Aalto-yliopisto
Aalto-universitetet
Aalto University

Master's Programme in Mechanical Engineering

EU carbon border adjustment mechanism and production location

Tanzin Ahmed

Master's thesis
2023

Aalto-yliopisto
Aalto-universitetet
Aalto University

Author Tanzin Ahmed

Title of thesis EU carbon border adjustment mechanism and production location

Programme Master's Programme in Mechanical Engineering

Major Production Engineering

Thesis supervisor Professor Esko Niemi

Thesis advisor(s) Dr Jaakko Peltokorpi

Date 29.05.2023 **Number of pages** (68 +19) **Language** English

Abstract

As part of the European green deal European Union (EU) has proposed Carbon Border adjustment mechanism (CBAM). Its purpose is to compensate for emission taxes within EU to avoid carbon leakage to non-taxing countries. Among all possible options, border tariffs for products imported from non-taxing countries to EU countries are set equal to emission taxes. This appears fair, but the economies of scale effects are not considered. This paper examines the effects of realistic cost functions on the resulting production allocation. We experiment with single product, four-country, equilibrium model where three countries are potential producers, and all four countries are markets. In our model, demand and supply (producer cost) function parameter values and transportation cost are equal, and total producer profit is maximized. Our cost function is a power curve entailing economies of scale. We primarily examine the effects of producer tax and border tariff levels on production and profit. We also consider the effect of consumer tax during experimentation. The results show that the amount of economies of scale strongly affects the profit-maximizing production allocation. It appears that under economies of scale effects the EU border tariff levels are far too low to create a fair marketplace. Low border tariffs under economies of scale lead to centralized production by a non-taxed producer using polluting technology, whereas sufficiently large border tariffs decentralize production to different countries, and the amount of polluting production is reduced significantly. The effects of short-run capacity constraints and market size on the production allocation are also examined.

Keywords Carbon border adjustment mechanism, Economies of scale, Production allocation, Capacity limit

Table of Contents

List of Tables

List of Figures

Acknowledgements

Above all I am grateful to the Almighty who give me the energy and courage to fulfil my dream.

This study was part of Aalto University, Mechanical Engineering department, research project, “Green Factory”. This project was funded by Business Finland.

First of all, I would like to thank my supervisor, prof. Esko Niemi, for trusting on me and for your constructive feedback during the whole journey. I feel so lucky that I found you as my supervisor. Your support always helped me to move forward and think out of the box. Once again thank you so much for all the time you put for supervising me on this project. I am also thankful to my advisor Jaakko Peltokorpi. You helped me a lot to organize my data and by asking always about future research plan. It helped me during the literature review time to go deeper on this topic. Thanks a lot!

Obviously, it was not possible for me to come this far without the support of my parents, my younger sister, and my husband. You helped me a lot to keep in track and never give up. I am very grateful also to my grandparents for motivating me to work actively and take care of my wellbeing. It is so special to me that at this stage of life, I have my grandparents to help me. Thank you so much to all my other family members also who helped me during the thesis. At last, I am grateful also to the “Bangladeshi Community of Finland” who guided me always to do my best.

Espoo, 29.05.2023
Tanzin Ahmed

Abbreviations

CBAM	Carbon Border Adjustment Mechanism
UNFCCC	United Nations Framework Convention on Climate Change
EU	European Union
ETS	Emissions Trading System
OECD	Organization for Economic Co-operation and Development
WTO	World Trade Organization
CN	Combined Nomenclature
UK	United Kingdom
CCS	Carbon Capture and Storage
BA	Border Adjustment
BCA	Border Carbon Adjustment
SCM	Supply Chain Management
BTA	Border Tax Adjustment

1 Introduction

1.1 Background

The European Council discussed with European Commission in December 2020 about implementing Carbon Border Adjustment Mechanism (CBAM) in the European Union (EU). CBAM is a system to charge tax on carbon-intensive products which are imported to the EU and similar taxes for the EU products which are produced within the EU or consumed within the EU. It will help to maximize the EU's efforts to reduce greenhouse gas emissions through taxing imports of goods made in non-EU nations, whose climate change policies are less aggressive than those in the European Union [1]– [4]. It will work for the EU climate neutrality objectives, in line with the Paris Agreement which was obtained in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC) [3]. It would be in complete accordance with international laws and regulations.

Primarily CBAM will apply to the most carbon-intensive products such as iron and steel, aluminium, cement, fertilizers, and electricity [1]– [4]. According to the proposal, CBAM will begin to be used in October 2023, with a three-year transition period, with full implementation beginning on January 1, 2026, and gradually progressing in until 2035 [3], [5]. Before the complete system goes into effect, manufacturers will track and update their emissions throughout the period of adjustment while CBAM will still be in effect. The transitory phase will enable the Commission to comprehend the market and compile data on each producer's carbon impact. EU announced the working mechanisms of CBAM, which will work from 2026 [6]. These are given below:

- Importers to the EU of products that are subject to the CBAM must register with individual member states to purchase CBAM certificates. The cost of such certificates will be determined based on the European Union Emissions Trading System (EU ETS) allowances' weekly average auction price, which is expressed in euros per tonne of CO_2 emitted.
- The number of goods and embedded emissions in those goods that were imported into the EU during the previous year must be declared by the EU importer by May 31 of each year. The importer also hands over the number of CBAM certificates that are equal to the quantity of greenhouse gas emissions contained in the products.
- If exporters can demonstrate that a carbon price was previously paid during the manufacture of the domestically produced goods, depending on relevant data from third-country producers, the appropriate amount might be subtracted from their fee.

The term CBAM is simple but complex. There are issues related to politics, ethics, and effectiveness in terms of implementing CBAM successfully [7]. Generally, most manufacturers try to get more profit than the buyers, but the manufacturers are now thinking about CBAM. They are afraid that CBAM can oppose the normal trend [7]. It means CBAM can decrease the profit of the manufacturers. The policymakers are also thinking about the same issue which can increase revenge, counter revenge, and lead toward a trade war [7]. That's why CBAM should be crafted carefully and bound with a legal, political, and diplomatic agenda [7]. In addition, there should be a clear statement about the use of revenue, earned from CBAM, so that, both the manufacturer and user can get the motivation to support CBAM and act accordingly. For example, share the revenue with the less developed countries so that there is no economical obstacle following from the new climate policy. Another action can be setting a limit at the border for which the producer will get an allowance if their products fulfil the criterion. In this way, the manufacturer will be motivated because they can compensate for the extra price of producing a green product from that allowance.

In the proposal of 14 July 2021, it is stated that CBAM will not apply to some countries such as Iceland, Liechtenstein, Norway, and Switzerland [8]. Some territories are also mentioned in the proposal, for which the CBAM will not apply. These territories are Büsingen, Heligoland, Livigno, Ceuta, and Melilla [8].

The EU commission mentioned three categories of risk associated with an ineffective CBAM implementation [9].

I. First one is the EU's capacity to undertake a substantive ETS reform that achieves "at least - 55 percent" climate objective by 2030. The need for a greater ETS price may raise the danger of carbon leakage for the EU industry [2], [9], [10]. The concern addressed by this idea of carbon leakage is the shifting of the industry to Organization for Economic Co-operation and Development (non-OECD) nations with weaker goals for reducing emissions [4].
II. Accurately identifying sectors at risk of leakage is challenging. In addition, when there are regulations only for selected sectors, it makes it less attractive for other sectors to invest in carbon-neutral technologies.
III. Binding CBAM with World Trade Organization (WTO) rules so that there will be no trade war [10]

EU believes that the plan can be strengthened in a specific manner by following several steps by the importer and exporter regarding this issue which are given below:

i. Importers have to collect CBAM data for their products and understand the overall policy.
ii. Importers should reveal their product emissions to the EU within 3 months intervals.

iii. EU will set a price for each product's carbon emission every week which will be called the CBAM certificate. Manufacturers have to buy this certificate for their products.
iv. There will be an authentic verifier who will verify the authenticity of the manufacturers and also adjust the price of the CBAM certificate according to that.
v. By a specific time of the year (31 may) verified data should be submitted to the authority of CBAM maintenance.

For the goal of achieving net zero carbon emission, European Commission has published a proposal called the "fit for 55 packages" [3], [4], [10] where the intention is to reduce 50 percent of emissions by 2030 compared to 1990 [3], [4], [10]. As a part of this package, the EU is thinking to address the border carbon tariff shortly by 2023 and broadly by 2026 [3], [4], [10]. Although it is not guaranteed that the current proposal will result in a prosperous and industrial Europe, some of the most significant challenges will likely need to be discussed in concurrent policies outside the CBAM. These policies should support the goal of decarbonizing the EU's industry sectors and maintaining their position as leaders in future global green markets.

1.2 Research Questions

Assessing the above steps of CBAM implementation there are some specific questions raised that this dissertation stresses to answer:

1. How the CBAM can be crafted so that both the EU countries and non-EU countries will benefit equally, and the global carbon emission will reduce?
2. What can be the scenario of production allocation for CBAM and other taxes?
3. What can be the scenario of profit and welfare resulting from the implementation of CBAM and other taxes?

1.3 Objective

In this study, the main focus is to understand the model, and how CBAM can work so that both the exporter and importer would get the motivation to deal with the new border tax. For the same model, we experiment with some other taxes such as producer tax and consumer tax to compare the effect of different taxes.

1.4 Scope

Numerical models are used to get results. Three different cost functions are implemented on three spreadsheets to analyze the effect of the border carbon tax. Parameters used for taxes, variable costs, and fixed costs are coherent with each other for the comparison of the different models. Functions are constructed and used to calculate profit, welfare, taxes, revenue, and per-unit costs. Different constraints are employed depending on different cost functions. Among the three models, one is for the basic scenario, the second one is for fixed capacity limit with fixed cost scenario and the final one is for a longer time frame where production allocation, profit, and welfare depend on the economics of scale, fixed cost, and variable cost.

2 Literature

2.1 Political Background

In December 2019, EU Commission targeted to make the EU a zero-carbon emitter territory by the year 2050. The European Climate Law bound this proposal with tighter legislation and asked to reduce 55 percent of emissions at the latest by the year 2030 [3], [4]. For the effectiveness of this legislation, the EU cohered with UNFCCC to contribute to the Paris Agreement, 2015, for which the outcome is undeniable as the EU already reduced 24 percent of its emissions compared to 1990 [11], though there are lots of industries growing around and the economy is expanding. This positive outcome made the EU think further and the proposal of CBAM arose. They also planned to combine the rules and regulations of CBAM to follow World Trade Organization´s rules and other obligations. Not only this but also in the next 7 years (2021 – 2027) funding of EU, 30 percent is for making a framework to support climate action and 37 percent is for recovery related to climate [12].

2.2 EU Plan

European Commission is planning to introduce CBAM as part of the “Fit for 55” package of legislative proposals which was released in July 2021 [4]. Generally, CBAM is a compensation for the higher carbon emitted products imported to the EU. There are five countries (China, Russia, India, Turkey, and Ukraine) that are the largest exporters of relevant products to the EU [4]. Products that will be covered by CBAM are iron and steel, aluminium, electricity, cement, and fertilizers. Among these, steel and aluminium are very crucial because the EU imports almost 65 percent of its steel and 23 percent of its total aluminium consumption [4]. For reducing emissions EU planned an Emission Trading System (ETS) in 2005 which covered 40 percent [4] of the total emissions over the year in the EU but in 2021 this system was criticized because of its low allowance which lead to a new proposal called CBAM. Under CBAM EU is planning to mark an average emission level for the exporting country. If the level is exceeded, then the exporting country will pay for that. But not the emission level nor the payment margin is selected yet. Period 2023 to 2025 is called a transition period because during this time producers of products will only be required to respond about their emissions [4]. But from 2026, producers have to purchase the certificate and the free allocation of emission allowances will start [4]. The share of free allowances will decrease over the years, and it will be zero by 2035 [4]. The funds from the revenues may be allocated for the covid 19 recovery project or for supporting the green deal [4]. The hardest part of CBAM is to measure the emission intensities of the products because of the lack of available data.

EU is believed to profit from the implementation of this proposal successfully because more employment options will be created, and the gross domestic product will increase accordingly by 0.2 percent and 0.4 percent by 2030 and 2050 [7].

2.3 Product codes covered by CBAM

There is a list of products made by the EU for which the CBAM will be implemented. The list represents a unique code with its definition and emission. The name of each code is combined nomenclature (CN). Shortly it is called CN code. EU published a brief description of the meaning of each code which can be found in the appendix section (Appendix A). Here in Table 1, only a group of codes for each product is shown.

Table 1: List of CN codes covered by EU CBAM

Cement	Electricity	Fertilizer	Iron and Steel	Aluminium
2523 10 00	2716 00 00	2808 00 00	72 (except 7202 and 7204)	7601
2523 21 00		2814	7301	7603
2523 29 00		2834 21 00	7302	7604
2523 90 00		3102	7303 00	7605
		3105	7304	7606
			7305	7607
			7306	7608
			7307	7609 00 00
			7308	
			7309	
			7310	
			7311	

Source: European Commission Report [8]

2.4 Calculation of product emissions

Specific actual embedded emissions of simple goods ($SEEg$) can be calculated with the following equation. Simple goods indicate those goods which have raw materials and fuels with zero emissions:

$$SEEg = \frac{AttrEmg}{ALg} \tag{1}$$

Here, $AttrEmg$ is attributed emissions (g referring to name of specific goods) which means emission generated in a country exactly where the production occurs. ALg is activity level which means the number of products manufactured throughout the reporting period in the installation.
Then we can calculate the assigned emission with the equation which is equivalent to the direct emission.

$$AttrEmg = DirEm \tag{2}$$

Here, *DirEm* is the direct emissions, coming from the manufacturing process, inside the system's limits, and represented in tonnes of CO2.
Now, for the calculation of the specific strung emission of complex goods, we can use the below equation. Complex goods mean goods that require simple goods as raw materials.

$$SEEg= \frac{AttrEmg + EEInpMat}{ALg} \tag{3}$$

Here, *EEInpMat* is the embedded emissions of the input materials consumed in the production process.
For complex goods, embedded emissions of the input materials consumed in the production process can be calculated with the below equation.

$$EEInpMat = \sum_{i=1}^{n} Mi \cdot SEEi \tag{4}$$

Here, *Mi* is the mass of input material, *SEEi* is specific embedded emissions for the input material.

2.5 Assessment of criteria

For taking care of WTO requirements and the EU's international commitments, the impact of CBAM for six different criteria was assessed by the scrutiny board [13]. It is an impartial organization inside the Commission. At the beginning of the legislative process, it offers fundamental standardization and assistance for the Commission's impact analyses and evaluations.

I. The first thing is to import products at the border by the manufacturer and they will pay a selective amount of money for their goods, and they should buy a certificate for that specific product by claiming the amount of direct carbon emission from that product. The policymaker should set a limit and according to that, the price will be calculated.
II. Secondly, a policy related to the EU ETS will be copied and applicable only to the domestic product. In addition, the national climate authorities will initiate the CBAM certificate and sell those to the importers according to their level of emissions. Importers will also get a chance to reduce the price of their certificate if their products emit less than before. It will happen at a specific time of the year when all the importers will show their products are improving or worsening from the previous year. According to this, the authority will initiate a new CBAM certificate for them.
III. Third option is kind of similar to the second option, the price of the carbon should be according to the amount of emission mentioned by the foreign country, not by the pre-set average value of the domestic country.
IV. Option 4 also supports option 3. It will take 10 years to successfully implement CBAM at the border from 2026, while at the same time, the EU ETS will reduce its implication. During this time, CBAM will work to minimize the number of free allowances.
V. Goods that are carbon intensive, either it is final or semi-final products, would be part of CBAM. A supply chain that will predict product price, different types of cost, and border adjustment for a suitable implementation of CBAM would be highly appreciated.
VI. The final one is a consumer tax, which will be applicable for both domestic and foreign products in EU countries.

Though the impact assessments of these options were found positive, results show that the determination of the price of carbon-intensive products by the producer country or by the default average value from the EU may cause problems. But there is no doubt that CBAM will reduce emissions. On the other hand, phasing out free allocation day by day and phasing in CBAM may cause a decrease in jobs. In addition, CBAM will cause little impact on small industries compared to bigger industries. It is because at first, it will apply to some specific products which are responsible for a huge amount of emissions from those industries [4], [6], [13]. That's why small-scale industries will suffer less.

2.6 Other countries´ plans

Carbon emission reduction is a way to reduce global emissions. The unilateral decision by one country or by one state alone cannot reduce global emissions. It is therefore necessary to work multilaterally.

2.6.1 UK

The United Kingdom (UK) has its own carbon emission reduction policy for its domestic production already, but they don't have any policy for imported products. There are some products that the UK produces in their own country and also export and import the same products [14]. In this situation, UK´s economy will surely be affected by CBAM if they do not maintain the same policy in their own country. Researchers say that 43 percent of the UK´s emissions are because of imported products [15]. In addition, decreasing global emissions will also not be possible. UK government is planning to phase out the free allowances for carbon emission like the EU and also planning to act with the border carbon adjustment. Several researchers agree on UK CBAM and most of them mentioned it as a positive approach to collaborate with EU CBAM. Besides, they need additional policies related to product standards and support for their low-carbon technologies [15]. Some of them also mentioned that the EU CBAM should not apply anything which can damage the UK economy [15].

Researchers also suggest that the price of EU CBAM should apply only to those products which are subjected to pay tax domestically by the producer and the price of CBAM should not exceed the domestic carbon price [15]. Primarily it should apply only to the most carbon-intensive products relevant for the UK. The revenue earned from CBAM should be distributed to the sectors which are also following the net zero carbon emission policy [15]. In addition, they also suggest that the government should communicate and negotiate with countries that have different perspectives but the same motive towards carbon emission.

To some extent, it is simple to hear and understand the meaning of CBAM, but it is not as easy as it sounds because there are lots of political, economical, and diplomatic issues behind this. Researchers also suggest that government should announce the proposal at least 5 years before it is fully implemented so that the supply chain can develop its network and easily adapt the EU policy [15]. Like other non-EU countries, the UK is tensed also about the reaction of their industries toward CBAM. There are different-sized industries in the UK which may be affected differently. Moreover, there are controversial opinions about the industrial reaction. Some think that small-sized industries will not be affected much as CBAM will apply primarily only to some specific sectors while others think that small-sized industries will be the biggest sufferers because they do not have enough resources to cope with a new policy immediately [15]. Besides, Northern Ireland is also a matter to think about. Because their electricity production is still ruled by the EU´s ETS [15]. For this specific part of the UK, it is advantageous for them to link with EU policy. So that it can give a better solution for exchanging electricity between the EU and Northern Ireland [15]. It is a random thought of the UK, that the EU can easily make positive consequences for them by normally saying, there is no need to pay extra tax as the UK is paying tax for their product somewhere else domestically [15]. On the other hand, the EU can become strict with the rules and can enforce same policy for UK products [15].

For the UK it is profitable to cooperate with the EU for establishing CBAM, otherwise, the risk of carbon leakage may occur mostly in the UK. Because the biggest threat of CBAM is, causing companies forward to the nearest country where there is no carbon price at the border and moving the industry to that country. Another problem is UK exports almost 13.5 percent (between 2010 and 2018) of its total amount of export to the EU which may hamper a considerable amount of the UK economy [14]. As the UK is also proposing net zero carbon emission, it is better to support the EU CBAM and make their own policy at the border for reducing emissions. This policy should align with EU policy though there are both advantages and disadvantages. One of the remarkable drawbacks of linking UK CBAM to EU is the lime production. Because it is controlled by an EU guideline that was established by a few plants in a narrow region of Europe with unique conditions and availability of biomass [15]. That’s why the process of this lime production will not get enough allocation if the UK is linked with the EU [15]. But for most of the sectors linking is profitable for the UK.

Researchers are expecting that the UK can apply CBAM only for their raw materials or for both raw materials and semi-finished products [14]. Because they analyze the economical effect if it only applies to raw materials which are significant. They found that if the UK tries to apply CBAM at the border for non-EU countries on raw materials of steel, cement, plastic, aluminium, and paper, the UK will earn £800 million per annum which is calculated by assuming carbon price of €50 per tonne [14]. If it is for both raw materials and semi-finished products, then the earnings from revenue will rise to £1.1 billion [14]. Both for the broad and narrow analysis it is highlighted that the highest income is from the steel and aluminium sector [14]. UK is expecting that a carbon price that is helpful in minimizing emission is £54 per ton of CO2 by 2021 and it can be between £60 to £140 by 2030 [14]. In addition, tax revenue from CBAM should be treated as an emission reduction policy, not as a way of earning money.

However, there is enough policy and research in the UK toward decarbonization. These are co-related to CBAM. But there is not enough policy in some EU countries, even in some cases, there are policies that do not satisfy CBAM [15]. So, it is recommended by UK researchers and policymakers that the EU should propose a policy toward CBAM that can satisfy UK´s own policy. The government of the UK told that the UK is eager to cooperate with the policy of the EU related to decarbonization if it will not hamper UK´s economy [15]. UK is thinking that if their policy satisfies the EU´s policy and the price is also the same then the EU should support the UK and exempt them from CBAM [15]. Moreover, there are several issues with CBAM certificates, coping with WTO rules, national and international obligations, and so on.

2.6.2 China

China is the highest emitter in the world and the EU imports the highest amount of products from China [16]. There is no doubt that the Chinese economy will be affected because of the CBAM. Chinese producers have to pay domestically for their emissions. In addition, they will also pay at the border for exporting to the EU [16]. So, it is high time for China to rethink how it will deal with the CBAM.

In 2021, Chinese government announced that they will cooperate with the EU and other countries for establishing CBAM so that there will be no obstacles [16]. But the specific policy regarding EU CBAM is not published in 2021. So, it is difficult to assume the exact plan and take the necessary steps. Chinese experts think that rather than carbon tariff, consumption tax and extension of EU ETS would be efficient for decarbonization. Other experts believe that EU industries will not look forward to low carbon emission technologies for them because most of the EU industries believe that tariff is not the prime solution to reduce carbon emission. Instead, it will hamper international collaboration. Electrical products, textiles, metals, and chemicals are the main sectors China exports to the EU but unfortunately, at the beginning stage of CBAM, these sectors will not be covered because of the difficulties to measure carbon content. Key sectors for EU CBAM highlighted were steel, aluminium, and cement because these sectors were found highly carbon intensive. On the other hand, China exports these products for more than half of the total needs of the EU [16], [17]. Steel can be produced in two ways such as primary and secondary [17]. The primary process is more carbon-intensive than the secondary one because it needs more energy [17]. Below is a table that shows the difference of the amount of carbon emission between the EU and China during steel production.

Table 2: Carbon emission per ton of steel produced [17]

State	Primary Process (amount of carbon emission tCO_2)	Secondary process (amount of carbon emission tCO_2)
EU	1.9 tCO_2	0.2-0.4 tCO_2
China	2-2.2 tCO_2	0.6 tCO_2

The sad news is still China produces 90 percent of its steel through the primary process while the EU produces only 59 percent [17].

Possible policy responses can be:

- China can change its export policy, for example, by reducing taxes or getting subsidies so that it can minimize the effect of CBAM. Though changing export policy will not help significantly to achieve the goal of low carbon emissions [17].
- China can identify those sectors which are much more carbon intensive and put strict regulations. For instance, from the aluminium sector, China emits a remarkable amount of indirect carbon emissions. So, implementing strict regulations can help the Chinese government to get rid of this kind of emission. Producers may take rapid action to identify the real cause of this and take the necessary steps [17].
- One of the effective policies can be to expand China´s ETS to cover the EU CBAM sectors. Because it is easier and faster to cover all the EU CBAM sectors rather than other policies [17].
- Connecting EU ETS with Chinese ETS could be another option. Though it will take a longer time, it is an effective option to minimize the effect of CBAM and the exporter can get rid of the extra cost [17].
- For some highly exported products to the EU, such as electronic and textile products, the Chinese government can apply a domestic tax. It will help China to earn revenue and will pressurize these sectors to apply low-carbon technologies. Though these sectors will not be covered by the EU CBAM initially, but people are assuming that it will cover later on because these are the highest exported products with much carbon emission. China can use the revenue earned from these sectors for the decarbonization of recent sectors covered by EU CBAM [17].
- Exact emission data is necessary to measure the CBAM effect on China and create a policy, for which China will be able to motivate industries and the R&D sector to adopt low-carbon technology along with Carbon capture and storage (CCS) or hydrogen-based steel production. This way China will be able to tackle EU CBAM in the long-run [17].

Besides, it is necessary to increase collaboration with the EU like the UK and other countries so that China will not lag behind to achieve the goal of mitigating emissions towards net zero carbon emission. EU should discuss its upcoming policy with China and should not create any policy unilaterally that can hamper both the EU and the Chinese economy. A bilateral solution is needed for both of them to make the world greener [17].

2.7 Difference between carbon tax and cap and trade system

Carbon tax is an example of a charge that companies must pay for excessive greenhouse gas pollution [18]. Typically, the fee is assessed per ton of greenhouse gas pollution. Cap and trade is a regulation program that aims to reduce or "cap" the overall level of emissions of certain chemicals, most notably carbon dioxide, as a consequence of industrial activity [19]. If an industry generates more emissions than its licenses allow, it must pay taxes. They might even face a fine for breaking the rules. On the other hand, industries that cut back on emissions can "trade" their credits with those that pollute much. Besides that, industries can store them for later use [19].

A carbon tax limits the amount of CO2 emissions while fixing the price. Contrarily, a Cap-and-trade system limits the total amount of emissions and permits the cost of CO2 emissions to change to meet the emissions cap [20]. A carbon price would have distributional effects comparable to a cap-and-trade system where all allowances are auctioned [20]. Policymakers are forced to choose how to spend the generated money under both strategies [20].

Additionally, the effects of a tax on impacted businesses and households are the same as those of a cap-and-trade with a chaffer in which the resultant allowed price is the same as the tax, before any use or redistribution of that cash. A carbon tax and a cap-and-trade system both offer different possibilities to reduce economic impacts, though. Policymakers can lessen the impact of a tax by allocating tax money, much like in a chaffer, or by granting tax exemptions, even though a tax cannot compensate harmed firms through the free distribution of allowances.

The benefit of the carbon tax is given below:

- The first one is the simplicity of carbon tax and it can be implemented rapidly [20]–[22]. The government only charges a fee per ton of carbon dioxide released, which makes it simple to grasp. Contrarily, the carbon prices imposed upon a cap-and-trade system change with changes in the market, making them unpredictable even for large corporations [21].

- Tax strategy avoids the political challenges of allocating allowances among economic sectors, but on the other side, it would put pressure on tax exemptions [20].
- A carbon tax would generate income that might be distributed to people, used to reduce tax distortions, support climate change programs, pay for other government initiatives, decrease the budget deficit, or help the most affected industries [20]. On the other hand, there is less chance of rebating or tax-shifting cap-and-trade pollution permit income since they are unpredictable [21].
- Under a cap and trade system, there is a chance of transaction cost which can raise overall compliance expenses but under carbon pricing, there is no risk of transaction cost [22].

So, there are some clear advantages of a carbon tax that can outweigh using a cap and trade system day by day. However, both carbon taxes and cap and trade systems have the goal of fixing a current market breakdown [23]. Both of them initially focus on a small number of businesses to increase emissions coverage while minimizing administrative expenses [23]. Both systems demand the same data on carbon emission, disclosure and validation of that data, and regulation in the case of violation [23].

Overall, policymakers and economists believe that a nicely crafted carbon tax would work efficiently to minimize emission [24]. A carbon tax's financial, economical, sectoral, and environmental effects will ultimately rely on how that tax is structured. The majority of carbon tax plans also use a border adjustment [24]. There are risks of leakage and competitiveness when it will apply on the border. For example, a tax on all products with a high carbon footprint produced domestically in the US might encourage businesses to move their operations abroad to evade the levy. The carbon tax will be ineffective in pricing the emissions that were previously produced in the United States if businesses move production offshore to countries without one. In addition, there might be practical difficulties. Such as information on the carbon content of each commodity imported into and exported from would be necessary for a complete border adjustment. However, a border carbon tax can generate revenue and reduce emissions which is the positive side of this term. For seeing the positive impact and outweigh the negative impact (leakage) we need to design it carefully.

2.8 Revenue from tariff

In this section, the general theory of imposing tariffs and how the tariff behaves in the real market are shortly described. The graph below, in figure 1, is used to illustrate the difficulties related to tariffs and welfare loss easily.

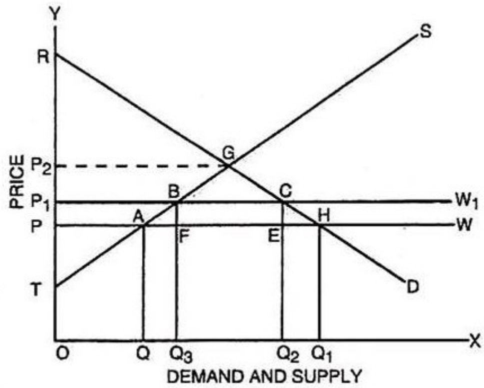


Figure 1: Demand and supply curve with tariff [25]

Axis OY represents the price and axis OX represents quantity. RD is the demand curve and TS is the supply curve. P2G is the domestic price. When there is no import price and tariff then the consumer surplus is RGP2 and the producer surplus is TGP2. But if there is import price PH then the consumer surplus increases from RGP2 to RGAP and domestic surplus decrease from TGP2 to TAP. For import price quantity imported is AHQ1Q. Now, if there is a tariff imposed on import prices then the producer surplus will increase and the consumer surplus will decrease. For example, a tariff is P1C for which producer surplus is TBP1 and consumer surplus is RGBP1. Now the highlighted thing is for imposing a tariff on import there is a government revenue BCEF though the imported quantity of product decrease from AHQ1Q to FEQ2Q3. At the same time, there is an economic loss which is called a deadweight loss. These are indicated by ABF and CHE triangles.

So, it is theoretically proved that imposing tariffs will generate government revenue but there will always be a welfare loss for any kind of tariff on imports.

2.9 Welfare

The field of study known as "welfare economics" focuses on how market organization and resource distribution affect society as a whole [26]. By using methods like cost-benefit analysis and social welfare functions, welfare economics aims to assess the advantages and disadvantages of economic changes and direct public policy in a way that increases the overall good of society [26]. The foundation of welfare economics is also the premise that human welfare can be measured, compared across people, and valued along with other ethical and philosophical notions of well-being [26]. The benefits of welfare economics are given below [27]:

- The most effective use of resources to meet human needs [27]
- It represents the significance of both visible and invisible market factors to stabilize the economy [27]
- It helps the market structure to maximize the consumer tax and producer tax [27]

2.10 Microeconomic approach

Microeconomics is the study of how individuals, such as homes, employees, and firms, behave inside its economy [28]–[30]. On the other hand, the macroeconomic perspective takes a broad view of the economy and concentrates on issues like rising living standards, reduced unemployment, and reduced inflation [28].

There are several topics under microeconomics such as demand, supply, elasticity, market equilibrium, market structure, cost function, and so on [28]–[30]. Microeconomic theory's demand and supply model clarifies the connection between both the number of a product that producers are willing to make and sell at various costs and the amount that purchasers are willing to purchase at such prices [28]–[30]. In a market system, number and cost are seen as the fundamental indicators of the items produced and traded [28]– [30]. In addition, there exist different types of market structures such as pure competition, monopoly, oligopoly, monopsony, and oligopsony [31]. For analyzing the effect of border carbon adjustment we can use these different market structures for different models.

Now if we think about different types of periods we can see that there are three types of time periods [32]. It varies from industry to industry and the fixed and variable costs also change depending on the time period. For example, when everything is fixed it is called the market period [32]. But if there is a combination of both fixed and variable costs it is called a short-run period [32]. Moreover, when both are variable, it is called the long-run period [32]. In terms of BCA, it is better to analyze the effect of these three market periods.

2.11 Prior paper review

Balistreri et al. and others worked with two good, two country hypothetical model to measure the effect of border carbon adjustment [33]. They numerically simulate the model to analyze the equilibrium theory. Both the theoretical model and simulation say that if the policy's objective is to protect the environment, carbon border adjustments should, in practice, be set much lower than the domestic carbon price. Because border tax set more than the domestic carbon price or equal to the domestic carbon price will increase the price of the carbon-intensive goods which will indirectly encourage the unregulated regions to consume those products.

Cheng made a two-country model with several intermediate goods producers and a final goods producer [34]. The final goods producer is a monopolist in the final goods market that chooses its assembly location endogenously. In his model, endogenous assembly sites and intermediary goods are present. If the assembly is located in a taxing nation, this paper discovered that BCAs prevent carbon leakage and lower global emissions if we limit the imports of polluting inputs. Eyland and Zaccour also made a two-country, two-goods model but in their case, the goods are homogenous [35]. It is a game theoretical setting and they discovered that instead of full Border tax adjustment (BTA) or no BTA, the ideal range of BTA is 0.40 to 0.48 which means the difference of tax rates between two different countries. This value can increase the total welfare. They calculate the welfare with the following equation:

Welfare = consumer surplus + producer surplus + revenue – environmental damage

Nurjanni et al. made a production optimization model to see the performance of border adjustment [36]. It is a mathematical modelling approach. They also applied this model to see its capacity to handle the border carbon adjustment issue. When they design the supply chain, they integrate a closed-loop network to support the reprocessing paradigm of disposal goods and a multi-objective optimization mathematical model to reduce total costs and carbon dioxide emissions. Finally, they discovered that their model is capable to handle BA's issues. However, they suggest more critical tests to see the definite behavior of the model.

On the other hand, Nimubona and Rus worked for combining environmental aid and adjusting border taxes in a two-country general equilibrium model [37]. They found that when the BTA and green technology transfer are both either effective or ineffective in reducing pollution, a rise in the BTA will decrease investment in green technology transfer if the level of the BTA and the degree of cross-border pollution are both sufficiently high. Higher BTA can cause a negative green technology transfer effect to the donor country and a negative welfare effect on the recipient country. In addition, Gros and Egenhofer also analyzed the border carbon adjustment effect with a general equilibrium model [38]. Their analysis showed that if the EU imports goods from a country where there is no climate policy and carbon pricing, in that case, BA will increase global welfare. Moreover, Jakob et al. also played with the 2×2 general equilibrium model where they showed Border Carbon Adjustment (BCA) can cause carbon leakage if the BCA is based on production rather than consumption [39]. They said more carbon-intensive countries can deprive to export their products to the EU. Instead, they can export to less carbon emission-restricting countries which will emerge carbon emissions. Our model suggests also for a consumption-based border tax. Markusen also played with a 2×2 general equilibrium model and compared among three different types of taxes (producer tax, consumer tax, border tax) where he addressed an optimal solution can be consumption-based border tax rather than production-based border tax like our model [40]. He also mentioned that consumer tax has no effect on the welfare and profit only border tax and producer tax have an effect.

Jakhar carried out a research in India under Supply Chain Management (SCM) optimization methodology [41]. He conducted personal interviews with 15 top management executives in the apparel industry. His research showed it is necessary to undertake green production, followed by green distribution and logistics in India. Now, a three-stage game theory model was made by Khourdajie and Finus where enterprises pick their outputs, governments choose their policy levels, and countries initially determine whether to join a climate pact [42]. At every level, the model's spontaneous selection of methods represents the strategic interplay between attendees and non-attendees. At each level, they showed that BCAs lower the profit disparity, but it does not eliminate it completely.

Wang et al. created two Stackelberg game choice models, with the government, manufacturer, and retailer participating in both centralized and decentralized supply chains [43]. They found that in comparison to the centralized decision-making chain, the decentralized supply chain, the retail price of the goods, and the government's unit carbon tax are all more expensive. The centralized supply chain has greater predicted total social welfare for the government, supply chain profit, and retailer stocking factor. We also experimented for our long-run model and get similar kind of result that a centralized supply chain is less expensive and has higher profit and welfare than the decentralized one. In addition, Li et al. worked with centralized and decentralized situations with a standardized price policy [44]. They examined the impact of the green degree, the cost of becoming green, and the sensitivity of the producer and retailer then created a coordinating system for the decentralized dual-channel green supply chain. They discovered that the manufacturers do not open their direct channel if the greening cost exceeds a certain threshold. Chain members' pricing methods for going green are significantly influenced by the level of customer loyalty to the retail channel, the cost of becoming green, and the sensitivity to go green. Compared to the decentralized dual-channel green supply chain, the retail price in the centralized dual-channel green supply chain is greater.

However, Fang et al. made a stylized global supply chain model where with the basic model they found no guarantee imposing the carbon tax will lower global emissions [45]. Instead of reducing emissions carbon tariff will increase carbon leakage. With their extended model, they found that carbon tariff will increase carbon emissions instead of reducing because of the carbon leakage. They suggested sharing technology and financial support instead of tariffs which will give both the exporter and importer a win-win situation. Thus, global emissions will reduce.

There are very few papers showing the difference between the cap and trade model and the carbon tax model. However, Xu et al. worked on it [46]. They analyzed a game theory in which the government is the leader and the producer is the follower. They described several advantages and disadvantages about cap and trade and carbon tax regulation. The highlighting thing of their paper is that carbon tax will also increase the overall welfare like the cap-and-trade system. There is no superiority between these two systems in terms of reducing emissions.

3 Model description

3.1 General introduction

We work with three different models. In the models, there are factories in different countries that supply the factory products to different markets. In figure 2, we can see, factories are located in Home (H), Foreign 1 (F1), and Foreign 2 (F2) countries, and markets are located in four different countries such as Home (H), Foreign 1(F1), Foreign 2 (F2), and Foreign 3 (F3).

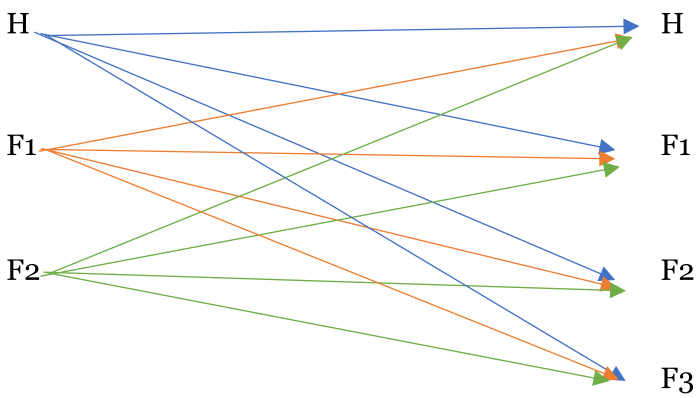


Figure 2: Product exportation

The three models differ in their relation to the assumed time horizon. In all models we maximize the total profit, assuming that by doing this we imitate the status of the system where all producers independently try to maximize their individual profits. We use sum of total profits and all taxes to represent the welfare of the society at large.

From the solution at problem, we can analyze a number of quantities of interest, such as distribution between producers and markets at:

- **Production:** Amount of product moving from factory to market depending on the consumer price of the market. There is a combination of variable cost, fixed cost, taxes, and capacity limits for the factories for different models.
- **Revenues:** Total revenues earned by the factories and also by each of the markets can be determined.
- **Profits:** Total profits for the system and also for each of the factories can be determined.
- **Taxes:** Taxes earned from the tariffs or paid by the factory or by consumers can be determined.

- **Welfare:** Total welfare for the system and also for each producer country and market can be determined. We use sum of profit and all taxes as a proxy for the welfare.

3.2 General description of models

The *demand* of the three models depends on the consumer price so that the higher the price is, the less products are consumed. The dependence is linear. There is a maximum price at which consumers are not willing to buy any products; i.e. the demand is zero. As the price goes down the demand increases as determined by the slope parameter at the demand equation. At the price zero, a certain maximum demand is reached.

We call the first model the *basic model* because we assume here is no fixed capacity for the factories which means that they can produce any amount they want. There is a production cost, producer tax for the carbon intensity of the product, and consumer tax as well. There is also a border carbon tax while exporting the product to other countries. There is a transportation cost for the movement of the product from one country to another country. So, for the basic model, the profit and welfare will depend on the amount of production, price, and cost. The total production will vary depending on the demand, taxes, and production cost. There are no other limitations to produce any product.

We call the second model the *short-run* model because there is a capacity limit for each of the factory. We add a constraint in the model according to that. So, the total production at each factory is less than or equal to the capacity. In addition to the variable cost, producer tax, consumer tax and transportation cost, there is also a fixed cost for the factories. Because we know that in the short-run investment capital, such as the size of a warehouse or a number of pieces of heavy machinery, is fixed. The total cost for short-run is the summation of fixed cost and variable cost. So, here the production of each factory will depend on the fixed cost and variable production cost including all the taxes. And also, the total production will not exceed the capacity limit. In the model, there is also an auxiliary constraint for each of the factory, so that the model will only generate production in case the fixed investment cost takes place.

We call the third model the *long-run* model because the investment is variable here. This means all the fixed costs and variable costs depend on the amount of total productions of each factory and the economies of scale. Economies of scale can be caused by the distribution of one-time expenses over a variety of goods such as equipment, tools, setups, supply agreements, etc. Types of production system, specialization such as right technology and equipment for each process. Large dimensions can also affect the economics of scale for example, while relative area increase is square, tank capacity rises cubically in respect to tank diameter. Risk sharing can also affect such as spare component, buffer, and stock expenses rise in a square root relationship rather than linearly in relation to production volume. In addition, there is also the production cost, border tax, consumer tax, producer tax, and transportation cost like the first and second models. This model is non-linear.

So, the main difference between the short-run and long-run model is the fixed cost. In the short-run, there is at least one fixed cost but in the long-run, all costs are variable.

The following common assumptions apply for all models which are:

- Border adjustment and transportation costs are only applicable when the product is moving to a different country rather than its own country.
- Demand dependence on product price is similar in all models
- Parameters for the demand function are the same for all models

3.3 List of notations for all models

Symbols	Descriptions
z_{ij}	total amount of production supply from factories *i* to market *j*, decision variables
a_i	production cost per unit at factory *i*
b_{ij}	border adjustment per unit from factory *i* to market *j*
l_i	producer tax per unit at factory *i*
m_j	consumer tax per unit at market *j*
n_{ij}	transportation cost per unit (fixed) from factory *i* to market *j*
c_i	production costs for each factory *i*
d_j	demand parameter indicating maximum price for the consumer countries *j*
r_i	revenues earned by the market *j*
t_{ij}	taxes paid for the supply from factory *i* to market *j*
p_i	profits earned by each factory *i*
k_j	price parameter for per unit consumer price for market *j*
F_i	fixed cost for each factory *i* for the short-run model
G_i	fixed cost for each factory *i* for the long-run model
L_i	production capacity limit
M_i	big *M* constraints for handling the total amount of production for each factory *i*
e_i	level of economic scale for the cost analysis of the factory *i* which should be $-1<e_i<0$.

c	variable cost c for the long-run model
Q_j	consumer price for market j
P_{tot}	summation of profits earned by all the factories
R_{tot}	summation of revenues earned by all the factories
C_{tot}	total production cost for all the factories
y_i	binary variable for factory i

3.4 Model 1: Basic model

The main objective of this model is to maximize the overall profit P_{tot} where the number of products to be determined are $z_{ij} \geq 0$ produced at factory i for markets j.

$$P_{tot} = R_{tot} - C_{tot} \qquad (5)$$

where,

R_{tot} = total revenue
C_{tot} = total production cost

Revenue R_{tot} is calculated based on the consumer price just by multiplying per unit consumer price with total production.

$$R_{tot} = \sum_j (Q_j \times \sum_i z_{ij}) \qquad (6)$$

Consumer price for per unit product for a market j (Q_j) is calculated according to the maximum consumer price, price parameter and amount of total demand (= $\sum_i z_{ij}$) at the market.

$$Q_j = d_j - k_j \times \sum_i z_{ij} \qquad (7)$$

Total production cost C_{tot} is calculated by summing up all cost items per product and multiplying by z_{ij}.

$$C_{tot} = \sum_i C_i = \sum_i \sum_j (a_i + b_{ij} + l_i + m_j + n_{ij}) \times z_{ij} \qquad (8)$$

Solving the problem provides the optimal amounts of products produced at each factory for each market. From the solution we can calculate any other interesting values;

profits for each factory (p_i):

$$p_i = \sum_j \left(Q_j - c_{ij}\right) \times z_{ij} \qquad (9)$$

Taxes for a country j can be calculated by summing up all producer taxes for production in the country, consumer taxes for consumption in the country and border tariffs for all imported products. Total taxes collected (T_{tot}):

$$T_{tot} = \sum_i \sum_j t_{ij} = \sum_i \sum_j (b_{ij} + l_i + m_j) \times z_{ij} \quad (10)$$

Total welfare (W_{tot}) is:

$$W_{tot} = P_{tot} + T_{tot} \quad (11)$$

Welfare for each producing country i (w_i):

$$w_i = \sum_i p_i + \sum_i t_i \quad (12)$$

The basic model is a convex quadratic program (QP) and therefore easily solvable with common algorithm and software.

3.5 Model 2: Short-run model

The main objective of this model is same as in the basic model, so that, the overall profit maximized p (z_{ij}) but there are some constraints in the model to limit the amount of total productions z_{ij} to capacity and to involve the investment cost of starting production.

The objective function P_{tot} is similar to equation number (5). Also, the revenue and demand function follow the same in equation number (6) and (7). However, the cost function is different now because there is a fixed cost in the short-run model in addition to the variable cost. So, the cost function (C_{tot}) is:

$$C_{tot} = \sum_i C_i = \sum_i \sum_j (a_i + b_{ij} + l_i + m_j + n_{ij}) \times z_{ij} + \sum_i F_i \times y_i \quad (13)$$

Here, y_i is a binary variable takes value 1 if there is production in factory i. This is realized by an auxiliary constraint:

$$\sum_i z_{ij} \leq M \times y_i; \ \ for\ all\ i \quad (14)$$

Where, M is a large number.

Fixed cost (F_i) is a cost which is fixed for a factory for certain period and we cannot change that cost. If there is any production in any factory then the fixed cost is common for that production but the producer tax, consumer tax, border adjustment can be varied depending on the market situation.

The production amounts (z_{ij}) are constrained to the factory capacities (L_i); which in practice largely depend on fixed cost (F_i).

$$\sum_i z_{ij} \leq L_i; \quad for\ all\ i \tag{15}$$

By solving the problem, we can obtain other interesting values such as profits and welfare for each factory, total welfare of the system, total taxes, and so on. We can follow the same equations described in equation numbers (9), (12), (11) and (10) accordingly under the section 3.4 for these values. The model is quadratic and binary-constrained, but solvable in reasonable time using an appropriate enumeration algorithm.

3.6 Model 3: Long-run model

The main objective of this model is similar to the first and second models that we maximize the overall profit *(P_{tot})* which is also described under section 3.2.

Like the first and second models the objective function P_{tot} follows the same equation described in equation number (5). Besides, the revenue and demand functions follow equation numbers (6) and (7) as well. However, the cost function is different now because there is a fixed cost and economic scale *e* also for the fixed cost in the long-run model in addition to the variable cost. So, the average cost function (C_{ave}) is:

$$C_{ave} = \sum_i C_i = \sum_i \sum_j (G_i \times z_{ij}^{e}) + (a_i + b_{ij} + l_i + m_j + n_{ij}) \tag{16}$$

And total cost (C_{tot}) is:

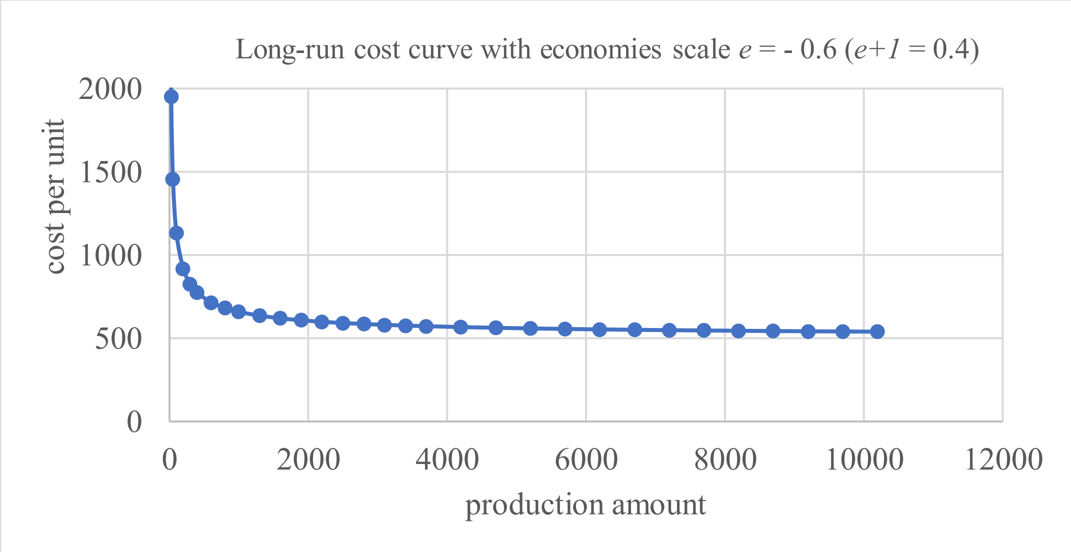
$$C_{tot} = \sum_i C_i = \sum_i \sum_j (G_i \times z_{ij}^{e+1}) + (a_i + b_{ij} + l_i + m_j + n_{ij}) \times z_{ij} \tag{17}$$

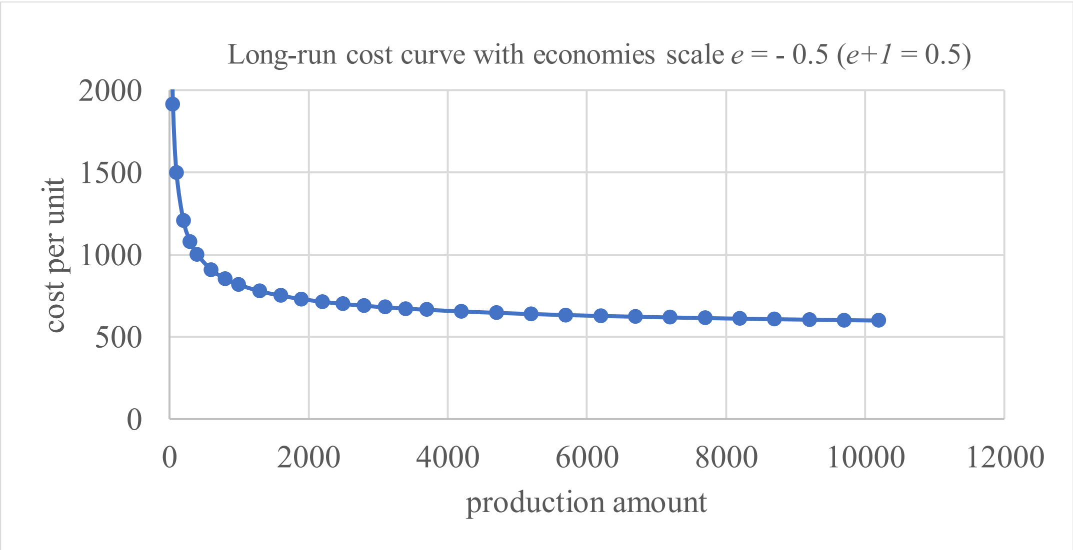
Here, *e+1* is the level of economic scale. In the long-run, fixed cost is not fixed because of the economic scale. If the economic scale changes the value of fixed cost is changed also. So, there is no fixed cost in the long-run model in that sense. It is the main difference between the short-run and long-run model. There is no big *M* constraint or capacity limit either for the long-run model. So, amount of production will depend upon the investment cost, variable cost, economic scale, and taxes.

Again, as the short-run model described under section 3.5, for the long-run model, we can get other interesting values such as profits and welfare for each factory, total welfare of the system, total taxes, and so on by solving this equation number (17) of cost function. We can follow the same equation described in equations numbers (9), (12), (11) and (10) under the section 3.4 for those values.

The model is nonlinear smooth but further analysis at derivations of the functions reveals that it is non-convex. Heuristic or multi-start gradient algorithms can be applied for solving. However, optimality of the results may not be guaranteed.

Below we show some graphs to understand the behaviour of the long-run curve in terms of economies scale. The curve is becoming steeper when we increase the value of *e+1*. In the following curves, we only change the economic factor; fixed cost and variable cost remain same which is 10,000 and 500 accordingly.





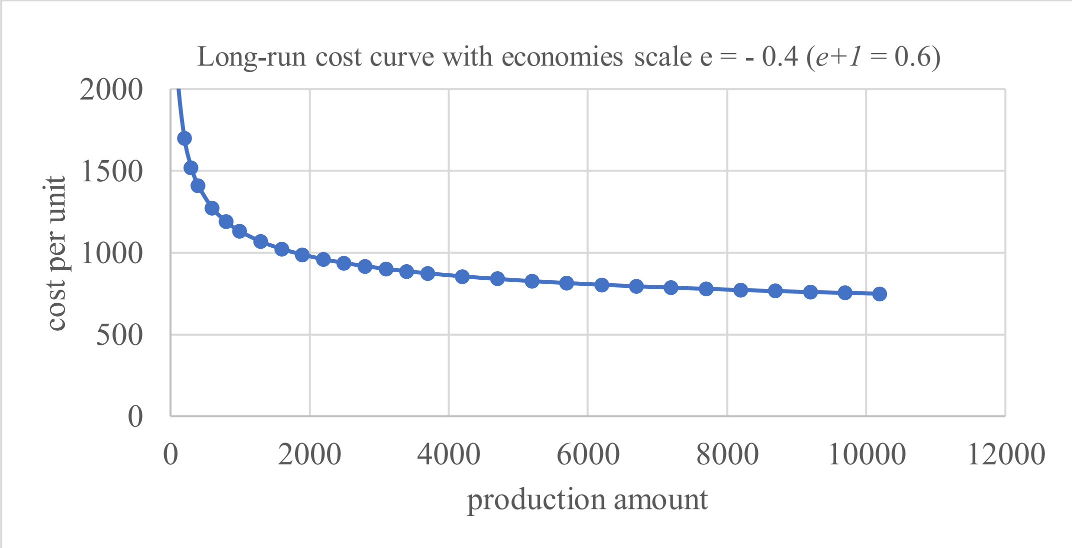


Figure 3: Behaviour of long-run curve with the variation of economies of scale

4 Experiments and results

This section introduces the experimental producer-market system, and default values of parameters used in different models, whether they are kept constant or adjusted. Then we justify the values and provide different ranges. For seeing the effects of the taxes with a range of values for different parameters we run the three models several times.

From figure 2, we can see that there are three producers and four markets in the system. We experiment with different kinds of taxes for the markets and producers to see the effects on production allocation, profit, and welfare. These taxes are producer tax, consumer tax, and border tax. There is also transportation cost, but we assume a constant value for it for all experiments. So, there is no effect of varying the transportation cost in the results of the experiments. Beside taxes, there is demand function, variable production cost, fixed cost, the coefficient for economic scale, and capacity limit. In addition to the taxes, these have effects on the production allocation, profit, and welfare too.

Firstly, the demand function from equation number (7) determines the per unit consumer price (Q_j). There is a maximum consumer price (d_j) for each market. It is set to 1000 and we assume it is fixed for all markets. Price parameter (k_j) is fixed as well, and it is set to 0.1. The amount of total production (z_{ij}) will be determined by solving the model.

Secondly, for calculating total production cost by following the equation number (8), we need to sum up all the taxes; border tax (b_{ij}), producer tax (l_j), consumer tax (m_j), transportation cost (n_{ij}) and production cost (a_i). We obtain the amount of total taxes by multiplying the amount of total production (z_{ij}) with per unit tax rate.

We assume a constant value for production cost which is 500 as we set the consumer price at zero demand to 1000, so initially, we assume the production cost to be half of the maximum price. We assume a constant transportation cost which is 5. These values are based on a hypothetical 100 kg steel construction for which we also assume producer tax to be 20, consumer tax 20, and border tax 20 initially. These values are justified by per ton of steel production co_2 emission 2 tons, co_2 emission tax 100 euros/ton. The production cost at 5 euros/kg should be realistic for a simple steel construction. The values for the taxes can be adjusted, from 0 upwards.

The fixed cost (F_i) for the short-run model (equation 13) is set to 100,000 which is equal for all factories. Production Capacity limit (L_i) in model 2 is equal for all factories and it is varied depending on the experimental setting. The big M value used in the constraints of the models is fixed at 99999.

Finally, for the long-run model, there is also the investment cost parameter (Gi). It is set to 10,000. Level of economic scale $e+1$ is set to 0.40 and variable cost c is set to 500.We experiment with different values of the input parameters. Our purpose is to gain general insight of the system; particularly the effects of the taxes under different circumstances to see:

- Outputs of different producers
- Profits of the factories and profits of the whole system
- Welfare of the factory and market locations and welfare of the whole system

4.1 Experiments without tax

4.1.1 Basic model without tax

First, we experiment with the models, assuming that there is no tax.

Table 3: Production allocation for the basic model when there is no tax

Markets	Factories		
	H	F1	F2
H	2500	0	0
F1	0	2500	0
F2	0	0	2500
F3	825	825	825
Sum	3325	3325	3325
Total	9975		

From Table 3, we can see that under the basic model, production at each factory is equal when there is no tax. When a product is transported into a different market rather than its own market, there is a fixed transportation cost. There is no production allocation to foreign markets because of the transportation cost. For the F3 market, situation is different. Even though there is a shipping cost, all factories allocate same amount of production to the F3 market. This is due to the fact that F3 factory is not manufacturing anything. Only goods from other factories, such as H, F1, and F2, are sent to the F3 market.

Table 4: Profit, welfare, and revenue for the basic model when there is no tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	625000	0	1874999	0	0	0	0	0	0
F1	0	0	0	625000	0	1874999	0	0	0
F2	0	0	0	0	0	0	625000	0	1874999
F3	204187	0	620814	204187	0	620814	204188	0	620812
Sum	829187	0	2495813	829187	0	2495813	829188	0	2495810
	Total profit			Total welfare			Total revenue		
	2487552			2487552			7487436		

Table 4 shows that the distribution of profits of factories follows the distribution of production. Because each factory receives an equal share of the production, each one makes an equal amount of profit. Where there is no production, the profit is 0. The sum of the individual factories´ entire profits makes up the system's overall profit.

The welfare of each factory is comparable to the distribution of production. Each factory generates an identical amount of welfare. Because there are no taxes; profit, and welfare are similar. Revenue is equal for H, F1, and F2 markets because their consumer price and production allocation are equal. It is different for F3 market because production allocation and consumer price are different for them.

4.1.2 Short-run model without tax

Table 5: Production allocation for the short-run model when there is no tax

Markets	Factories		
	H	F1	F2
H	2500	0	0
F1	0	2500	0
F2	0	0	2500
F3	825	825	825
Sum	3325	3325	3325
Total	9975		

From Table 5, we can see that with a capacity limit 3325 we have an equal amount of production allocation for each factory. But if we increase the capacity limit more than 3325 then the allocation for F3 market will reduce because it is the optimal amount of allocation for that market which has higher profit. If we increase the allocation one more unit of that market, then the consumer price goes down which will decrease the profit also. So, capacity limit 3325 is the critical point for allocation of this short-run model.

The second critical point is 4300 for which their production allocation is only in two factories. Because it is profitable to centralize production to two factories only and therefore lower the total fixed cost.

Table 6: Profit, welfare, and revenue for the short-run model when there is no tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	546711	0	1874999	0	0	0	0	0	0
F1	0	0	0	546711	0	1874999	0	0	0
F2	0	0	0	0	0	0	546710	0	1874999
F3	182477	0	620814	182477	0	620814	182477	0	620812
Sum	729188	0	2495813	729188	0	2495813	729187	0	2495810
	Total profit			Total welfare			Total revenue		
	2187562			2187562			7487436		

From Table 6, we can see that we have an equal amount of profit for all factories as production allocation is equal for capacity limit 3325. Revenue is equal for all markets also because of equal allocation. Revenue is collected to those markets only where there is allocation.

4.1.3 Long-run model without tax

Table 7: Production allocation for the long-run model when there is no tax

Markets	Factories		
	H	F1	F2
H	2418	0	0
F1	2393	0	0
F2	2393	0	0
F3	2393	0	0
Sum	9598	0	0
Total	9598		

We can see from the above Table 7 that we only have production in one factory for the long-run model. All productions are moving from the H factory to H, F1, F2, and F3 markets. Clearly, the production could take place in any factory, either in the H factory, F1 factory, or F2 factory.

While in the short-run model manufacturers can only affect prices through changes to production levels, in the long-run model all productions and costs are variable, and these are adjusted to maximize profit.

Table 8: Profit, welfare, and revenue for the long-run model when there is no tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	525660	0	1836166	0	0	0	0	0	0
F1	514243	0	1823220	0	0	0	0	0	0
F2	514242	0	1823220	0	0	0	0	0	0
F3	514243	0	1823220	0	0	0	0	0	0
Sum	2068388	0	7305825	0	0	0	0	0	0
	Total profit			Total welfare			Total revenue		
	2068388			2068388			7305825		

Table 8 shows that due to the production allocation to only one plant, the profit for the long-term model is for that factory only. As opposed to other markets, we can observe that we make more money when goods are sold from our production location to our market because there are no transportation costs involved in moving a product from a domestic producer to a domestic market. Other markets' profits are equal since those markets have set transportation costs.

Welfare for the long-run model is similar to the profit. As there are no taxes, welfare is equal to profit. Revenue is for those markets only where there is production supply. Where there is no production, there is no revenue.

4.2 Effect of producer tax

When a producer tax is imposed on a factory, it will reduce the quantity that will be sold in the market because per unit production cost is increased. Therefore, consumer price is increased, and demand is decreased. Producer tax goes to the market where the factory is situated.

4.2.1 Basic model with producer tax

Now, we see the result of experimentation with producer tax 20 at each factory. There are no other taxes such as consumer tax or border tax.

Table 9: Production allocation for the basic model when there is producer tax

Markets	Factories		
	H	F1	F2
H	2400	0	0
F1	0	2400	0
F2	0	0	2400
F3	792	792	792
Sum	3192	3192	3192
Total	9582		

From Table 9, we can see that there is an identical amount of production at each factory for the basic model where there is a producer tax in each factory. Due to the producer tax, the quantity of production allocation is currently less than it was in the no tax system (Table 3). However, the behaviour of production allocation is similar to the system with no taxes.

Table 10: Profit, welfare, and revenue for the basic model when there is producer tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	576000	48000	1824796	0	0	0	0	0	0
F1	0	0	0	576000	48000	1824731	0	0	0
F2	0	0	0	0	0	0	576000	48000	1824667
F3	188020	15833	604137	188020	15833	604137	188022	15833	604140
Sum	764020	63833	2428934	764020	63833	2428868	764022	63833	2428809
	Total profit			Total welfare			Total revenue		
	2292062			2483563			7296193		

Table 10 indicates that profit for the basic model with producer tax is equal for each factory. The profit is lower compared to the no tax system (Table 4) because of the producer tax, which causes higher prices and therefore lower demand.

Each producer receives the same amount of welfare because each producer makes an identical amount of profit and generates an identical amount of taxes. If we compare with no tax system, then the total welfare is smaller now. Revenue is generated in those markets where there is production supply.

4.2.2 Short-run model with producer tax

Table 11: Production allocation for the short-run model when there is producer tax

Markets	Factories		
	H	F1	F2
H	2399	0	0
F1	0	2399	0
F2	0	0	2399
F3	791	791	791
Sum	3190	3190	3190
Total	9570		

Table 11 shows that the behaviour of production allocation for the short-run model under producer tax 20 for all factories is now almost identical to that of the no-tax system. Capacity limit we use for this experiment is 3190.

Because this is the first critical point now with which we can get equal allocation for all markets. If we set the allocation more than 3190, for example, 3195 or higher we will have unequal allocation for one foreign factory. It is because with producer tax 20 and capacity limit 3190 we can get the optimal amount of profit for the system. But with higher capacity limit, total optimal allocation is below the capacity limit, and it does not increase. Therefore, the allocation to factories do not need to be equal anymore. Previously, when there were no taxes, the first critical point was 3325.

The second critical point for capacity limit with producer tax 20 is 4000. That means when we have producer tax 20 and a capacity limit 4000 the short-run model will stop production for one factory. Because of this, 4000 is the second critical limit for capacity with producer tax 20. Previously when there were no taxes, the second critical point was 4300.

Table 12: Profit, welfare, and revenue for the short-run model when there is producer tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	497829	47975	1823350	0	0	0	0	0	0
F1	0	0	0	497829	47975	1823350	0	0	0
F2	0	0	0	0	0	0	497829	47975	1823350
F3	166192	15825	603427	166192	15825	603427	166192	15825	603427
Sum	664021	63800	2426777	664021	63800	2426777	664021	63800	2426777
	Total profit			Total welfare			Total revenue		
	1992062			2183462			7280331		

From Table 12, we can see that profit follows the allocation of production. It implies that there is profit wherever there is production. A reduced production allocation results in a lesser profit. Total welfare is higher than total profit because of the producer tax. Taxes and revenue are collected at the location where there is allocation.

4.2.3 Long-run model with producer tax

Table 13: Production allocation for the long-run model when there is producer tax

Markets	Factories		
	H	F1	F2
H	2321	0	0
F1	2296	0	0
F2	2296	0	0
F3	2296	0	0
Sum	9210	0	0
Total	9210		

From Table 13, we can see that for the long-run model, when there is producer tax, the production allocation is lower than the no-tax case (Table 7). But the characteristic of the result is similar to the no-tax system (Table 7).

Table 14: Profit, welfare, and revenue for the long-run model when there is producer tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	478293	46325	1782483	0	0	0	0	0	0
F1	467403	45825	1769027	0	0	0	0	0	0
F2	467403	45825	1769027	0	0	0	0	0	0
F3	467403	45825	1769026	0	0	0	0	0	0
Sum	1880501	183800	7089563	0		0	0		0
	Total profit			Total welfare			Total revenue		
	1880501			2064300			7089563		

From Table 14, we can see that profit for the long-run model follows production allocation which means where there is production, there is profit. But profit is lower than the no tax case because there is producer tax now. Welfare is higher than the profit because of the producer tax.

However, welfare is lower compared to no tax system, it is also because of the producer tax. Profits follow revenues and revenues follow production allocation. Revenue decreased compared to the no tax system because of the producer tax.

Here, we can see again that production allocation is always in one factory only like in the no tax system. With higher producer tax instead of 20, the allocation is still in one factory. Only difference is that allocation is decreased with higher producer tax.

4.3 Effect of cross-country border tax

Border tax means when product is moving to a different country rather than producer country there is a tax. It goes to the market who is imposing the tax during import of a product.

Balancing both markets' profit and welfare with other taxes such as producer tax, consumer tax, or by increasing product price could be an option.

4.3.1 Basic model with cross country border tax

Now, we will examine the effect of cross country border tax to production allocation, profit, and welfare. The amount we use for our experiment is 20. There are no other taxes than this.

Table 15: Production allocation for the basic model when there is cross country border tax

Markets	Factories		
	H	F1	F2
H	2500	0	0
F1	0	2500	0
F2	0	0	2500
F3	792	792	792
Sum	3292	3292	3292
Total	9875		

We can see from the above Table 15 that we have an equal amount of production allocation for factory H to market H, for factory F1 to market F1, for factory F2 to market F2. It is because there is no border tax. On the other hand, for market F3 there is less production allocation from all factories (H, F1, F2) but the amount is equal for all factories though there is a border tax. It is because F3 is not producing anything, only the market exists, and the tax increases the optimal price.

Table 16: Profit, welfare, and revenue for the basic model when there is cross country tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	625000	0	1874999	0	0	0	0	0	0
F1	0	0	0	625000	0	1874999	0	0	0
F2	0	0	0	0	0	0	625000	0	1874999
F3	188012	15833	603617	188012	15833	603617	188039	15835	603703
Sum	813012	15833	2478616	813012	15833	2478616	813039	15835	2478703
	Total profit			Total welfare			Total revenue		
	2439062			2486563			7435937		

Table 16 indicates that profit is where there is production and the amount also follows the production allocation amount which means where there is higher production allocation, there is higher profit. However, taxes are collected only in F3 market while the product is imported from H, F1, or F2 factories.

Welfare is higher than the profit because of the border tax. However, it is lower than the no tax system because of the border tax also. If we experiment with higher border tax than 20, the welfare will decrease more.

4.3.2 Short-run model with cross country border tax

Table 17: Production allocation for the short-run model when there is cross country border tax

Markets	Factories		
	H	F1	F2
H	2500	0	0
F1	0	2500	0
F2	0	0	2500
F3	791	791	791
Sum	3291	3291	3291
Total	9873		

Table 17 illustrates that scenario of production allocation for the short-run model is similar to the basic model. Where there is border tax, there is no production allocation. Where there is no border tax, production allocation is higher there. For F3 market there is equal amount of border tax to all other markets but there are still sales, produced by the factories in the other locations.

Table 18: Profit, welfare, and revenue for the short-run model when there is cross country border tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	534022	0	1874750	0	0	0	0	0	0
F1	0	0	0	534022	0	1874750	0	0	0
F2	0	0	0	0	0	0	534022	0	1874750
F3	178999	15830	603558	178999	15830	603558	178999	15830	603558
Sum	713021	15830	2478308	713021	15830	2478308	713021	15830	2478308
	Total profit			Total welfare			Total revenue		
	2139062			2186552			7434925		

Table 18 shows that profit follows the behaviour of production allocation. The behaviour is same to the basic model which means where there is higher production allocation there is higher profit. The first critical point with border tax 20 is now 3291. That means when we have border tax 20 and capacity limit 3291, we will get equal production allocation for all factories. If we increase the capacity limit more than 3291, we may get unequal allocation for one of the foreign factories. Previously, for no tax case, the first critical point was 3325 and for producer tax (20) case, the first critical point was 3190.

The second critical point with border tax 20 is 4400. That means when we have a capacity limit 4400 and border tax 20, one of the factories will stop production. Previously, for no tax case, second critical point was 4300 and for producer tax (20) case, second critical point was 4000.

4.3.3 Long-run model with cross country border tax

Table 19: Production allocation for the long-run model when there is cross country border tax

Markets	Factories		
	H	F1	F2
H	2417	0	0
F1	2292	0	0
F2	2292	0	0
F3	2292	0	0
Sum	9292	0	0
Total	9292		

From Table 19 we can see that for the long-run model, production allocation is similar to the scenario while there is no tax or there is producer tax. So, in the long-run, border tax has no effect on production allocation if the amount of tax is small. If we increase the border tax from 20, the amount of production allocation will decrease a little.

Table 20: Profit, welfare, and revenue for the long-run model when there is cross country border tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	523761	0	1832703	0	0	0	0	0	0
F1	468024	45836	1766560	0	0	0	0	0	0
F2	468024	45836	1766562	0	0	0	0	0	0
F3	468024	45836	1766561	0	0	0	0	0	0
Sum	1927831	137508	7132386	0	0	0	0	0	0
	Total profit			Total welfare			Total revenue		
	1927831			2065339			7132386		

From Table 20, we can see that for the long-run model, profit, welfare, and revenue decreased, compared to the no tax system. It is because of the border tax. However, profit, welfare and revenue increased compared to the producer tax system.

As production allocation, profit, and welfare for the long-run model goes always in one factory, we try to see at which point we have production allocation for all factories with higher border tax. By trial-and-error method we find out that if we set border tax to 85 and transportation cost at 5, we have production allocation in each factory.

Table 21: Production allocation for the long-run model with border tax 85, transportation cost 5

Markets	Factories		
	H	F1	F2
H	2308	0	0
F1	0	2368	0
F2	0	0	2308
F3	0	1918	0
Sum	2308	4286	2308
Total	8901		

From above Table 21, we can see that in the long-run model, we get decentralized allocation in all factories by adjusting higher border tax.

Table 22: Profit, welfare, and revenue for the long-run model with border tax 85, transportation cost 5

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	399854	0	1775367	0	0	0	0	0	0
F1	0	0	0	466527	0	1807054	0	0	0
F2	0	0	0	0	0	0	399854	0	1775366
F3	0	0	0	291564	162997	1549888	0	0	0
Sum	399854	0	1775367	758090	162997	3356942	399854	0	1775366
	Total profit			Total welfare			Total revenue		
	1557798			1720796			6907675		

Table 22 shows that we have profit for each factory with higher border tax, but the overall profit, revenue, and welfare of all factories reduce remarkably compared to the no tax system (Table 8) because of the higher border tax. Welfare is now higher than profit because of the tax but it is equal to the profit when there is no taxes. Revenue is generated at those factories where there is production. However, taxes are collected only in the F3 market, while the products are imported from F1 factory.

4.4 Effect of the combination of producer tax and border tax

Previously we experimented with either border tax or producer tax. Now, we are experimenting with these two taxes at the same time, because if there is producer tax in some factories then border tax can also be used to balance the allocation.

Let us assume, we have both the producer tax and border tax to see the effect in production allocation, profit, and welfare when we have both taxes.

4.4.1 Basic model with combination of producer tax and border tax

Now, we have both producer tax 20 and border tax 20, for our models

Table 23: Production allocation for the basic model when there is producer tax and border tax

Markets	Factories		
	H	F1	F2
H	2400	0	0
F1	0	2400	0
F2	0	0	2400
F3	758	758	758
Sum	3158	3158	3158
Total	9475		

From above Table 23, we can see that the amount of production allocation and behaviour is almost similar to the case while there was only either producer tax or border tax. When there was only producer tax the production allocation for each factory was 3192 and when there was only border tax, production allocation for each factory was 3292. Now, with the combination of producer tax and border tax, the production allocation is 3158. So, we have a little bit lower allocation compared to either producer tax or border tax case.

Table 24: Profit, welfare, and revenue for the basic model when there is producer tax and border tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	576000	48000	1823999	0	0	0	0	0	0
F1	0	0	0	576000	48000	1823999	0	0	0
F2	0	0	0	0	0	0	576000	48000	1823999
F3	172512	30332	585782	172512	30332	585782	172539	30336	585873
Sum	748512	78332	2409782	748512	78332	2409782	748539	78336	2409873
	Total profit			Total welfare			Total revenue		
	2245562			2480563			7229437		

When we have producer tax only, the overall profit and welfare of the system is 2292062 and 2483563 accordingly (Table 10). Again, when we have border tax only, the profit and welfare is 2439062 and 2486563 accordingly (Table 16). Now from Table 24, we can see that for the combination of producer tax and border tax, the profit and welfare of the system are 2245562 and 2480563. So, we have lower profit and welfare for the combination of both taxes compared to the single tax system.

We can see the amount of each tax, and in which market the taxes are collected from the below tables.

Table 25: Distribution of producer tax according to target market

Markets	Factories		
	H	F1	F2
H	48000	0	0
F1	0	48000	0
F2	0	0	48000
F3	15166	15166	15168

In Table 25, the distribution of producer tax collected at the producing factory location is shown according to the market where the products are consumed.

Table 26: Border tax collection

Markets	Factories		
	H	F1	F2
H	0	0	0
F1	0	0	0
F2	0	0	0
F3	15166	15166	15168

In Table 26, we can see the amount of border taxes collected. All border taxes are collected at the F3 market only because other allocation is only from the factory to its own market, in which case there is no border tax.

4.4.2 Short-run model with combination of producer tax and border tax

In our short-run model, there is a constraint called capacity constraint to limit the production allocation. We have to set the value of the capacity limit depending on our need. For example, equal allocation in each factory, allocation in two factories only, allocation in one factory only and so on.

Table 27: Production allocation for the short-run model when there is producer tax and border tax

Markets	Factories		
	H	F1	F2
H	2400	0	0
F1	0	2400	0
F2	0	0	2400
F3	758	758	758
Sum	3158	3158	3158
Total	9474		

Table 27 shows that the scenario of production allocation for the short-run model is similar to the basic model. Where there is taxes, there is no production allocation. Where there is no tax, production allocation is higher there. For F3 market, there is equal amount of taxes like other markets but there is still production, which is equal from each factory to F3 market. It is because F3 is not producing anything, only consuming. That's why taxes will not affect the allocation from different factories to F3 market

Table 28: Profit, welfare, and revenue for the short-run model when there is producer tax and border tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	485606	47995	1823870	0	0	0	0	0	0
F1	0	0	0	485606	47995	1823870	0	0	0
F2	0	0	0	0	0	0	485606	47995	1823870
F3	162915	30330	585767	162915	30330	585767	162915	30330	585767
Sum	648521	78325	2409637	648521	78325	2409637	648521	78325	2409637
	Total profit			Total welfare			Total revenue		
	1945562			2180537			7228911		

Table 28 illustrates that when we have both the producer tax and border tax, at that time the first critical point is 3158. That means if we have capacity limit 3158 with border tax 20 and producer tax 20, we will get equal allocation for all markets. If the capacity limit is more than 3158 then production allocation will be unequal. Previously for no tax case, the first critical point was 3325, for producer tax (20) case it was 3190, for border tax (20) case it was 3291.

The second critical point for the combination of border tax 20 and producer tax 20 is 4250. That means when we have a capacity limit 4250 with border tax 20 and producer tax 20, one of the factories will stop production. Previously, for no tax case, the second critical point was 4300, for the producer tax (20) case it was 4000 and for the border tax (20) case, it was 4400.

Let us see the amount of each tax and the behaviour of the collection of taxes from the below table:

Table 29: Distribution of producer tax according to target market

Markets	Factories		
	H	F1	F2
H	47995	0	0
F1	0	47995	0
F2	0	0	47995
F3	15165	15165	15165

In Table 29, the distribution of producer tax collected at the producing factory location is shown according to the market where the products are consumed. It is similar to the basic model (Table 25).

Table 30: Border tax collection

Markets	Factories		
	H	F1	F2
H	0	0	0
F1	0	0	0
F2	0	0	0
F3	15165	15165	15165

In Table 30, we can see the amount of border taxes collected. All border taxes are collected at the F3 market only, similar to the basic model (Table 26) because other allocation is only from the factory to its own market, in which case there is no border tax.

4.4.3 Long-run model with combination of producer tax and border tax

Table 31: Production allocation for the long-run model when there is producer tax and border tax

Markets	Factories		
	H	F1	F2
H	2321	0	0
F1	2245	0	0
F2	2246	0	0
F3	2246	0	0
Sum	9057	0	0
Total	9057		

From Table 31 we can see that for the long-run model, we have similar effect in production allocation like the basic and short-run model which is we have little bit lower production allocation for the combination of both taxes than in the single tax system.

Table 32: Profit, welfare, and revenue for the long-run model when there is producer tax and border tax

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	477324	46420	1782296	0	0	0	0	0	0
F1	422631	89800	1740998	0	0	0	0	0	0
F2	422595	89840	1741549	0	0	0	0	0	0
F3	422595	89840	1741549	0	0	0	0	0	0
Sum	1745145	315900	7006391	0	0	0	0	0	0
	Total profit			Total welfare			Total revenue		
	1745145			2060171			7006391		

From Table 32, we can see that the amount of profit, welfare, and revenue is also lower than either the producer tax or border tax system.

Similar to the basic and short-run model, let us see the amount of each tax and the behaviour of collection of each tax from the below tables:

Table 33: Distribution of producer tax according to target market

Markets	Factories		
	H	F1	F2
H	46420	0	0
F1	44900	0	0
F2	44920	0	0
F3	44920	0	0

In Table 33, the distribution of producer tax collected at the producing factory location is shown according to the market where the products are consumed similar to the basic and short-run model (Table 25 and Table 29).

Table 34: Border tax collection

Markets	Factories		
	H	F1	F2
H	0	0	0
F1	44900	0	0
F2	44920	0	0
F3	44920	0	0

In Table 34, we can see the amount of border taxes collected. All border taxes are collected at the foreign markets (F1, F2, F3) only because other allocation is only from the factory to its own market, in which case there is no border tax similar to the basic and short-run model (Table 26 and Table 30).

4.5 Effect of consumer tax

Consumer tax is a tax while purchasing a good or service. It goes to the market where the product is purchased by customers.

4.5.1 Basic model, short-run model and long-run model with consumer tax

Now, we experiment with consumer tax 20 for all markets for all the models; basic model, short-run model, and long-run model. We get similar production allocation, profit, welfare, and revenue to the case of producer tax 20 for each factory. This is because both for producer tax case and consumer tax case, we use same amount. Only difference is producer tax is collected at the market where the factory is situated, and consumer tax is collected at the market where the product is consumed.

4.6 Sensitivity analysis

4.6.1 Sensitivity analysis by adjusting producer tax and border tax for the basic model

If we set producer tax 20 only for home factory and border tax 20 with the below combination in Table 35, we will get decentralized allocation in all factories.

Table 35: Border taxes in Combination 1

Markets	Factories		
	H	F1	F2
H		20	20
F1	20		20
F2	20	20	
F3	20	20	20

Table 35 shows the border tax amount and the cross country movement where the taxes are collected, for the sensitivity analysis of the basic model.

Let us see the allocation, profit, welfare, and revenue for the basic model with the above combination 1 (Table 35).

Table 36: Production allocation for combination 1 for the basic model

Markets	Factories		
	H	F1	F2
H	2400	0	0
F1	0	2500	0
F2	0	0	2500
F3	0	1187	1188
Sum	2400	3687	3688
Total	9775		

Table 36 shows the production allocation with producer tax in home factory only and cross country border tax 20. We can see that allocation in home factory is lower than other factories. It is because producer tax applies only in home factory now.

Table 37: Profit, welfare, and revenue for combination 1 for the basic model

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	576000	48000	1823999	0	0	0	0	0	0
F1	0	0	0	625000	0	1874999	0	0	0
F2	0	0	0	0	0	0	625000	0	1874999
F3	0	0	0	282030	23750	905465	282032	23750	905471
Sum	576000	48000	1823999	907030	23750	2780465	907032	23750	2780471
	Total profit			Total welfare			Total revenue		
	2390062			2485562			7384935		

From Table 37, we can see we have less profit, welfare, and revenue in home factory compared to the foreign factories due to less allocation in that factory.

4.6.2 Sensitivity analysis by adjusting producer tax and border tax for the short-run model

We assume producer tax 20 for home factory only and border tax 20 with combination 1 (Table 35) to see at which capacity limit we can get decentralized allocation. We find that if capacity limit is 3158, then we can get decentralized allocation for all factories.

Table 38: Production allocation for combination 1 for the short-run model

Markets	Factories		
	H	F1	F2
H	2400	0	0
F1	0	2400	0
F2	0	0	2400
F3	758	758	758
Sum	3158	3158	3158
Total	9474		

From Table 38, we can see we have equal allocation in all factories though we have producer tax in home factory. It is because of capacity limit. So, unlike the basic model (Table 36) where we have less allocation for the home factory; we have now equal allocation in all factories. Because now we have capacity limit for the short-run model which is absent in the basic model. But if we increase the border tax value than 20, allocation for producer taxed factory will reduce. To get equal allocation with higher border tax we have to set different capacity limit.

Table 39: Profit, welfare, and revenue for combination 1 for the short-run model

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	780422	48620	2135512	0	0	0	0	0	0
F1	0	0	0	829042	0	2135512	0	0	0
F2	0	0	0	0	0	0	829042	0	2135512
F3	242476	29080	647721	257016	14540	647721	257016	14540	647721
Sum	1022898	77700	2783233	1086058	14540	2783233	1086058	14540	2783233
	Total profit			Total welfare			Total revenue		
	3195013			3301793			8349698		

If we set the capacity limit 3937 with the same border tax(20) and producer tax(20), then one factory will stop production. So, there will be decentralized allocation only in two factories. So, for this case 3158 is the first critical point and 3937 is the second critical point.

If we set the border tax at 30 then the first critical point is 3142 and the second critical point is 4022. So, for increasing border tax the first critical capacity limit would be lower, but the second critical capacity limit would be higher than the border tax 20 case.

4.6.3 Sensitivity analysis by adjusting producer tax and border tax for the long-run model

In the long-run model, there is a significant effect of economic scale. For all our above cases, we use economies scale, $e+1$ = 0.40. If we increase the value of the economic factor, production cost (per piece) decreases less with volume and the production goes down and the amount of profit and welfare decreases (see figure 3).

We assume we have no taxes, only the transportation cost 5.

Let us see the difference of production allocation, profit, and welfare for different economies scale.

Table 40: Sensitivity analysis for the long-run model

Economic Scale	Production allocation	Profit and welfare
0.1	9918	2415143
0.2	9815	2362665
0.3	9589	2222527
0.4	9599	2067513
0.5	8863	1492656
0.6	6299	230264
0.7	0	0

So, we can see from the above Table 40, when economies of scale decreases (factor increases), production allocation, profit, and welfare decreases. It is because per unit production cost increases which also increases the consumer price. For this, production allocation, profit, and welfare decreases. At some point, consumer price is equal to the maximum price at which demand is 0, for this production is stopped and profit tends to 0. From the above table, we can see, when economic scale is 0.70, production allocation, profit, and welfare is 0 for that. It is because, for 0.70, consumer price is over 1000 which is equal to the maximum consumer price.

We have done sensitivity analysis for the long-run model also by changing fixed cost, variable cost, and economies of scale. If we change the fixed cost, variable cost, or economies of scale then we have to change the border tax also. For example, if we set a higher fixed cost 20,000 instead of 10,000 then we have to increase the border tax also to achieve decentralized allocation.

Let us set a fixed cost 20,000 instead of 10,000, economic scale, variable cost, and producer tax similar to the previous case 0.40, 500, and 20. Now, we will adjust the border tax to see at which value we can get a decentralized allocation. We find that with border tax 209 we can get decentralized allocation which is double to 105. As we double the fixed cost, so we have to double the border tax to get decentralized allocation. Again, we set economic scale at 0.50 instead of 0.40 and fixed cost, variable cost, producer tax for home factory to 10,000, 500 and 20. Now we experiment with different border tax to see at which point we get decentralized allocation. We find that with border tax 208 we can get decentralized allocation which is double compared to 105 as we set economic scale at 0.5 instead of 0.4. Again, we set fixed cost at 10,000, economic of scale at 0.4, variable cost at 700 to see at which border tax we can get decentralized allocation. We find that with border tax 166 we can get decentralized allocation because we set higher variable cost.

Now, we assume for the long-run model we have producer tax in home factory only. For which there is no production in home factory, only foreign factories are producing. Let us see at which border tax we have production in all factories though there is producer tax in home factory.

First, we will try with producer tax 20 for home factory and border tax 85 with the below combination:

Table 41: Border taxes in Combination 2

Markets	Factories		
	H	F1	F2
H		85	85
F1	85		85
F2	85	85	
F3			

So, we set border tax 85 (Table 41) for the foreign factories from where we are importing products. There is no border tax for H factory to H market because we set producer tax 20 for the home factory while producing. In addition to that, there is no border tax for F3 market because F3 is not producing anything.

Table 42: Production allocation for combination 2

Markets	Factories		
	H	F1	F2
H	0	0	1944
F1	0	2355	0
F2	0	0	2429
F3	0	0	2357
Sum	0	2355	6730
Total	9085		

We can see from above Table 42 that with the producer tax 20 for home factory and border tax 85 for foreign factories, we have no production allocation from home factory to home market.

Table 43: Profit, welfare, and revenue for combination 2

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	0	0	0	0	0	0	320983	165083	1566044
F1	0	0	0	399649	0	1800184	0	0	0
F2	0	0	0	0	0	0	501854	0	1839154
F3	0	0	0	0	0	0	492168	0	1801573
Sum	0	0	0	399649	0	1800185	1315005	165083	5206771
	Total profit			Total welfare			Total revenue		
	1714216			1879450			7006956		

As we have no production allocation from home factory to markets, so all the taxes, profit, and revenue from H factory to H, F1, F2 and F3 markets are zero (Table 43). It is because production is decentralized to foreign factories only. In addition, while the product is moving from F1 to F1 there is no producer tax or border tax that's why they have allocation and therefore profit but no taxes. Similar scenario from F2 factory to F2 market. Besides, allocation for F3 market takes place only from F2 factory.

Now, let us try with same producer tax 20 for home factory but border tax 105 with the below combination:

Table 44: Border taxes in combination 3

Markets	Factories		
	H	F1	F2
H		105	105
F1	105		105
F2	105	105	
F3			

Table 44 shows the amount of border tax and the cross country matrix where the taxes are collected for another sensitivity analysis of the long-run model.

Table 45: Production allocation for combination 3

Markets	Factories		
	H	F1	F2
H	2201	0	0
F1	0	2376	0
F2	0	0	2308
F3	0	2350	0
Sum	2202	4726	2308
Total	9235		

Now, from Table 45, we can see that we have decentralized production allocation in all factories (H, F1, F2). It is because of the higher border tax.

Table 46: Profit, welfare, and revenue for combination 3

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	354746	44053	1716807	0	0	0	0	0	0
F1	0	0	0	475156	0	1811482	0	0	0
F2	0	0	0	0	0	0	399854	0	1775055
F3	0	0	0	464323	0	1797669	0	0	0
Sum	354746	44053	1716807	939479	0	3609151	399854	0	1775055
	Total profit			Total welfare			Total revenue		
	1694079			1738108			7101013		

In Table 46, we have lower profit than the previous one though we have equal producer tax. It is because of the higher border tax. In addition to that welfare is reduced significantly and no border crossing between production locations. Revenue increased because production amount is increased. Besides, all the taxes are now collected in home market.

Now, we will try with higher producer tax (105) for home factory and border tax 105 with the below combination:

Table 47: Border taxes in combination 4

Markets	Factories		
	H	F1	F2
H		105	105
F1	105		105
F2	105	105	
F3			

Table 47 shows another combination of border tax for the sensitivity analysis of the long-run model. Amount and collection matrix of the border tax for combination 3 (Table 44) and 4 (Table 47) is similar. Only difference is the producer tax amount.

Table 48: Production allocation for combination 4

Markets	Factories		
	H	F1	F2
H	0	0	1848
F1	0	2308	0
F2	0	0	2398
F3	0	0	2373
Sum	0	2308	6619
Total	8927		

For this case, we can see from above Table 48 that we have decentralized production allocation in foreign factories (F1 and F2), no allocation in home factory as producer tax is increased but border tax remains same. Total production allocation is also lower because of the higher producer tax in home factory.

Table 49: Profit, welfare, and revenue for combination 4

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	0	0	0	0	0	0	284967	194040	1506491
F1	0	0	0	399854	0	1775357	0	0	0
F2	0	0	0	0	0	0	501668	0	1822964
F3	0	0	0	0	0	0	490522	0	1809896
Sum	0	0	0	399854	0	1775357	1277158	194040	5139350
	Total profit			Total welfare			Total revenue		
	1676574			1870615			6914708		

From Table 49, we can see that profit, welfare, and revenue are significantly lower than in previous case. It is because of the higher producer tax, which has reduced allocation and all the productions of home factory are shifted from home factory to foreign factories.

Let us try with producer tax 105 again for home factory and border tax also with 105. But this time we will set border tax for F3 market also like the below combination:

Table 50: Border taxes in combination 5

Markets	Factories		
	H	F1	F2
H		105	105
F1	105		105
F2	105	105	
F3	105	105	105

Table 50 shows the collection matrix of border tax collection and amount for another sensitivity analysis of the long-run model.

Table 51: Production allocation for combination 5

Markets	Factories		
	H	F1	F2
H	0	0	1843
F1	0	2308	0
F2	0	0	2393
F3	0	0	1843
Sum	0	2308	6078
Total	8386		

Table 51 illustrates that we have lower production allocation now compared to the previous one (Table 48) because we introduced the border tax for F3 market now which reduced the allocation for F3 market from F2 factory therefore total allocation is also reduced.

Table 52: Profit, welfare, and revenue for combination 5

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	0	0	0	0	0	0	280194	193481	1503129
F1	0	0	0	399854	0	1775352	0	0	0
F2	0	0	0	0	0	0	495393	0	1820164
F3	0	0	0	0	0	0	280241	193469	1503058
Sum	0	0	0	399854	0	1775352	1055828	386950	4826352
	Total profit			Total welfare			Total revenue		
	1455245			1842195			6601705		

From Table 52 we can see that behaviour of profit, welfare, and revenue is almost similar to the previous case because of the similar combination of border tax. But we have lower profit, welfare, and revenue compared to the previous case because of the new border tax in F3 market.

Let us try with producer tax 50 for home factory and border tax 105 with the below combination:

Table 53: Border taxes in combination 6

Markets	Factories		
	H	F1	F2
H		105	105
F1	105		105
F2	105	105	
F3			

From Table 53, we can see another combination of border tax for sensitivity analysis of the long-run model.

Table 54: Production allocation for combination 6

Markets	Factories		
	H	F1	F2
H	0	0	1846
F1	0	2308	0
F2	0	0	2398
F3	0	0	2372
Sum	0	2308	6616
Total	8924		

We can see from the above Table 54 that we have higher production allocation now compared to the previous case but still decentralized to foreign factories only because of the increased producer tax (50) and similar border tax compared to the Table 44.

Table 55: Profit, welfare, and revenue for combination 6

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	0	0	0	0	0	0	284998	193850	1505348
F1	0	0	0	399854	0	1775266	0	0	0
F2	0	0	0	0	0	0	501647	0	1822789
F3	0	0	0	0	0	0	490512	0	1809242
Sum	0	0	0	399854	0	1775267	1277157	193850	5137378
	Total profit			Total welfare			Total revenue		
	1676574			1870424			6912645		

From Table 55 we can see that total profit, welfare, and revenue is lower than the case of producer tax 20, and border tax 105. It is because we have now a higher producer tax (50) though the border tax is same.

Finally, we will try with producer tax 30 for home factory and border tax 105 with the below combination.

Table 56: Border taxes in combination 7

Markets	Factories		
	H	F1	F2
H		105	105
F1	105		105
F2	105	105	
F3			

From Table 56, we can see our final combination of border tax for the sensitivity analysis of the long-run model.

Table 57: Production allocation for combination 7

Markets	Factories		
	H	F1	F2
H	0	77	1906
F1	0	2341	0
F2	0	0	2405
F3	0	0	2342
Sum	0	2418	6654
Total	9072		

Now, we can see from Table 57 that we have decentralized production allocation in two foreign factories (F1 and F2). Allocation is lower than the producer tax 20 with border tax 105 case (Table 45). It is because producer tax is higher for which there is no allocation in home factory thus total allocation is also reduced.

Table 58: Profit, welfare, and revenue for combination 7

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	0	0	0	7563	8073	61637	268492	200176	1528330
F1	0	0	0	404026	0	1793105	0	0	0
F2	0	0	0	0	0	0	501835	0	1826723
F3	0	0	0	0	0	0	491733	0	1793692
Sum	0	0	0	411589	8073	1854742	1262060	200176	5148745
	Total profit			Total welfare			Total revenue		
	1673212			1881461			7003487		

From Table 58, we can see that profit, welfare, and revenue are lowered also because of higher producer tax (30). All the taxes are collected in the foreign factories while in the producer tax 20 case all taxes are collected in home factory.

So, the best solution we get is to set producer tax 20 for home factory then set a high border tax (more than 5 times higher than the producer tax) for foreign factories from where we are importing product in home market. In addition, we set no border tax for those markets where there is no production, but they import products from other countries.

4.7 Effect of market size

The term "market size" implies the maximum volume of sales or clients one´s company can handle, frequently calculated over a period of a year [47]. Before introducing a new product line or line of business, it's beneficial to understand the potential market size because that can help one decide whether it's an effective use of both time and resources [47].

4.7.1 Effect of market size for the basic model

Now, we will increase the market size at 0.05 instead of 0.1 to see the effect of allocation, profit, welfare, and revenue for the basic model.

Table 59: Production allocation with higher market size in the baseline

Markets	Factories		
	H	F1	F2
H	4800	0	0
F1	0	5000	0
F2	0	0	5000
F3	0	2375	2375
Sum	4800	7375	7375
Total	19550		

From Table 59, we can see that we have decentralized allocation in all factories, but the amount is higher because of the increased market size.

Table 60: Profit, welfare, and revenue with higher market size in the baseline

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	1152000	96000	3647999	0	0	0	0	0	0
F1	0	0	0	1250000	0	3749999	0	0	0
F2	0	0	0	0	0	0	1250000	0	3749999
F3	0	0	0	564139	47506	1811185	563986	47494	1810691
Sum	1152000	96000	3647999	1814139	47506	5561183	1813986	47494	5560689
	Total profit			Total welfare			Total revenue		
	4780125			4971125			14769871		

We can see from the above Table 60 that we have higher allocation, profit, welfare, and revenue compared to the market size (0.1). It is because the market size is increased (0.05).

4.7.2 Effect of market size for the short-run model

Again, if we increase the market size for short-run model, for example, set market size at 0.05 instead of 0.1 with producer tax 20 for home factory and border tax 20, we will get similar allocation compared to 0.1 market size, but this time profit, welfare, and revenue increased. It is because of the higher market share.

Let us see the allocation, profit, welfare, and revenue with higher market size.

Table 61: Production allocation with higher market size in the short-run

Markets	Factories		
	H	F1	F2
H	2431	0	0
F1	0	2431	0
F2	0	0	2431
F3	727	727	727
Sum	3158	3158	3158
Total	9474		

From Table 61, we can see that the allocation is not increased even the market size is increased because of the capacity limit.

Table 62: Profit, welfare, and revenue with higher market size in the short-run

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	780422	48620	2135512	0	0	0	0	0	0
F1	0	0	0	829042	0	2135512	0	0	0
F2	0	0	0	0	0	0	829042	0	2135512
F3	242476	29080	647721	257016	14540	647721	257016	14540	647721
Sum	1022898	77700	2783233	1086058	14540	2783233	1086058	14540	2783233
	Total profit			Total welfare			Total revenue		
	3195013			3301793			8349698		

So, we can see from Table 62 that with a higher market size we have higher profit, welfare, and revenue though the allocation is not changed. It is because in the short-run, we have capacity restrictions.

4.7.3 Effect of market size for the long-run model

For the long-run model, we also set higher market size 0.05 instead of 0.1 to see the behaviour of allocation, profit, welfare, and revenue.

Table 63: Production allocation with higher market size in the long-run

Markets	Factories		
	H	F1	F2
H	4544	0	0
F1	0	4837	0
F2	0	0	4751
F3	0	4787	0
Sum	4544	9624	4751
Total	18920		

From Table 63, we can see that for the long-run model, allocation is increased compared to the previous smaller market size because of the increased market size.

Table 64: Profit, welfare, and revenue with higher market size in the long-run

Markets	Factories								
	H			F1			F2		
	profit	tax	revenue	profit	tax	revenue	profit	tax	revenue
H	858337	90888	3511817	0	0	0	0	0	0
F1	0	0	0	1051628	0	3667199	0	0	0
F2	0	0	0	0	0	0	951293	0	3622466
F3	0	0	0	1028790	0	3641258	0	0	0
Sum	858337	90888	3511817	2080417	0	7308457	951293	0	3622466
	Total profit			Total welfare			Total revenue		
	3890048			3980936			14442740		

We can see from the above Table 64 that with a higher market size, we can get higher profit, welfare, and revenue in the long-run.

5 Analysis

We described multiple cases and their results earlier. In short, we can generalize our outcomes. It is highlighted that there is a significant effect of capacity constraints at the short-run model and there is also significant effect of economies of scale at the long-run model. Outcomes of our experiments are summarized in the table below:

Table 65: Results of experiments

Different Cases	Basic model	Short-run model	Long-run model
No tax	All factories receive an equal production allocation.	Equal production allocations for all factories.	Allocation is only in one factory.
Producer tax	All factories receive an equal production allocation but lower than no tax case.	Equal production allocation for all factories but lower than no tax case.	Allocation is in one factory but lower than no tax case.
Border tax	All factories receive an equal production allocation but lower than no tax case and higher than producer tax case.	Equal production allocation for all factories but lower than no tax case and higher than producer tax case.	Allocation is in one factory but lower than no tax case and higher than producer tax case.
Combination of producer tax and border tax	All factories receive an equal production allocation but lower than any other cases above.	Equal production allocation for all factories but lower than any other cases.	Allocation is in one factory but lower than any other cases.
Consumer tax	All factories receive an equal production allocation, and the amount is similar to producer tax case.	All factories receive an equal production allocation, and the amount is similar to producer tax case.	All factories receive an equal production allocation, and the amount is similar to producer tax case.
Sensitivity analysis concerning producer tax in one factory and border adjustments	When there is producer tax in one factory only, allocation will reduce in that factory. Even highering the border tax will not increase the allocation of that factory.	When there is producer tax in one factory only, allocation will still be same in that factory. But with higher border tax allocation will reduce for that producer taxed factory.	When there is producer tax in one factory only, there is no allocation in that factory but if we set higher border tax, we can get decentralized allocation.
Market size	All factories receive an equal production allocation but if we increase the market size, allocation will increase, if we reduce market size, allocation will reduce also.	All factories receive an equal production allocation. When market size is increased, profit, welfare, and revenue is increased but allocation is still the same for all factories.	All factories receive an equal production allocation but if we increase the market size, allocation will increase, if we reduce market size, allocation will reduce also.

So, from the above results (Table 65) we can say individual taxes affect the behaviour of allocation. Specially for the long-run case allocation difference is higher. In a similar way, total profit, welfare, and revenue of the system follow the behaviour and amount of allocation. Our basic model indicates that when we merely impose the combination of producer tax and border tax, we make less money. In addition, our short-run model also indicates that when we have both the producer tax and border tax, we will get less money. We have also different capacity limits affecting the allocation of production to factories differently. These are shown below in a table:

Table 66: Critical points for the short-run model

Numbers	Different cases	First critical point	Second critical point
1	No tax system	3325	4300
2	Producer tax system	3190	4000
3	Border tax system	3291	4400
4	Combination of producer tax and border tax system	3158	4250

Here, in Table 66, first critical point means allocation is equal for all factories until that capacity. Second critical point means allocation is only in two factories after that point. If we change the amount of producer tax or border tax from the default values, the critical points for capacity limit will also change.

Our long-run model indicates that when we have both border tax and producer tax, profit, revenue, and welfare will be lower (Table 32) compared to the single tax system (Table 14 and Table 20).

During the sensitivity analysis, for the long-run model, we get decentralized allocation in the case of producer tax in one factory only and border adjustments. Depending on the amount of producer tax and border tax the allocation is decentralized in foreign factories only. With high border taxes we reach a critical point, after which the production is decentralized in all factories. First, we set producer tax 20, for home factory only and border adjustments to 85. We get decentralized allocation in foreign factories and profit is 1714216, welfare is 1879450 and revenue is 7006956 (Table 42 and Table 43). We find that with border adjustments 105 and producer tax 20, we get decentralized allocation (Table 45) to all three factories, but profit is reduced 1.17% and welfare is reduced 7.5% compared to the previous border tax 85 case (Table 43). However, revenue is increased 1.13% due to the higher border tax than before.

In addition, in the long-run model, if we increase the fixed cost, variable cost or economic factor then we have to increase the border tax also to get decentralized allocation. This is because economies of scale are effectively increased either by changing the unit cost curve steeper or by moving the curve so that the profit maximizing operating quantities take place at steeper parts of the curve.

6 Conclusions

To fulfil EU´s goal to reduce carbon emission from carbon intensive products CBAM is a way to tackle the situation. Though there are several alternative options for reducing emissions instead of border tax, for example, producer tax, consumer tax and so on, our research finds that the combination of producer tax and border tax option is the best policy for the sake of the overall economy.

The results show that the amount of economies of scale strongly affects the profit maximizing production allocation. It appears that under economies of scale effects, the EU border tariff levels are far too low to create a fair marketplace. Our long-run model indicates that under economies of scale we get centralized allocation with lower border tariffs whereas with sufficiently higher border tariffs we get decentralized allocation to different countries and the amount of polluting production is reduced significantly.

The effects of short-run capacity constraints and market size on the production allocation are also examined in the study. With bigger market size, profit and allocation will be big compared to the small market size. However, if there are capacity restrictions for the amount of productions, the total amount of production will be limited by the capacity even when the market size is increased. So, market size has no or limited effect on allocation.

In the analysis, consumer tax instead of producer tax does not affect the total production and welfare, it only has an effect on where the taxes are collected. Producer tax benefits the producing factory country, whereas consumer tax is collected at the consuming market.

In this study, all the models were deterministic, the results were obtained using the Microsoft Excel standard add-in solver and therefore no repetition of the same experiments was needed. So, each result is unique and reliable. Experiments were performed using realistic values for different taxes in the factories. Correspondingly, depending on the model different technologies were represented by the parameter values of the cost functions. It can be noted that sometimes, minor variation of the results was observed during running the same experiment repeatedly due to the characteristics of the solver used. So, careful observation is needed. Better solver could also be used for more precise results.

References

[1] S. Lowe, "A report on the EU's carbon border adjustment mechanism: How to make it work for developing countries," London, Brussels, Berlin, 2021.

[2] J. Titievskaia, H. Morgado Simões, and A. Dobreva, "A report on EU carbon border adjustment mechanism," Brussels, 2023.

[3] European Commission, "Proposal for a regulation of the European Parliament and of the council for establishing a carbon border adjustment mechanism," Brussels, 2021.

[4] A. Marcu, M. Mehling, A. Cosbey, and A. Maratou "A report on Addressing Carbon Leakage in the EU: Making CBAM work in a Portfolio of Measures," 2021.

[5] Gide Loyrette Nouel, "A report on Carbon Border Adjustment Mechanism (CBAM) - EU proposal,"2021[Online]. Available:
https://eur-lex.europa.eu/legal-co-
tent/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#docu-
ment2

[6] European Commission, "A report on Carbon Border Adjustment Mechanism," 2021. doi:
10.2778/584899.

[7] S. Markkanen et al., "A report on the Borderline: The EU CBAM and its place in the world of trade," Cambridge, 2021.

[8] European Commission, "A report on Carbon Border Adjustment Mechanism (CBAM)," Brussels, 2021.

[9] A. Gläser and O. Caspar, "A report on Less confrontation, more cooperation, review on Increasing acceptability of the EU Carbon Border Adjustment in key trade partners," Berlin, 2021. [Online]. Available:
www.germanwatch.org

[10] European Commission, "A report on Inception Impact Assessment," Brussels, 2021. [Online]. Available:
https://ec.europa.eu/info/consultations_en

[11] European Environment Agency, "A report on Is Europe reducing its greenhouse gas emissions?" 2021. [Online]. Available:

https://www.eea.europa.eu/highlights/small-cut-in-eus-total

[12] European Commission, "proposal on European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions" Brussels, Jul. 2021.

[13] European Commission, "Annexes to the regulation of the European Parliament and of the council for establishing a carbon border adjustment mechanism," Brussels, 2021.

[14] J. Burke, M. Sato, C. Taylor, and F. Li, "A report on What does an EU Carbon Border Adjustment Mechanism mean for the UK? Summary," London, 2021. [Online]. Available:
www.cccep.ac.uk

[15] Authority of the House of Commons, "A report on Greening imports: a UK carbon border approach," London, 2022.

[16] S. Qi, Z. Xu, and Z. Yang, "China's carbon allowance allocation strategy under the EU carbon border adjustment mechanism: An integrated non-parametric cost frontier approach," J. Sci. Total Environ., vol. 831, Jul. 2022, doi:
10.1016/j.scitotenv.2022.154908.

[17] C. Kardish, L. Li, M. Hellmich, M. Duan, and Y. Tao, "A report on The EU carbon border adjustment mechanism (CBAM) and China," Berlin, 2021.

[18] Kagan Julia, "What Is a Carbon Tax: Basics, Implementation, Offsets," Oct. 02, 2022. Available:
https://www.investopedia.com/terms/c/carbon-dioxide-tax.asp (accessed Apr. 03, 2023).

[19] Kenton Will, "Cap and Trade Basics: What It Is, How It Works, Pros & Cons," Dec. 05, 2020. Available:
https://www.investopedia.com/terms/c/cap-and-trade.asp (accessed Apr. 03, 2023).

[20] R. N. Stavins, "A review of a meaningful U.S Cap and Trade system to address climate change," 2008.

[21] Carbon Tax Center, "Overview on Cap and Trade." Available:
https://www.carbontax.org/carbon-tax-vs-the-alternatives/cap-and-trade/
(accessed Apr. 03, 2023).

[22] N. Stavins Robert, "A report on Harvard Project on Climate Agreements, Carbon Taxes vs. Cap and Trade: Theory and Practice," Cambridge, United States of America, 2019.

[23] Pew Center on Global Climate Change, "Climate Policy Memo #1 - Cap and Trade v Taxes," Arlington, Virginia, United States, 2009. [Online]. Available:
http://www.c2es.org/publications/cap-trade-vs-taxes

[24] E. Asen and K. Pomerleau, "Carbon Tax and Revenue Recycling: Revenue, Economic, and Distributional Implications," Washington DC, 2019. [Online]. Available:
https://www.leadoncarbonpricing.com/participating-companies/.

[25] S Aahana, "Effects of Tariffs under Partial Equilibrium | International Economics." Available:
https://www.economicsdiscussion.net/tariffs/effects-of-tariffs-under-partial-equilibrium-international-economics/30452 (accessed Apr. 03, 2023).

[26] The Investopedia Team, "Welfare Economics Explained: Theory, Assumptions, and Criticism," 2022. Available:
https://www.investopedia.com/terms/w/welfare_economics.asp (accessed Apr. 03, 2023).

[27] Wallstreetmojo Team, "Welfare Economics." Available:
https://www.wallstreetmojo.com/welfare-economics/ (accessed Apr. 03, 2023).

[28] S. A. Greenlaw and Shapiro David, "Principles of Microeconomics," 2017.

[29] R. S. Pindyck and Daniel L. Rubinfeld., Microeconomics, eight edit. United States of America.

[30] D. Curtis and I. Irvine, "Principles of Microeconomics," 2017.

[31] H. Von Stackelberg, "Market structure and equilibrium," New York, 1934.

[32] Dr. David A. Dilts, Introduction to Microeconomics, Sixth edit. Purdue: Indiana - Purdue University, 1995.

[33] E. J. Balistreri, D. T. Kaffine, and H. Yonezawa, "Optimal Environmental Border Adjustments Under the General Agreement on Tariffs and Trade," J.

Environ. Resour. Econ., vol. 74, no. 3, pp. 1037–1075, Nov. 2019, doi: 10.1007/s10640-019-00359-2.

[34] H. Cheng, "Border carbon adjustments with endogenous assembly locations," J. Econ. Model., vol. 105, Dec. 2021, doi:
10.1016/j.econmod.2021.105666.

[35] T. Eyland and G. Zaccour, "Carbon tariffs and cooperative outcomes," J. Energy Policy, vol. 65, pp. 718–728, 2014, doi:
10.1016/j.enpol.2013.10.043.

[36] K. P. Nurjanni, M. S. Carvalho, and L. Costa, "Green supply chain design: A mathematical modeling approach based on a multi-objective optimization model," Int. J. Prod. Econ., vol. 183, pp. 421–432, Jan. 2017, doi: 10.1016/j.ijpe.2016.08.028.

[37] A. D. Nimubona and H. A. Rus, "Green Technology Transfers and Border Tax Adjustments," J. Environ. Resour. Econ., vol. 62, no. 1, pp. 189–206, Sep. 2015, doi:
10.1007/s10640-014-9821-9.

[38] D. Gros and C. Egenhofer, "The case for taxing carbon at the border," J. Clim. Policy, vol. 11, no. 5, pp. 1262–1268, 2011, doi:
10.1080/14693062.2011.592669.

[39] M. Jakob, R. Marschinski, and M. Hübler, "Between a Rock and a Hard Place: A Trade-Theory Analysis of Leakage Under Production- and Consumption-Based Policies," J. Environ. Resour. Econ., vol. 56, no. 1, pp. 47–72, 2013, doi:
10.1007/s10640-013-9638-y.

[40] J. R. Markusen, "International Externalities and Optimal Tax Structures," J. Int. Econ., vol. 5, no. 1, pp. 15–29, 1975, doi:
10.1016/0022-1996(75)90025-2.

[41] S. K. Jakhar, "Designing the green supply chain performance optimisation model," Glob. J. Flex. Syst. Manag., vol. 15, no. 3, pp. 235–259, 2014, doi:
10.1007/s40171-014-0069-6.

[42] A. Al Khourdajie and M. Finus, "Measures to enhance the effectiveness of international climate agreements: The case of border carbon adjustments," Eur. Econ. Rev., vol. 124, May 2020, doi:
10.1016/j.euroecorev.2020.103405.

[43] C. Wang, W. Wang, and R. Huang, “Supply chain enterprise operations and government carbon tax decisions considering carbon emissions,” J. Clean. Prod., vol. 152, pp. 271–280, May 2017, doi: 10.1016/j.jclepro.2017.03.051.

[44] B. Li, M. Zhu, Y. Jiang, and Z. Li, “Pricing policies of a competitive dual-channel green supply chain,” J. Clean. Prod., vol. 112, pp. 2029–2042, Jan. 2016, doi: 10.1016/j.jclepro.2015.05.017.

[45] Y. Fang, Y. Yu, Y. Shi, and J. Liu, “The effect of carbon tariffs on global emission control: A global supply chain model,” J. Transp. Res. Part E Logist. Transp. Rev., vol. 133, 2020, doi: 10.1016/j.tre.2019.11.012.

[46] X. Xu, X. Xu, and P. He, “Joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations,” J. Clean. Prod., vol. 112, pp. 4093–4106, 2016, doi: 10.1016/j.jclepro.2015.08.081.

[47] Melendez Steven, “What Is the Definition of Market Size?” 2019. Accessed: Apr. 03, 2023. [Online]. Available: https://smallbusiness.chron.com/definition-market-size-65724.html

Appendix A

Cement

CN code	Greenhouse gas
2523 10 00 – Cement clinkers	Carbon dioxide
2523 21 00 – White Portland cement, whether or not artificially coloured	Carbon dioxide
2523 29 00 – Other Portland cement	Carbon dioxide
2523 90 00 – Other hydraulic cements	Carbon dioxide

Electricity

CN code	Greenhouse gas
2716 00 00 – Electrical energy	Carbon dioxide

Fertilisers

CN code	Greenhouse gas
2808 00 00 – Nitric acid; sulphonitric acids	Carbon dioxide and nitrous oxide
2814 – Ammonia, anhydrous or in aqueous solution	Carbon dioxide
2834 21 00 - Nitrates of potassium	Carbon dioxide and nitrous oxide
3102 – Mineral or chemical fertilisers, nitrogenous	Carbon dioxide and nitrous oxide
3105 – Mineral or chemical fertilisers containing two or three of the fertilising elements nitrogen, phosphorus and potassium; other fertilisers; goods of this chapter in tablets or similar forms or in packages of a gross weight not exceeding 10 kg - Except: 3105 60 00 – Mineral or chemical fertilisers containing the two fertilising elements phosphorus and potassium	Carbon dioxide and nitrous oxide

Iron and Steel

CN code	Greenhouse gas
72 – Iron and steel Except: 7202 – Ferro-alloys 7204 – Ferrous waste and scrap; re-melting scrap ingots and steel	Carbon dioxide
7301- Sheet piling of iron or steel, whether or not drilled, punched or made from assembled elements; welded angles, shapes and sections, of iron or steel	Carbon dioxide
7302 – Railway or tramway track construction material of iron or steel, the following: rails, check-rails and rack rails, switch blades, crossing frogs, point rods and other crossing pieces, Sleepers (cross-ties), fish- plates, chairs, chair wedges, sole plates (base plates), rail clips, bedplates, ties and other material specialised for jointing or fixing rails	Carbon dioxide
7303 00 – Tubes, pipes and hollow profiles, of cast iron	Carbon dioxide
7304 – Tubes, pipes and hollow profiles, seamless, of iron (other than cast iron) or steel	Carbon dioxide
7305 – Other tubes and pipes (for example, welded, riveted or similarly closed), having circular cross-sections, the external diameter of which exceeds 406,4 mm of iron or steel	Carbon dioxide
7306 – Other tubes, pipes and hollow profiles (for example, open seam or welded, riveted or similarly closed), of iron or steel	Carbon dioxide
7307 – Tube or pipe fittings (for example, couplings, elbows, sleeves), of iron or steel	Carbon dioxide
7308 – Structures (excluding prefabricated buildings of heading 9406) and parts of structures (for example, bridges and bridge-sections, lockgates, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, shutters, balustrades, pillars and columns), of iron or steel; plates, rods,	Carbon dioxide

angles, shapes, sections, tubes and the like, prepared for use in structures, of iron or steel	
7309 – Reservoirs, tanks, vats and similar containers for any material (other than compressed or liquefied gas), of iron or steel, of a capacity exceeding 300 l, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide
7310 – Tanks, casks, drums, cans, boxes and similar containers, for any material (other than compressed or liquefied gas), of iron or steel, of a capacity not exceeding 300 l, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide
7311 – Containers for compressed or liquefied gas, of iron or steel	Carbon dioxide

Aluminium

CN code	**Greenhouse gas**
7601 – Unwrought aluminium	Carbon dioxide and perfluorocarbons
7603 – Aluminium powders and flakes	Carbon dioxide and perfluorocarbons
7604 – Aluminium bars, rods and profiles	Carbon dioxide and perfluorocarbons
7605 – Aluminium wire	Carbon dioxide and perfluorocarbons
7606 – Aluminium plates, sheets and strip, of a thickness exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
7607 – Aluminium foil (whether or not printed or backed with paper, paper-board, plastics or similar backing materials) of a thickness (excluding any backing) not exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
7608 – Aluminium tubes and pipes	Carbon dioxide and perfluorocarbons
7609 00 00 – Aluminium tube or pipe fittings (for example, couplings, elbows, sleeves)	Carbon dioxide and perfluorocarbons