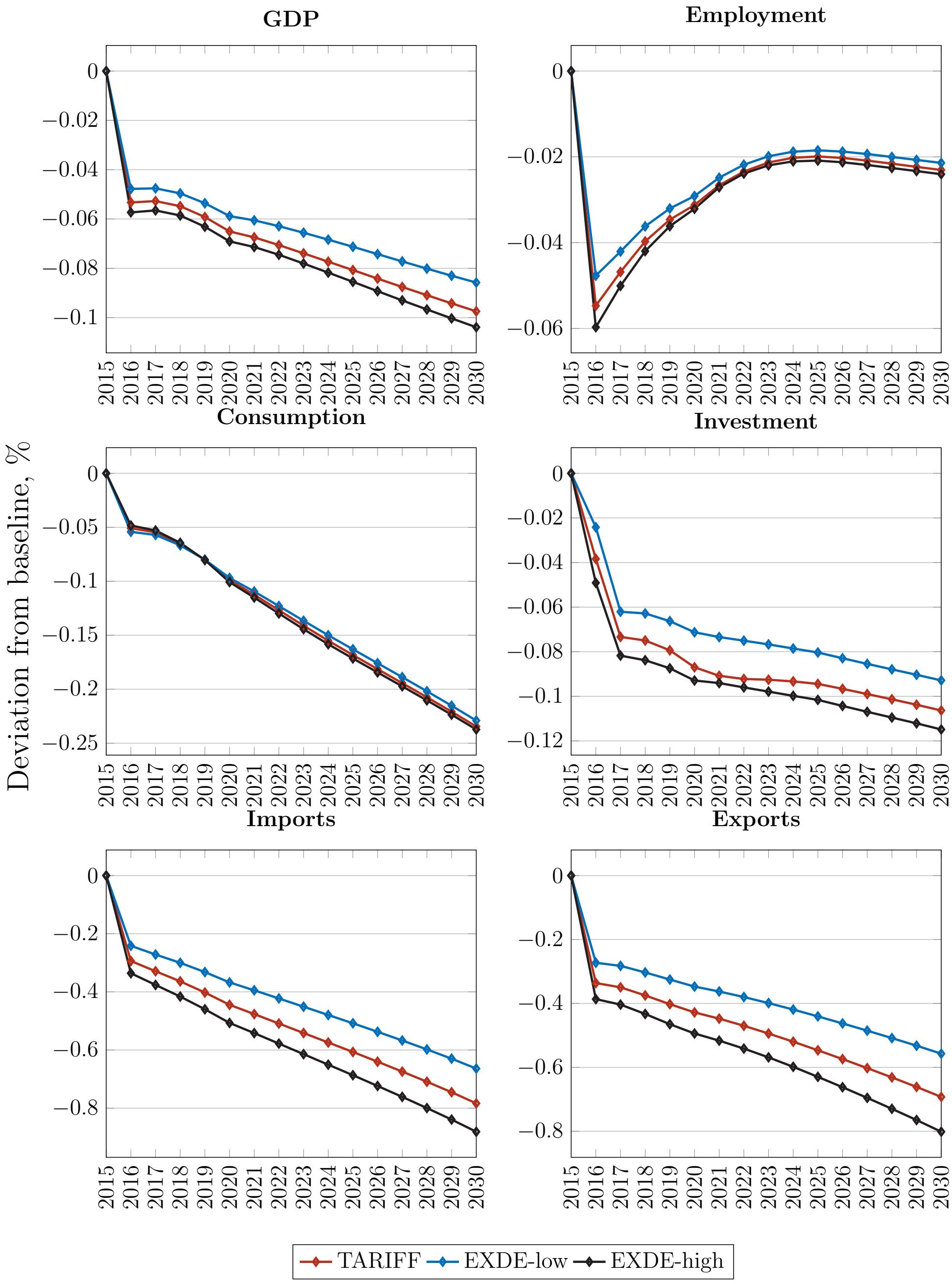

Figure B.2: Sensitivity analysis for export demand elasticity.

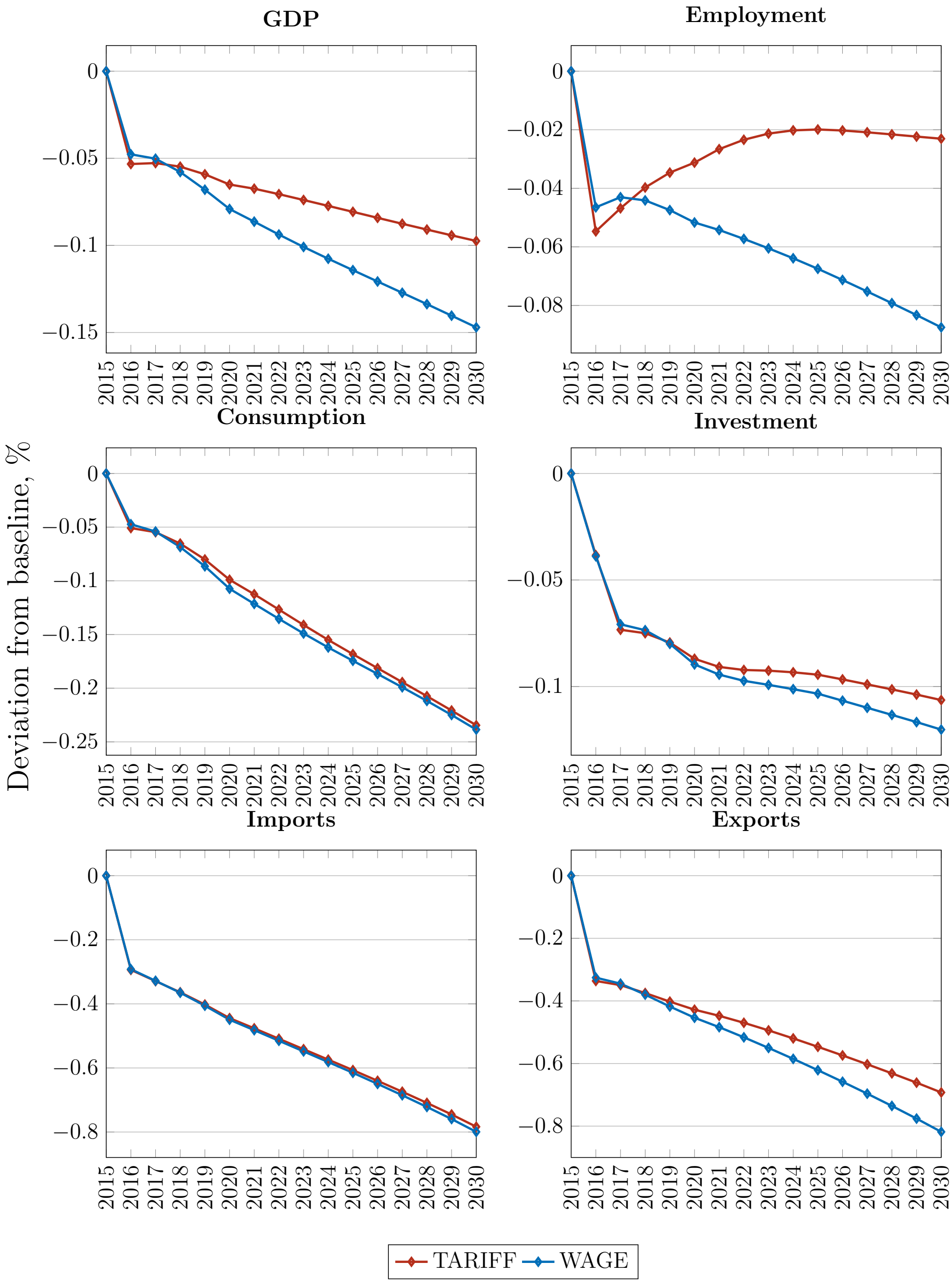

Figure B.3: Sensitivity analysis for real wage adjustment.