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Impact of Carbon Border Adjustment Mechanism (CBAM) on Textile Exports of Pakistan

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ABSTRACT

The European Union's Carbon Border Adjustment Mechanism (CBAM) marks a major change in global trade by connecting trade with emissions. This study looks at how CBAM might affect the textile exports of a developing country like Pakistan. Because there is no detailed data on individual company emissions, the analysis uses existing national and international data on trade, energy use, and carbon emissions from 2003 to 2023.

The study creates specific emissions and cost indicators for the textile industry by distributing industrial emissions and applying carbon prices similar to those in the EU Emissions Trading System (ETS). It uses a thorough empirical approach that includes descriptive analysis, correlations, checks for data stability, econometric models in both original and adjusted forms, lagged dynamic models specifications. These results are further supported by machine learning models and future scenario predictions up to 2030, along with Monte Carlo sensitivity analysis to handle the uncertainty around carbon prices and emission levels.

The study finds that, in the past, Pakistan's textile exports haven't been greatly affected by carbon intensity because there has not been carbon pricing in global trade. However, future simulations show that CBAM could change export trends significantly once carbon costs start to have a real impact, especially if carbon prices rise or enforcement becomes stricter. The results show the risk of uneven effects on developing countries and stress the need for better energy efficiency, accurate emissions tracking, and international policies that support these nations. Overall, the study offers clear insights into how carbon border policies might change trade competitiveness in the future.

Keywords: Carbon Border Adjustment Mechanism (CBAM), textile exports, carbon emissions, trade competitiveness

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CHAPTER 1

INTRODUCTION

1.1 Background

The textile industry in Pakistan is crucial for the country's economy. It contributes about 8.5% to the GDP, accounts for over half of the industrial manufacturing output, and provides jobs to more than 15 million people (State Bank of Pakistan, 2023). Textiles make up a significant portion of Pakistan's exports, with the European Union being the largest market. In 2023, exports of textiles and clothing from Pakistan to the EU-27 reached about $6.23 billion, which represents a large share of the country's total goods exports (The Textile Think Tank, 2023).

Historically, Pakistan's textile exports depended on the EU's Generalised Scheme of Preferences Plus (GSP+). This program allowed duty-free access to over 85% of tariff lines. This trade arrangement helped keep Pakistan's textiles competitive with major exporters such as Bangladesh, Vietnam, and India (European Commission, 2023).

However, global trade is changing due to new climate policies. The European Union launched the Carbon Border Adjustment Mechanism (CBAM) in 2023. This policy adds a carbon cost to imports of goods with high carbon emissions. Initially, it included products such as cement, steel, aluminum, fertilizers, and electricity, but it is likely to cover textiles as more information about carbon intensity becomes available. The CBAM ensures that imported goods bear the same carbon cost as products made in the EU to prevent carbon leakage.

For Pakistan, this presents a significant challenge. The textile industry, which includes spinning, weaving, dyeing, and finishing, relies heavily on natural gas, oil, and coal for energy. Estimates indicate that textile production contributes nearly 5% of Pakistan's total greenhouse gas emissions, primarily from energy-intensive finishing processes (Global Green Growth Institute, 2023). If a carbon price is implemented, both export and production costs will increase, which could weaken the competitiveness of Pakistan's textiles in the EU market.

1.2 Pakistan's Textile Sector: Structure and Dynamics

The sector includes the entire value chain as shown in figure 1.1:

1. **Fiber and Yarn Production:** Predominantly cotton-based, with high energy consump-

tion in spinning units.

2. **Fabric Manufacturing:** Weaving and knitting operations that contribute to both energy use and chemical emissions.

3. **Dyeing and Finishing:** Highly carbon-intensive stages where thermal and electrical energy demands are significant.

4. **Garment Production and Exports:** Focused on bed linen, knitwear, and ready-made garments for the EU market.

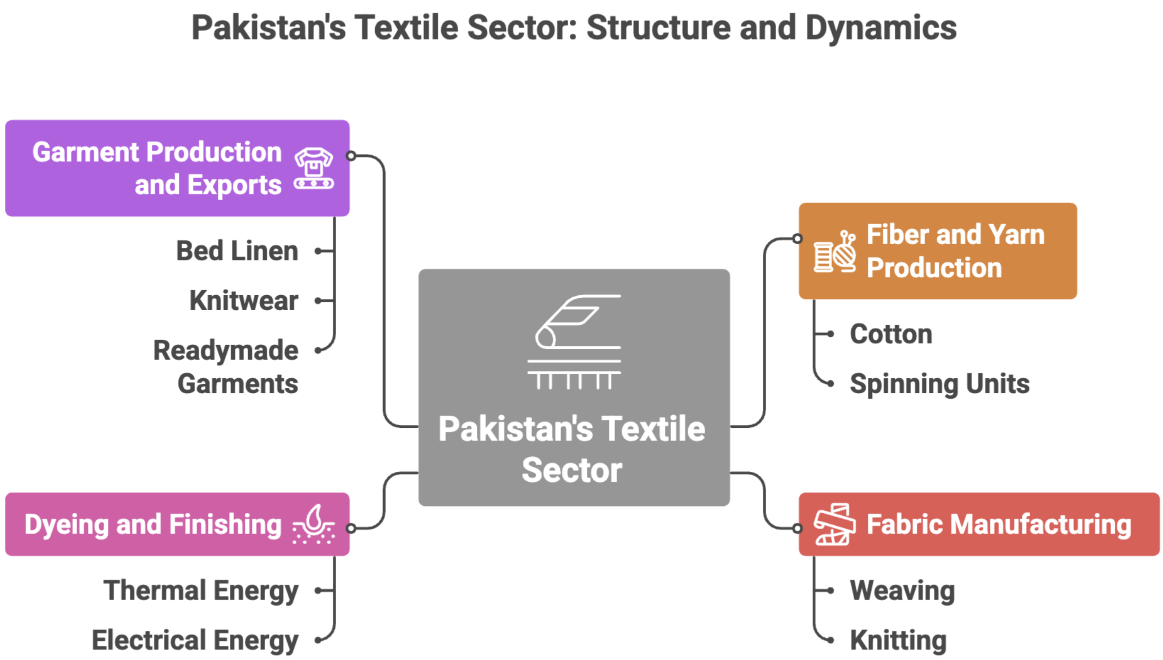


Figure 1.1: Structure and Dynamics of the textile sector in Pakistan

Despite some modernization, many textile mills still use outdated and inefficient machines and do not systematically track their carbon emissions (Pakistan Textile Exporters Association, 2023). This situation calls for the use of the Internet of Things (IoT) to improve performance. As a result, Pakistan's textile exporters face significant risks from the costs associated with complying with CBAM requirements.

The EU's CBAM is a key part of the European Union's Green Deal, which aims to help the EU achieve climate neutrality by 2050 (European Commission, 2023). Its main objective is to prevent carbon leakage, which occurs when companies relocate production to countries with less strict climate regulations. CBAM ensures that imported goods bear a carbon cost that matches the cost of producing goods within the EU under the Emissions Trading System (ETS).

Initially, CBAM targets industries that generate high emissions, such as cement, steel, aluminum, fertilizers, electricity, and hydrogen. These industries were selected because they emit large amounts of carbon and face global competition. Textiles are not yet included in this

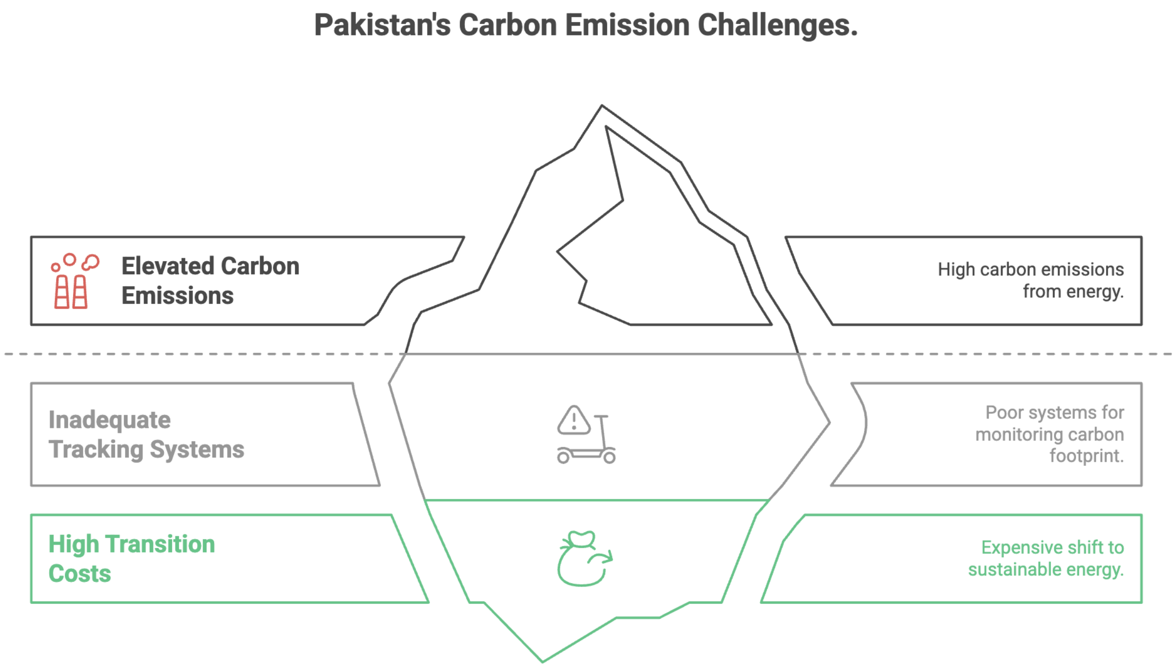


Figure 1.2: Pakistan Carbon Emission Challenges

stage but may be added in the future. This is particularly relevant for countries like Pakistan, which exports a significant quantity of textiles to the EU.

Exporters sending goods to the EU must track and report the greenhouse gas emissions associated with their products. This requires strong monitoring, reporting, and verification systems that comply with EU standards. Many developing countries, including Pakistan, encounter significant challenges in meeting these requirements due to a lack of technical skills, data systems, and appropriate institutions.

Under CBAM, EU importers must buy certificates that correspond to the carbon emissions of imported products exceeding EU benchmarks. The cost of these certificates is similar to the carbon price in the EU ETS. This means that foreign producers either incur higher costs or need to reduce their emissions to remain competitive.

The transition began in 2023, requiring only emissions reporting, with no payments involved. Starting in 2026, importers will need to pay for the certificates, making energy-intensive exports less competitive in the EU market.

For Pakistan, CBAM presents significant economic and structural challenges.The challenges associated with textile production in relevance to the CBAM are visually represented in figure 1.2. The country's energy system relies heavily on fossil fuels, resulting in industries that are highly carbon intensive. Additionally, many smaller exporters lack the infrastructure needed to measure and report emissions. To cope with these changes, Pakistan must invest in cleaner energy, enhance efficiency, and establish effective systems for tracking emissions. Without these improvements, Pakistani exports,especially in energy-intensive sectors like textiles,risk becoming less competitive and incurring higher costs in the EU market.

1.3 Literature Gap and Rationale

Most research on CBAM focuses on heavy industries such as steel, cement, and aluminum (Branger et al., 2021). However, there is limited real-world evidence on how developing countries like Pakistan will be impacted by CBAM policies. Many studies rely on theoretical models instead of actual trade and emissions data.

This study addresses that gap by combining historical trade data with proxy emissions data from global energy datasets to evaluate the actual impact of CBAM on Pakistan's textile exports.

1.3.1 Research Problem

The EU's Carbon Border Adjustment Mechanism (CBAM) seeks to curb carbon leakage by expanding trade regulations beyond sectors like steel and cement to include textiles, a key EU import. This poses significant risks for Pakistan, where 8.5 % of total GDP. Most Pakistani textile exporters lack carbon pricing, emission tracking, and recognized sustainability certifications. Government policies focus on export growth but neglect climate compliance, emission disclosure, and life cycle reporting. Additionally, there is scarce firm-level research on CBAM readiness, leaving exporters and policymakers ill-prepared to manage its compliance and financial challenges.

1.3.2 Research Questions

The main research question guiding this work is:

How will the EU's CBAM affect Pakistan's textile exports to the EU?

Sub-questions include:

1. What is the carbon footprint of Pakistan's textile production compared to national emissions?

2. How do CBAM-related factors, like cost share and emission intensity, affect export performance?

3. How can machine learning models be used to predict future exports under different CBAM scenarios?

1.3.3 Research Aim and Objectives

Aim: To quantify and predict the impact of CBAM on Pakistan's textile exports by using trade, energy, and emission data.

Objectives:

1. Conduct an exploratory analysis of trade and emissions trends from 2003 to 2023.
2. Normalize national emissions based on the textile sector's GDP share to estimate its carbon exposure.
3. Simulate CBAM costs (USD per ton of CO_2) and calculate their share of exports.
4. Test if CBAM cost share and emission intensity have a statistical impact on export volumes using correlation, regression, and t-tests.
5. To apply machine learning models (Random Forest, Gradient Boosting, ARIMA) to forecast textile exports under CBAM policy scenarios.

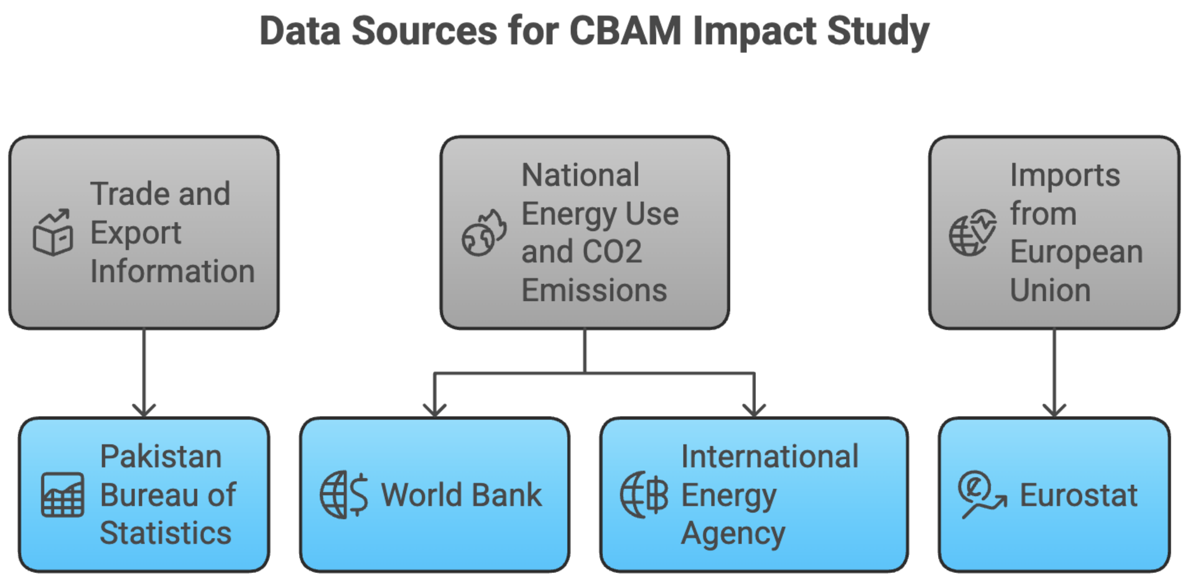


Figure 1.3: Data sources for the study. PBS, World Bank, IEA and Eurostat data were mined to gather the relevant data for the study.

1.4 Significance of the Study

This study provides quantitative critical insights into the impact of the European Union's CBAM on textile sector of Pakistan, one of the prime contributors to the country's total exports. The significance of this research can be summarized as follows:

- **Empirical Contribution:** This study is one of the first to quantitatively study the impact of CBAM on Pakistan's textile industry using trade, emissions, and energy data. It utilizes these data to understand the risks of exporting carbon related products, which helps fill a missing part in current research.

- **Policy Relevance:** The findings offer useful information for policymakers to create plans that reduce the risks from CBAM. The results can help in making decisions about policies to cut carbon emissions, support exports, and ensure compliance with international standards.
- **Industrial Insight:** By showing the possible costs of CBAM, the research helps exporters understand the financial and operational challenges they may face. It also assists industry groups in planning ways to increase carbon efficiency and maintain competitiveness in European markets.

Table 1.1: Alignment of Research Questions with Objectives

Research Questions	**Corresponding Objectives**
How will the EU's CBAM affect Pakistan's textile exports to the EU?	Conduct an exploratory analysis of trade and emissions trends from 2003 to 2023. Simulate CBAM costs (USD per ton of CO_2) and calculate their share of exports. Apply machine learning models (Random Forest, Gradient Boosting, ARIMA) to forecast textile exports under CBAM scenarios.
What is the carbon footprint of Pakistan's textile production compared to national emissions?	Normalize national emissions based on the textile sector's GDP share to estimate its carbon exposure. Conduct an exploratory analysis of trade and emissions trends from 2003 to 2023.
How do CBAM-related factors, like cost share and emission intensity, affect export performance?	Simulate CBAM costs (USD per ton of CO_2) and calculate their share of exports. Test if CBAM cost share and emission intensity have a statistical impact on export volumes using correlation, regression, and t-tests.
How can machine learning models be used to predict future exports under different CBAM scenarios?	Apply machine learning models (Random Forest, Gradient Boosting, ARIMA) to forecast textile exports under CBAM policy scenarios.

1.5 Thesis Structure

- Chapter 1: Introduction - context, motivation, and objectives.
- Chapter 2: Literature Review - theory and previous empirical work on CBAM and trade.
- Chapter 3: Methodology - datasets, variable definitions, and modeling strategy.
- Chapter 4: Results - statistical tests, regression outcomes, and forecasting.

- Chapter 5: Discussion - interpretation, sensitivity analysis, and comparison with peers.
- Chapter 6: Conclusion and Recommendations - key insights and policy actions.

1.6 Conclusion

The European Union's CBAM exemplifies how international trade rules and climate policies are converging, indicating a broader global shift toward trade practices that consider carbon emissions. CBAM ensures that the cost of carbon emissions is factored into trade between countries. This means that EU's climate policies extend beyond its borders and directly impact countries that produce high-carbon products. For Pakistan, this is particularly significant since the textile industry is crucial for the country's exports and employment. This industry relies heavily on fossil fuels and lacks robust systems to monitor emissions, making it more susceptible to the added costs associated with CBAM. Adjusting to these new regulations involves not only environmental considerations but also maintaining Pakistan's textiles' competitiveness in the EU market.

This research employs econometric analysis, scenario-based simulations, and machine learning to assess how CBAM might impact Pakistan's textile exports under various regulatory approaches. Econometric analysis identifies the connections between carbon production, CBAM compliance costs, and export performance. Simulations estimate potential regulatory costs, while machine learning models reveal complex and changing impacts that other methods might miss.

Together, these approaches provide valuable insights to assist government and industry leaders in making informed decisions. The research emphasizes the need for cleaner energy, better emission reporting systems, and more efficient technologies to avoid losing competitiveness due to CBAM. Overall, this study helps inform policies that support Pakistan's export industries in meeting new global standards focused on climate, ensuring they remain competitive in an increasingly carbon-conscious economy.

CHAPTER 2

LITERATURE REVIEW

2.1 Background: CBAM and Pakistan's Textile Sector

The European Union's Carbon Border Adjustment Mechanism (CBAM) marks a significant change in how global trade is managed by linking climate goals with trade policies. It was created to support the EU Emissions Trading System (EU ETS) by adding a cost for products imported from countries that have less strict climate rules. This is meant to stop carbon leakage, where companies move production to areas with weaker environmental rules, and to encourage cleaner production methods around the world.

For countries like Pakistan, the textile industry is especially affected by CBAM. This sector uses a lot of energy, depends mostly on fossil fuels, and typically has low profits. A large part of Pakistan's textile exports goes to the EU, making them very sensitive to changes in trade costs caused by carbon pricing. Additionally, Pakistan faces challenges such as weak institutions, limited systems for measuring, reporting, and verifying emissions (MRV), and no domestic carbon pricing. These issues make the sector more vulnerable. As a result, CBAM brings both risks and chances for change in the industry, especially in areas like improving energy efficiency, using more renewable energy, and being transparent about emissions.

2.1.1 CBAM in Global Climate Trade Governance

The European Union's CBAM represents a significant change in global trade management by putting climate issues at the heart of trade rules. It was introduced to support the European Union Emissions Trading System (EU ETS), which sets a price on carbon emissions. The main goal of CBAM is to tackle carbon leakage, a situation where companies relocate to countries with weaker environmental rules to avoid higher costs. CBAM requires importers to purchase certificates that represent the cost of carbon in the EU, effectively applying the EU's carbon price to certain imported goods. This levels the playing field between companies producing goods inside and outside the EU.

While CBAM appears to be an environmental policy, many researchers view it as a trade policy tool affecting countries outside the EU. Unlike international environmental agreements that rely on cooperation and voluntary action, CBAM reflects a single country's approach that can influence global practices, thanks to the EU's economic power. This is part of the "Brussels Effect," where European regulations shape other countries' policies as businesses and governments adjust their practices to remain competitive in the EU market. In this way, CBAM not only reduces environmental harm but also motivates other countries to adopt similar regulations, including systems for tracking emissions and implementing climate strategies.

For developing countries, CBAM presents both challenges and opportunities. Research shows that nations with weaker emissions management systems face higher costs when complying with CBAM. These costs include establishing solid systems for tracking and reporting emissions, collecting detailed information at the factory level, and managing financial costs tied to carbon pricing without government or technological support. Access to green financing and clean technologies is not uniform across the globe. This disparity can hinder companies in developing countries from meeting CBAM requirements and remaining competitive in global markets. As a result, CBAM could worsen existing inequalities in trade by increasing costs for countries with a smaller historical role in emitting greenhouse gases when exporting energy-intensive products.

Among these nations, Pakistan stands out as a particularly vulnerable case. The country's exports are primarily in the textile and clothing sector, which is energy-intensive, relies on fossil fuels, and often has low profit margins. The EU is one of Pakistan's largest trading partners, especially through trade agreements, which amplifies the impact of CBAM on its exports. Studies reveal that Pakistan lacks a clear carbon pricing system or detailed emissions data at both the company and industry levels, putting its exporters at a disadvantage compared to countries with more developed climate policies. For Pakistan's textile sector, CBAM is not just about compliance; it is a strategic issue affecting industrial policy, employment, and export earnings.

Further research suggests that CBAM's effects extend beyond immediate trade costs to influence long-term decisions regarding production and investment. The prospect of facing higher carbon costs when exporting could encourage companies to invest in cleaner technologies, enhance energy efficiency, and adopt renewable energy. However, without adequate policy support, these changes could be uneven, leading some companies to exit the industry, merge with others, or shift exports to less regulated markets. This raises concerns about whether CBAM will drive the world toward a cleaner future or alter trade patterns in ways that make it harder for developing economies to catch up.

Despite the growing body of research on CBAM, several areas remain underexplored. First, most studies focus on sectors such as steel, cement, and aluminum, which are major carbon emitters, while giving less attention to the textile industry, crucial for many developing countries. Second, many studies examine broad economic trends or partial market changes, potentially overlooking significant differences between companies based on their emissions levels, compliance abilities, and adaptability. Third, there is limited integration of trade policy with detailed insights into industrial processes, especially concerning energy systems, financing constraints, and supply chain management in developing countries.

2.2 Global Economic and Environmental Impacts of CBAM

Early research on CBAM primarily addresses its effect on international competitiveness, minimizing carbon leakage, and overall economic well-being. Much of this research uses computable general equilibrium (CGE) models, which is appropriate since the policy impacts the entire economy and interacts with trade, production, and consumption. In this context, studies by Marcu et al. (2021) and Bellora and Fontagné (2022) indicate that CBAM can help reduce carbon leakage by narrowing the cost gap between EU and non-EU producers. However, both studies note that the effectiveness of CBAM hinges on its design, particularly regarding how export rebates are handled, which sectors are included, and how the revenue from CBAM is utilized.

Their findings suggest that while CBAM may assist in reducing global emissions, it does not necessarily encourage cleaner technologies in exporting countries. Instead, emissions might decline simply because production shifts to locations with looser climate regulations rather than leading to genuinely environmentally friendly practices. This is significant, as it implies that CBAM may merely relocate emissions geographically without fundamentally changing production methods, limiting its long-term environmental benefits.

Building on this, Acar et al. (2021) examined how Turkey could be affected by CBAM. They employed a combination of CGE and input-output models to analyze the effects of different carbon pricing scenarios. Their results show small but significant negative impacts on economic well-being, slight GDP declines, and diminished export competitiveness, particularly in energy-intensive sectors such as steel, cement, and chemicals. Importantly, these negative consequences worsen as the EU's carbon price increases, illustrating how sensitive CBAM's outcomes are to changes in carbon pricing. The authors argue that without robust domestic environmental policies and technology improvements, CBAM might primarily become an additional cost for trade instead of promoting greener growth.

More detailed studies utilizing CGE models also support these conclusions. Shuai et al. (2024) focused on the steel industry using the GTAP-E model. They found that CBAM benefits the EU by protecting local producers and imposing carbon costs at the border. However, these benefits are countered by declines in GDP, reduced exports, and tougher trade terms for major steel-exporting countries like India, Turkey, and Ukraine. These uneven outcomes highlight a significant challenge in the CBAM discussion: environmental benefits may come with unfair economic burdens across different regions.

Collectively, these early studies on CBAM offer valuable lessons for future research. First, CBAM can help reduce carbon leakage if designed effectively, but it does not always lead to cleaner technology adoption in exporting countries. Second, the economic burdens of CBAM are distributed unevenly, with emerging and developing economies bearing more of the impact

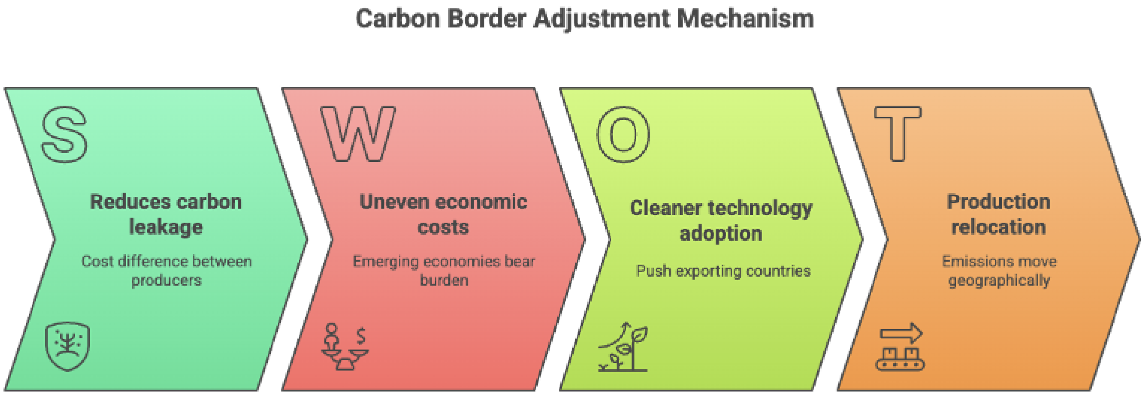


Figure 2.1: An illustration of SWOT analysis for CBAM.

due to higher carbon emissions, fewer policy options, and limited access to green technology. Third, while aggregate CGE models effectively portray large-scale effects, they may overlook key differences among companies and industries, particularly in textiles, where emissions, energy use, and profit margins can vary significantly. These limitations underscore the need for more detailed, focused studies, especially concerning the export sectors of developing countries, which have been insufficiently researched in the CBAM literature.

2.3 Developing Country Vulnerabilities and Equity Concerns

A growing body of research looks at how developing countries are at a disadvantage under CBAM due to weak institutions. Ahmed and Chatterjee (2023) point out that South Asia is especially vulnerable because of poor systems for measuring and reporting emissions, low energy efficiency, and no domestic carbon pricing. Since these countries export a lot to the EU, these weaknesses make them more exposed to CBAM costs.

Foundation for European Progressive Studies (2024) offer numbers on these risks, estimating that exporters without verified emissions data might face hidden costs of 15 to 30 percent of the product's value. These costs come from the carbon price itself, default assumptions about emissions, administrative expenses, and the uncertainty of compliance. This suggests that CBAM could act as a non-tariff barrier for companies in places with weak regulation, even if their emissions are similar to or less than those of EU producers.

Beyond economics, there's also discussion about the legal and fairness aspects of CBAM. While CBAM might be seen as a valid environmental measure, differences in how countries comply could affect fairness. This is a big concern for developing countries that get trade benefits from the EU, like through the GSP+ scheme. CBAM could reduce these benefits without breaking any trade rules.

Overall, this work shows that CBAM isn't a neutral tool but a policy with big effects on how resources and opportunities are shared. For developing countries, CBAM interacts with existing challenges like energy systems, industry structure, regulatory power, and access to

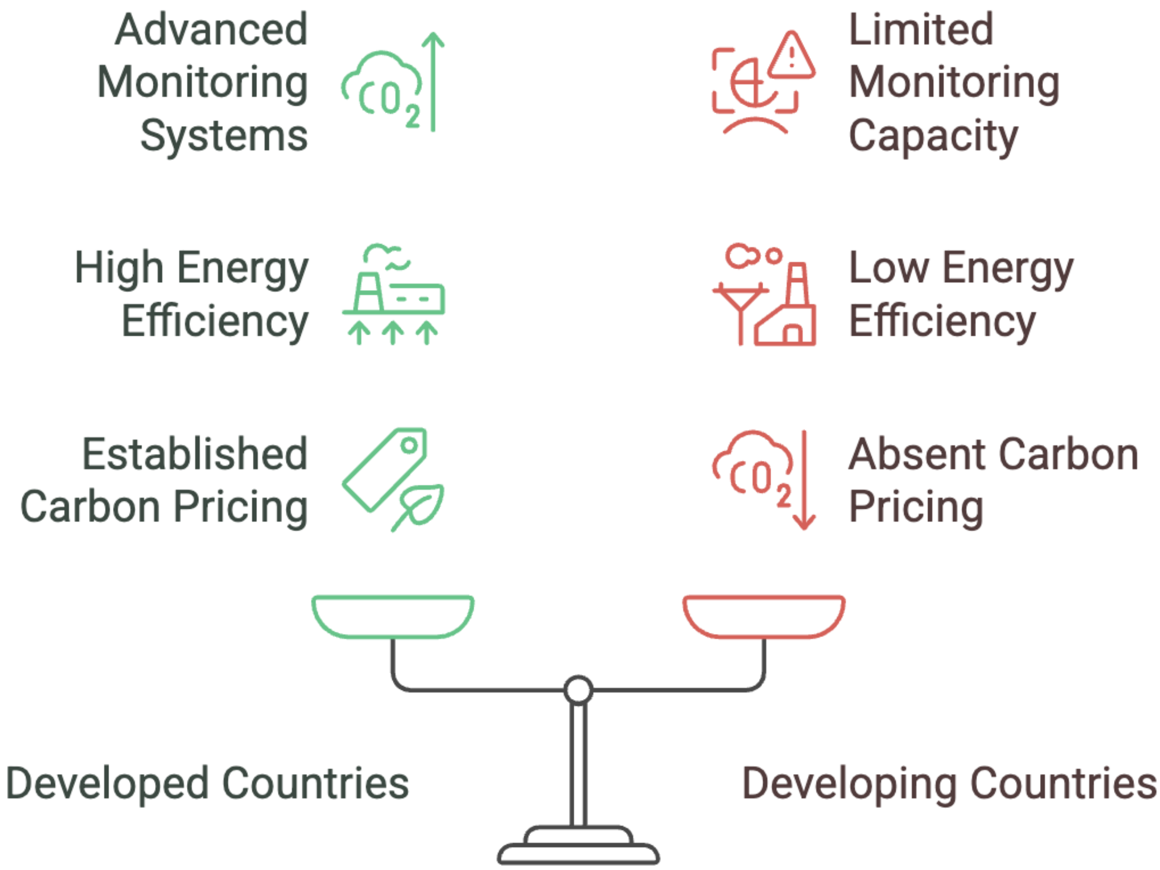


Figure 2.2: Impact of CBAM on Developing countries.

money. These interactions shape both short-term trade outcomes and long-term development. These insights are important for detailed studies, especially for countries like Pakistan, where heavy reliance on exports and weak institutions make them more exposed to CBAM's effects.

2.4 CBAM and Industrial Decarbonization Pathways

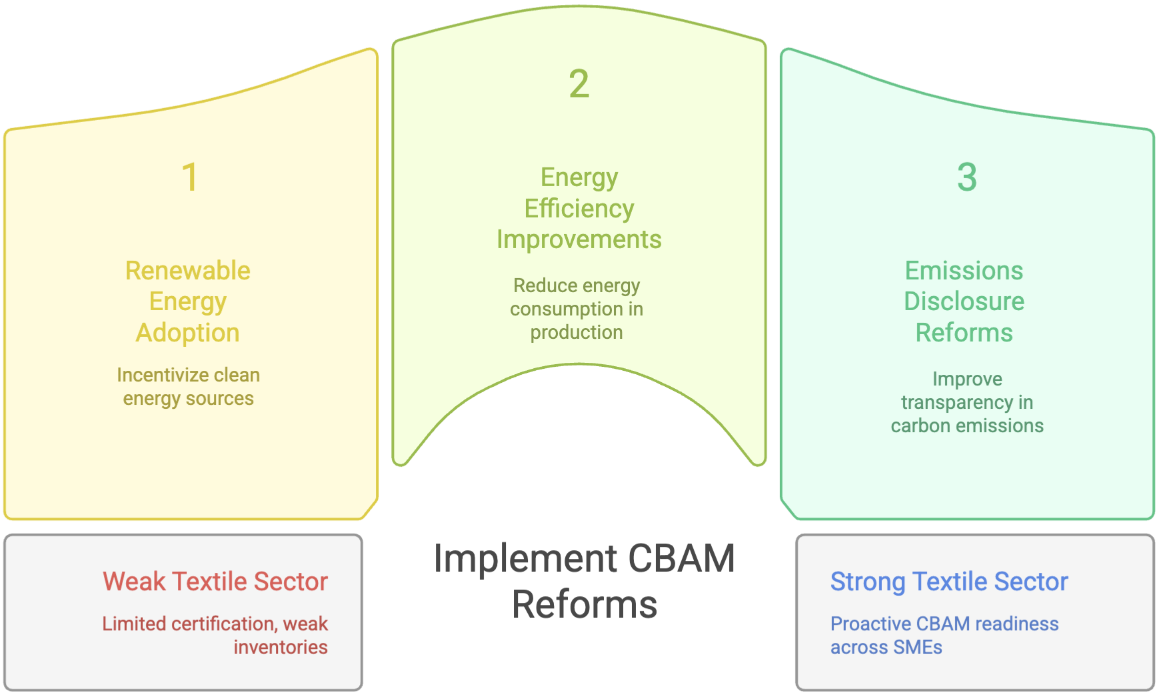


Figure 2.3: An illustration of CBAM as Industrial Transformation Catalyst

Several studies view CBAM as a catalyst for industrial transformation rather than merely a trade barrier. Acworth and Cosbey (2023) argue that CBAM incentivizes alignment between trade and industrial decarbonization strategies. Institutional reports by UNCTAD (2025), SDPI (2024), and GGGI (2024) reinforce this view in the Pakistani context, identifying CBAM as a potential driver of renewable energy adoption, energy efficiency, and emissions disclosure reforms.

Pakistan's textile sector is repeatedly identified as highly exposed. UNCTAD (2025) finds limited certification coverage and weak emissions inventories across the textile value chain. SDPI (2024) highlights a sharp divide between large exporters and SMEs, with only the former showing proactive CBAM readiness. GGGI (2024) further demonstrates that the absence of carbon markets and emissions baselines constrains compliance.

2.5 Firm Level and Cluster Based Evidence from Pakistan

Micro-level studies offer detailed insights into how ready companies are for the CBAM. Research by Khan and Ahmed (2023) and Siddiqi and Rashid (2024) shows that while some companies have environmental certifications, very few keep emissions records that match CBAM requirements. The cost of following the rules is about $10,000 each year for medium-sized mills, which is too high for small and medium enterprises.

Studies focusing on clusters by Patel and Zafar (2023) and those focusing on energy by Farooq and Latif (2024) show that using shared facilities and switching to renewable energy can greatly cut down emissions and reduce the impact of CBAM. Specifically, research on dyeing processes by Virk and Shah (2023) points out that improving water and energy efficiency is a key way to reduce emissions, with the potential to cut them by up to 60

2.6 Trade, Demand Side, and Strategic Responses

Several studies model trade outcomes under CBAM pricing scenarios. Hussain and Malik (2023) forecast export declines of 10–15% for textiles under a $60/tCO_2$ scenario, while Butt and Siddiqi (2024) show that export diversification toward lower-carbon sectors can partially offset losses.

Demand-side evidence by Rehman and Yasin (2024) suggests that EU consumers are willing to pay a premium for low-carbon textiles, indicating potential for exporters to recoup compliance costs through carbon labeling. Digital solutions are explored by Khan and Qureshi (2025), who demonstrate that emissions digitalization reduces reporting costs and improves data accuracy.

2.7 Research Gap

Systematic evidence from Zhong and Pei (2024) shows that research on CBAM is mostly focused on CGE models and pays little attention to textiles, South Asia, and firm-level predictions. Although policy reports highlight potential risks and opportunities, there is not much quantitative work that combines trade, energy, and emissions data specifically for Pakistan's textile industry.

This thesis tackles these gaps by creating an empirical framework that looks at how sensitive the textile sector is to CBAM and how it might change in the future. This framework includes real trade data, emissions intensity, and energy structure, providing backed-up information on ways to reduce the environmental impact of Pakistan's textile exports.

2.8 Theoretical Framework and Research Hypotheses

2.8.1 Theoretical Background

The theoretical basis of this study is based on trade and environmental economics. It looks at how carbon pricing and border adjustment mechanisms affect the export performance of industries that produce a lot of carbon emissions. The main idea is that the cost of carbon emissions directly influences the competitiveness of exports, especially in developing countries that do not have their own carbon pricing systems and have limited data on sector-specific emissions.

Key ideas that form the basis of this framework include:

1. **Carbon Cost Transmission Theory:** The CBAM adds a financial cost to products based on the carbon they contain. This cost might be taken by the exporters, lowering their profits, or passed on to the importers. In highly competitive sectors like textiles, it's reasonable to assume that exporters will absorb this cost in the short term.

2. **Export Performance Sensitivity to Carbon Pricing:** Export levels and values are influenced by production costs. The CBAM raises these costs, which could reduce exports from sectors that are high in carbon emissions.

3. **Sectoral Emission Intensity and Trade Linkages:** Sectors with high emissions face greater CBAM costs, which could affect their competitiveness. The connection between how much carbon is emitted and export levels is a key point of this analysis.

4. **Time Lag in Adjustment:** Companies may need time to change their production processes, adopt cleaner technologies, or alter their market strategies. To account for this, the model includes effects that occur over a period of time.

5. **Predictive and Scenario-based Assessment:** Future export performance under the CBAM depends on changes in emissions, energy efficiency, and trade costs. Using scenario and predictive modeling helps to simulate these potential outcomes.

2.8.2 Conceptual Model

The theoretical model connects the following elements:

- **Exports** ($Exports_t$) This is the dependent variable that shows how well textile sector is performing in trade.

- **CBAM Costs (CBAM_Cost$_t$)** This is an independent variable that represents the financial burden of carbon pricing.

- **Emission Intensity** ($\text{Emission\_Intensity}_t$) This is the amount of carbon emissions per unit of product.
- **Energy Use** (Energy_per_GDP_t) This serves as a proxy for energy efficiency.
- **Macroeconomic Conditions (GDP_t)** This is a control variable that shows the overall health of the economy.

The conceptual model can be written as:

$$Exports_t = f(CBAM\_Cost_t,\ Emission\_Intensity_t,\ Energy\_per\_GDP_t,\ GDP_t, \epsilon_t) \quad (2.1)$$

where ϵ_t represents other factors that might affect exports.

2.8.3 Research Hypotheses

Based on the theoretical framework, the study suggests the following hypotheses:

- **H1:** Higher CBAM costs will have a negative impact on Pakistan's textile exports to the EU.

  Rationale: These additional costs may make Pakistan's exports less competitive, possibly leading to a decrease in export volumes.

- **H2:** There will be delayed effects of CBAM costs on exports, meaning companies adjust over time and not immediately.

  Rationale: Firms need time to adapt their production methods and strategies in response to the CBAM.

2.8.4 Link to Methodology

This theoretical framework directly influences the methodological approach used in the study:

- **Variable Construction:** Emission intensity and CBAM costs are key explanatory variables.
- **Econometric Modeling:** Log-linear regression and lagged dynamic models are used to test H1 through H4.
- **Scenario Analysis:** Different scenarios, such as baseline, partial, and full CBAM, are used to evaluate sensitivity.
- **Predictive Modeling:** Forecasting under various CBAM price and energy intensity scenarios provides estimates of future impacts.

This framework ensures that the study maintains a clear connection between its theoretical foundations, empirical findings, and policy insights.

2.9 Conclusion

This chapter has looked at the growing body of research on the European Union's CBAM, placing it at the crossroads of climate policy, international trade, and industrial growth. The information shows that CBAM isn't just an environmental tool or a standard trade restriction, but a mixed policy with significant impacts on the economy, institutions, and how wealth is distributed. While studies using computable general equilibrium models show CBAM's ability to cut carbon leakage, they also show that emissions might drop because production moves from one region to another instead of because of real improvements in technology. These findings raise big questions about how effective CBAM really is in the long run and point to the possibility of unfair economic pressures, especially for countries that are still developing.

For Pakistan, and specifically its textile industry, the research shows a clear picture of high risk and low readiness. Across global models, regional policies, and firm-level studies, Pakistan is seen as vulnerable because it relies heavily on fossil fuels for energy, has weak systems for monitoring emissions, lacks domestic carbon pricing, and has a lot of small and medium-sized companies that don't have much financial or technical support. At the same time, evidence from institutions and firms suggests that CBAM could push for better industrial practices if it's backed by helpful domestic policies, access to green financing, and coordinated efforts to transition to cleaner energy. The fact that there's both risk and opportunity means that the real effect of CBAM on Pakistan's textile exports will depend more on how quickly domestic institutions, companies, and energy systems can adapt than on the policy itself.

Even though there's more research now, this chapter finds a major gap in data-driven analysis for Pakistan's textile sector. Most studies are either at the country level, missing out on differences between firms, or are qualitative, without the numbers to predict future outcomes. There's not much work that combines trade flows, emissions levels, and energy use to understand how sensitive the sector is to CBAM and how competitive it will be in the future. Filling this gap is important for going beyond general policy talks to get real, specific insights for the sector. The next chapter builds on this by creating an empirical framework that combines trade, energy, and emissions data to evaluate CBAM-related risks and paths toward reducing emissions in Pakistan's textile industry.

Table 2.1: Synthesis of CBAM Literature and Implications for Pakistan's Textile Sector

Literature Stream	**Key Findings**	**Implications for Pakistan**
Global CGE and Trade Models	CBAM reduces carbon leakage but may distort trade and shift production geographically rather than technologically.	High risk of export competitiveness loss without parallel domestic decarbonization.
Developing Country Vulnerability Studies	Weak MRV systems and absence of carbon pricing lead to implicit cost penalties and non-tariff barriers.	Pakistan faces elevated compliance costs due to limited emissions data and institutional capacity.
Legal and Equity Analyses	CBAM may comply with WTO environmental exceptions but raises fairness and procedural equity concerns.	Preferential trade benefits (e.g., GSP+) may be eroded despite formal legal compliance.
Industrial Transformation Literature	CBAM can incentivize energy efficiency, renewable adoption, and emissions disclosure reforms.	Potential pathway for textile sector upgrading if supported by policy and finance.
Firm-Level and Cluster Evidence	Large firms adapt faster; SMEs face prohibitive compliance and reporting costs.	Risk of firm exit or consolidation without targeted SME support mechanisms.
Identified Research Gap	Limited integration of trade, emissions, and energy data at sectoral and firm levels.	Necessitates empirical CBAM sensitivity and forecasting analysis for textiles.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the research methodology used to measure and predict the economic impact of the European Union's CBAM on Pakistan's textile exports. Since there is no available firm level data on emissions or costs, the analysis uses secondary data from trusted national and international sources as explained earlier in Chapter 1. This limitation requires a broader, macro and sector level approach that looks at overall export trends while aligning with the design of CBAM.

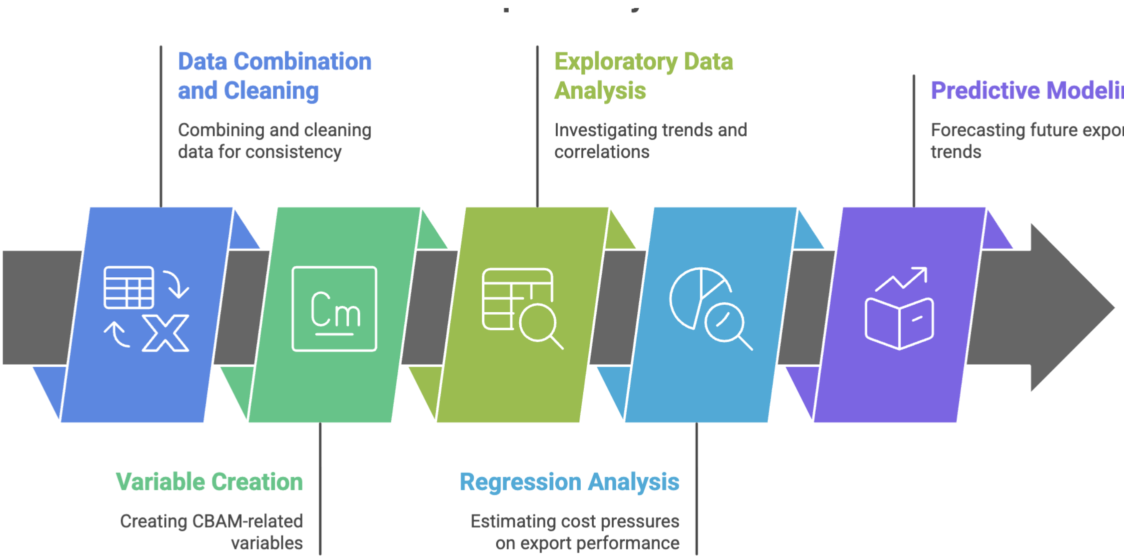


Figure 3.1: The mixed-method quantitative approach

To meet the research goals, the study uses a mixed-methods quantitative approach that includes descriptive statistics, inferential techniques, econometric modeling, and predictive forecasting. This comprehensive method allows for both understanding past connections between carbon intensity and exports and simulating future outcomes under various CBAM compliance scenarios.

The dataset used in the study is built and managed using Python programming language, which helps ensure that data integration, transformation, and analysis can be repeated and verified. This is critical for reproduce ability of the study. National-level emissions and energy use indicators are adjusted using the textile sector's share of industrial output. This adjustment ensures that the estimated carbon exposure accurately reflects the textile industry's role in Pakistan's overall industrial structure. This step is important because it provides a reliable estimate of textile related CO_2 emissions when detailed sector specific emissions data is not available.

The analysis follows a structured process with several key steps.

1. Data from trade statistics, emissions accounts, and energy databases are combined and cleaned to make sure they are consistent over time, use compatible units, and are complete.

2. CBAM-related variables such as embedded emissions, carbon costs, emission intensity, and cost shares are created to translate regulatory requirements into measurable economic factors.

3. Exploratory data analysis and hypothesis testing are used to investigate trends, correlations, and differences between high- and low-emission periods.

4. Based on these early findings, regression analysis and sensitivity tests are used to estimate the size and significance of CBAM-related cost pressures on export performance, while accounting for macroeconomic and energy-efficiency factors.

5. Predictive modeling techniques, including statistical time series methods, are used to forecast future textile export trends under different CBAM compliance scenarios. These forecasts help assess the long term effects of carbon pricing on Pakistan's ability to compete in international markets.

Overall, this methodological approach provides a strong and transparent foundation for evaluating how new climate related trade policies might affect export outcomes in carbon-intensive developing countries. By combining empirical findings with forward looking simulations, the chapter supports data driven policy decisions that aim to reduce negative impacts while promoting a shift toward lower carbon industrial production.

3.2 Research Design

The study employs a quantitative design integrating multiple techniques:

- **Descriptive Analysis:** Historical behavior of Pakistan's textile exports to the EU.

- **Inferential Analysis:** Regression and hypothesis testing to measure the significance of emissions and CBAM cost effects.

- **Predictive Modeling:** Forecasting exports under different CBAM cost scenarios using ARIMA and ensemble models.

- **Sensitivity Analysis:** Quantifying the elasticity of exports with respect to CBAM price and carbon intensity.

3.3 Data Sources

3.3.1 Trade Data

Trade data serves as the main source for understanding how much Pakistan depends on the European Union market and how the CBAM might affect its textile exports. Trade data sources used to construct the dataset are shown in figure 3.2. The Pakistan Bureau of Statistics (PBS) provides detailed monthly and yearly information on textile products grouped under HS codes 61–63, which include clothing and other finished textile items. These data help measure the amount and value of exports, as well as how these exports change over time in Pakistan's textile trade.

Eurostat data help show the European Union's side of the trade, making sure the information matches the trade flows that are important for CBAM. This helps avoid any differences that might come from just relying on data provided by exporters. Using both sources makes the data more reliable and allows checking if the export figures are accurate.

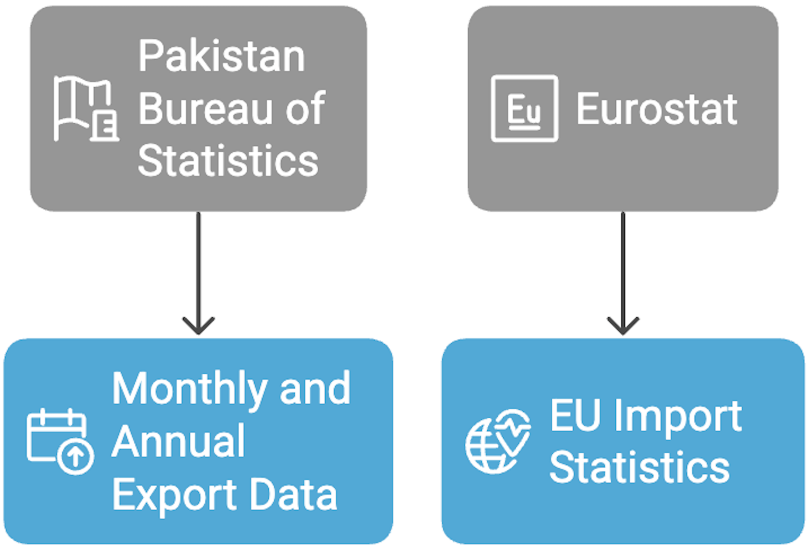


Figure 3.2: Trade Data Sources.

3.3.2 Energy and Emissions Data

Energy and emissions data are important for understanding the carbon footprint of Pakistan's textile industry and for creating data needed for CBAM. Energy and Emissions data sources used in the study are given in figure 3.3. The International Energy Agency (IEA) provides detailed data on how much energy each industry uses, which helps analyze the types of fuels

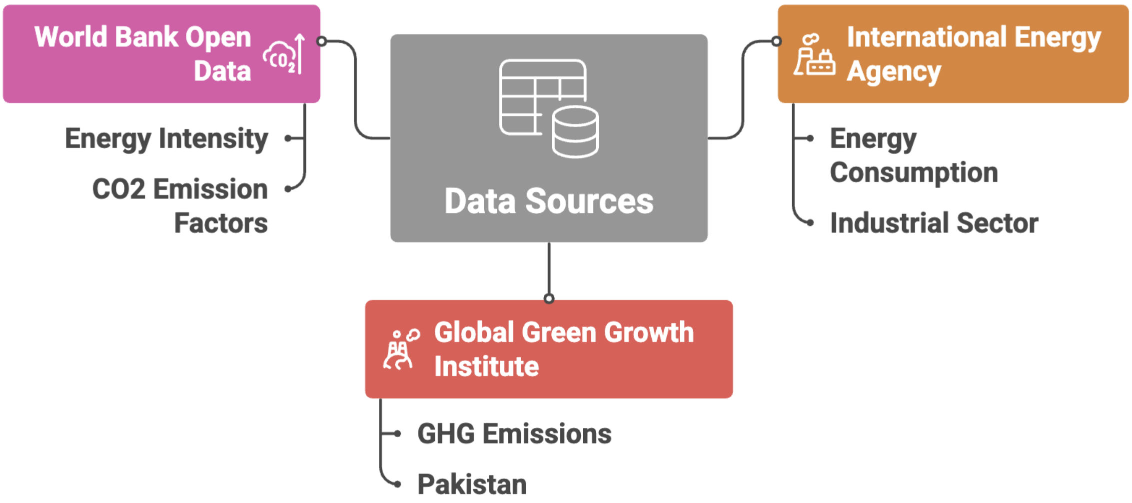


Figure 3.3: Energy and Emissions data sources.

used and how much the industry depends on energy for production. This data also helps in calculating how much energy is used for each unit of output and in identifying inefficiencies in how energy is used across industries.

The Global Green Growth Institute offers data on greenhouse gas emissions for Pakistan's industrial sectors. These data help in assigning national or industry-level carbon dioxide emissions to the textile sector, especially since there are not enough detailed records at the company or product level. This data is important for estimating the carbon exposure of the textile sector under CBAM.

The World Bank Open Data platform offers standard indicators for energy intensity and carbon dioxide emissions. These indicators are used to make emissions data consistent, allow comparisons between countries, and check the accuracy of emissions data from other sources. Together, these data sources create a reliable base for measuring carbon intensity and for estimating the costs of compliance with CBAM rules.

3.3.3 EU Policy and Price Data

European Union policies and price data form the basis for understanding how the CBAM will affect things. Information provided by the European Commission outlines the CBAM framework, including which industries are covered, what reporting is needed, and when different phases of the plan will take place. This helps ensure that any analysis done stays aligned with the rules and goals set by CBAM.

Data from the EU Emissions Trading System (EU ETS) is used to look at past trends in carbon prices. This is important because the prices of CBAM certificates are linked to the EU ETS allowance prices. These trends help predict how much and how much carbon costs might increase for non-EU exporters, like Pakistan's textile industry, if CBAM is fully implemented.

For the simulation, a CBAM price of 97.75$ per ton of CO_2 is used. This number is

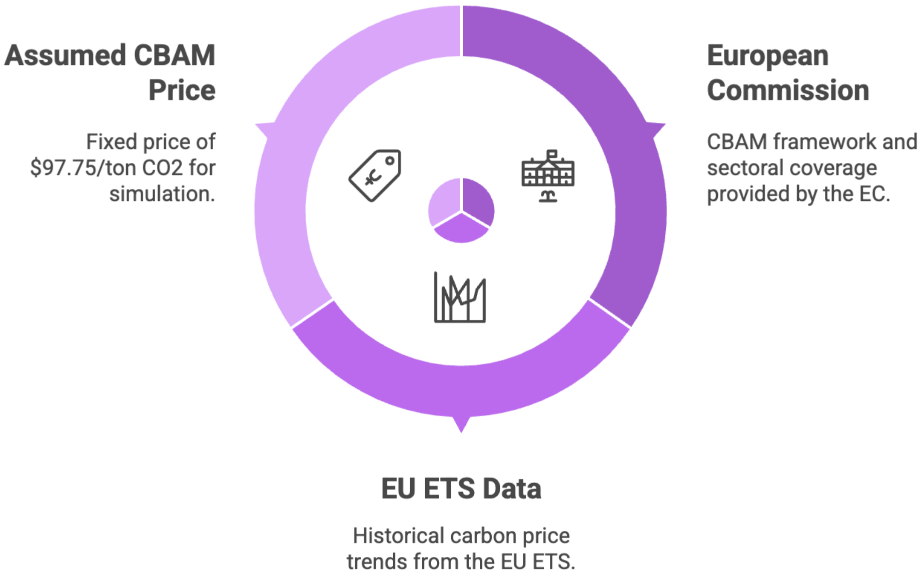


Figure 3.4: CBAM data sources.

based on recent EU ETS average prices and expectations for future prices. It serves as a realistic and consistent reference point to estimate the potential extra costs Pakistan's textile exports might face if CBAM is fully in effect.

3.4 Data Construction and Preprocessing

3.4.1 Normalization by Textile Share

Since sector-level emissions data are available only at the aggregate industrial level, textile specific emissions ($E_{\text{textile},t}$) are estimated using a proportional allocation approach:

$$E_{\text{textile},t} = E_{\text{industry},t} \times S_{\text{textile},t} \tag{3.1}$$

$E_{\text{industry},t}$ stands for the total emissions from all industries at time t, and $S_{\text{textile},t}$ shows the part of the textile industry in the total industrial production or jobs. This method uses the share of the textile sector to normalize emissions, assuming that energy use and emissions are spread out among different industries based on their economic size.

This way of normalizing helps to scale textile-related emissions from overall industrial data in a consistent manner. It avoids creating fake links or using random weights between sectors. By linking emissions to actual sector shares, this method gives a clear and repeatable way to measure carbon impact specific to the textile industry. This is important when assessing the costs linked to the CBAM, especially when detailed data on individual companies isn't available.

3.4.2 Variable Computation

Table 3.1: Definition of Variables Used in Econometric Analysis

Variable	Symbol	Definition
Exports	$Exports_t$	Total textile export value at time t (USD)
Log Exports	$\log(Export_t)$	Logarithm of textile exports
CBAM Cost	$CBAM\ Cost_t$	Estimated CBAM compliance cost at time t (USD)
CBAM Cost Share	$CBAM\ Cost\ Share_t$	Ratio of CBAM cost to total exports, $\frac{CBAM\ Cost_t}{Exports_t}$
Trade CO_2 Emissions	$Trade\ CO_{2,\text{textile},t}$	Estimated CO_2 emissions embodied in textile trade ($MtCO_2$)
Energy per GDP	$Energy\ per\ GDP_t$	Energy consumption per unit of GDP (energy intensity proxy)
Gross Domestic Product	GDP_t	Total real GDP of Pakistan (USD)
Log GDP	$\log(GDP_t)$	Logarithm of GDP
Error Term	ε_t	Stochastic disturbance term capturing unobserved factors

3.4.3 Data Cleaning and Transformation

Before starting the actual analysis, the dataset goes through several steps to make sure it's consistent, reliable, and statistically sound. Any missing data points are filled in using linear interpolation over time, which keeps the time sequence intact and helps keep important information from being lost.

To deal with extreme values that could make the results unreliable, outliers are adjusted by capping them at the 5th and 95th percentiles. This method helps reduce the effect of very high or very low values without removing any data points, which helps keep the sample size the same and makes the results more stable.

GDP and export variables are then transformed using the logarithm, written as $\log X$. This transformation helps make the data more consistent, reduces skewness, and makes it easier to interpret the results.

3.5 Analytical Framework

3.5.1 CBAM Cost Estimation

The estimated cost burden resulting from the CBAM is computed by translating textile related carbon emissions into a monetary value using the applicable CBAM carbon price:

$$CBAM\ Cost_t = E_{textile,t} \times P_{CBAM} \tag{3.2}$$

This expression defines $CBAM\ Cost_t$ as the total carbon compliance cost under the CBAM at time t. Here, $E_{textile,t}$ is the estimated amount of carbon dioxide emissions linked to textile exports, and P_{CBAM} is the carbon price used in the CBAM system. The equation assumes that all the emissions related to the product are fully subject to CBAM pricing.

To understand how this cost affects export performance, the actual export value is adjusted by taking away the estimated CBAM cost:

$$Export_{t,adj} = Export_t - CBAM\ Cost_t \tag{3.3}$$

In this case, $Export_t$ is the original value of textile exports, and $Export_{t,adj}$ is the export value after subtracting the CBAM-related costs. This adjusted measure shows how much export revenue might decrease because of CBAM compliance, assuming the exporters cover the carbon cost instead of passing it on to EU importers or end consumers.

The approach outlined depends on clear economic assumptions about how the costs linked to CBAM are shared. In the study , it is assumed that the costs of following CBAM rules are completely absorbed by the exporters, meaning that there is no extra cost passed on to the buyers in the EU or the end users. Because of this, the estimated cost $CBAM\ Cost_t$ directly lowers the revenue from exports, which is shown in the adjusted export value $Export_{t,adj}$.

This assumption works well in a short term situation where exporters have limited ability to raise prices in very competitive global textile markets and can't fully pass on extra costs to their customers. Therefore, this represents a cautious way of looking at how negative CBAM could be for export results.

To check how reliable the results are, we can look at other situations where only part of the cost is passed on. In these cases, exporters take on only a part $\theta \in [0, 1]$ of the CBAM cost, while the rest $(1 - \theta)$ is passed on to importers through higher prices. Even though this isn't included in the main equations, this setup lets us adjust the real cost burden by using the pass-through factor, making it easier to check how different market setups and power balances affect things.

3.5.2 Econometric Model

The baseline regression model is designed to examine how textile export performance relates to carbon emissions, energy use, and the costs linked to the CBAM. By using a log-linear model, the results can be interpreted as elasticities or semi-elasticities, making it easier to understand the economic meaning of the findings.

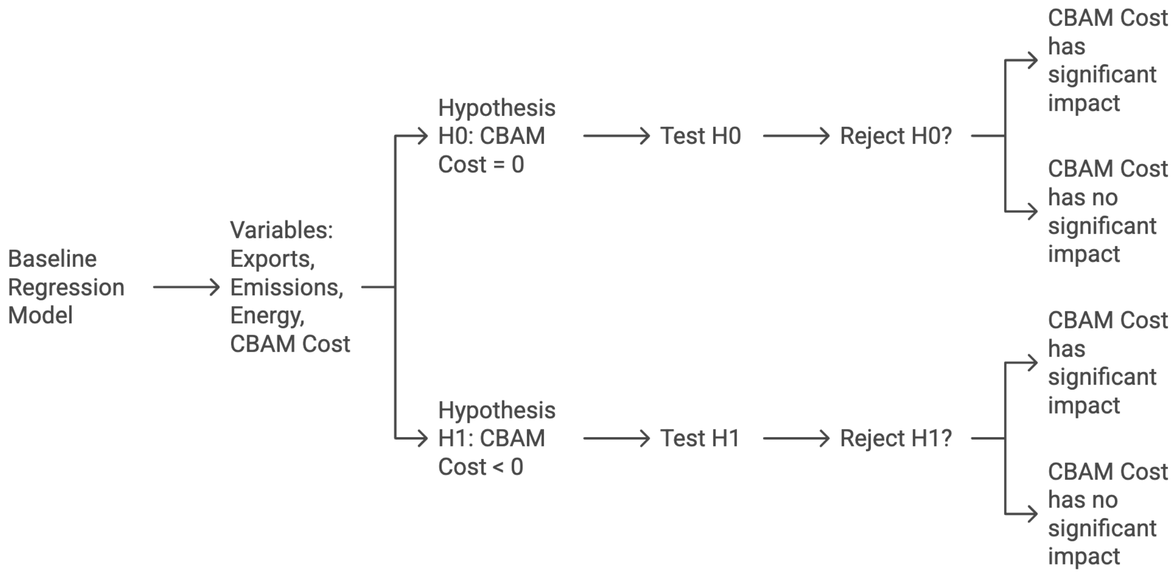


Figure 3.5: Econometric Model and Hypothesis Testing framework.

$$\begin{aligned}\log(\text{Exports}_t) = \beta_0 + \beta_1 \log(\text{Emission Intensity}_{\text{textile},t}) \\ + \beta_2 \text{Energy Per GDP}_t + \beta_3 \log(\text{GDP}_t) \\ + \beta_4 \text{CBAM Share of Exports}_t + \epsilon_t\end{aligned} \tag{3.4}$$

The error term ϵ_t includes other factors that may influence export performance but aren't directly measured.

The main focus of the analysis is on the coefficient β_4, which shows how much CBAM-related costs impact textile exports after considering all other variables. If β_4 is negative, it means higher CBAM costs could lead to lower export volumes or values.

We test the following hypothesis:

- **H0:** $\beta_4 = 0$ CBAM cost has no significant impact on textile exports.
- **H1:** $\beta_4 < 0$ Higher CBAM cost reduces textile exports to the EU.

If the null hypothesis is rejected in favor of the alternative, it suggests that the costs from CBAM are harming Pakistan's textile exports. This would support the idea that carbon pricing can influence trade in countries that produce a lot of carbon-intensive goods.

3.5.3 Extended Model with Lagged Effects

To handle possible delays in how emissions intensity, energy use, and CBAM related costs affect export performance, a dynamic model using lagged variables is used. This modeling framework takes into account that companies might take time to change their production, pricing, and market strategies after facing new regulatory costs or energy limitations..

$$
\begin{aligned}
\log(\Delta\text{Exports}_t) = \beta_0 + \beta_1 \log(\text{Emission Intensity}_{\text{textile},t}) + \beta_2\text{Energy Per GDP}_t \\
+ \beta_3 \log(\text{GDP}_t) + \beta_4\text{CBAM Share of Exports}_t \\
+ \beta_5 \log(\text{Emission Intensity}_{\text{textile},t-1}) + \beta_6\text{Energy Per GDP}_{t-1} \\
+ \beta_7 \log(\text{GDP}_{t-1}) + \beta_8\text{CBAM Share of Exports}_{t-1} + \epsilon_t
\end{aligned} \tag{3.5}
$$

In this model, the co-variates from the previous period are added to the model to incorporate the delayed effects. The parameter β_8 shows how CBAM costs from the last period impact exports now. This dynamic approach helps reduce issues from simultaneous influences and provides insight into how exporters adjust in the short term when dealing with carbon pricing. A statistically significant and negative value for β_4 would suggest that CBAM costs at time t have a negative impact on textile exports.

3.6 Hypothesis Testing and Exploratory Data Analysis

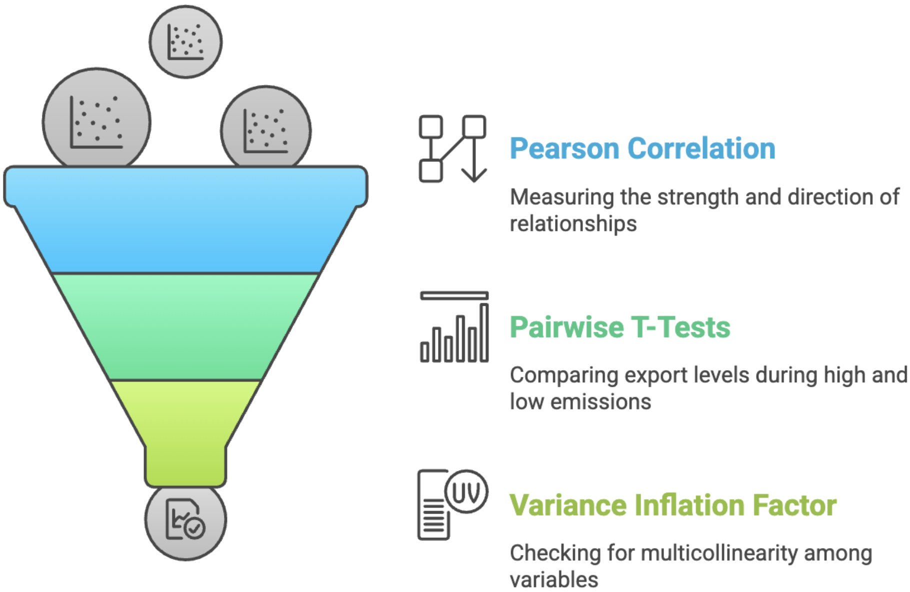


Figure 3.6: Exploratory Data Analysis and Hypothesis Testing.

Extensive statistical checks are done to examine as how exports, emissions, and carbon costs are connected, and to make sure the later regression results are reliable.

First, Pearson correlation coefficients are used to measure how strongly and in what direction exports, emissions, and carbon costs are linked. This helps to see if there are strong connections or if some variables might be too similar, which could cause problems in the analysis.

Next, pairwise t-tests are used to compare the average export levels during times with high emissions versus low emissions. This helps to check if exports change significantly depending on emission levels, which might show how sensitive exports are to carbon-intensive production.

Lastly, the Variance Inflation Factor (VIF) is calculated for each of the variables to check for multicollinearity. If VIF values are low, it means the variables are not too closely related, which helps ensure that the results from the regression models are clear and dependable.

3.7 Scenario and Sensitivity Analysis

To assess how the CBAM might affect Pakistan's textile exports, three different policy situations are considered. These situations show different levels of CBAM implementation and help understand both the usual export performance and how sensitive exports are to carbon related costs.

$$\text{Baseline: } Export_t^{(0)} = Export_t \tag{3.6}$$

$$\text{Partial CBAM: } Export_t^{(1)} = Export_t - 0.5CBAM\ Cost_t \tag{3.7}$$

$$\text{Full CBAM: } Export_t^{(2)} = Export_t - CBAM\ Cost_t \tag{3.8}$$

In the baseline scenario, it is assumed that CBAM costs do not affect exports, acting as a standard reference point. The partial CBAM scenario assumes only half of the carbon cost is applied, showing a case where there is partial compliance or some cost is passed on to consumers. The full CBAM scenario applies the full estimated carbon cost, showing the maximum possible effect on exports if all rules are strictly followed.

To quantify the sensitivity of exports to CBAM pricing, the elasticity of exports with respect to the carbon price is computed as:

$$\eta_t = \frac{\partial Export_t}{\partial P_{CBAM}} = \frac{Export_t^{(2)} - Export_t^{(1)}}{P_{CBAM}^{(2)} - P_{CBAM}^{(1)}} \tag{3.9}$$

Here, η_t shows how much exports change in response to a change in the CBAM price. This helps decision-makers and analysts see how export values might change with different levels of carbon pricing. A higher η_t means exports are more sensitive, pointing out which industries or times might face more challenges due to carbon cost pressures.

3.8 Predictive Modeling Framework

Although the core analysis of this study is econometric, predictive modeling is implemented to enhance robustness and generate future insights for policy analysis. These models allow simulation of textile export performance under varying levels of CBAM implementation and energy intensity scenarios.

3.8.1 Model Inputs

The predictive models utilize the following input vector at time t:

$$\mathbf{Z}_t = \left[\log(\text{Emission Intensity}_{\text{textile},t}),\ \text{Energy Per GDP}_t,\ \text{CBAM Share of Exports}_t,\ \log(\text{GDP}_t)\right] \tag{3.10}$$

This vector captures both carbon exposure and macroeconomic factors influencing export performance.

3.8.2 Forecast Models

1. Linear Regression Forecast with Lasso: A simple multivariate linear regression is applied to predict future export values, along with Lasso Penalty. This model provides a baseline forecast and allows direct interpretation of the marginal effects of each explanatory variable.

2. ARIMA Time-Series Model: To capture serial dependence and trends in export data, an autoregressive integrated moving average (ARIMA) model is specified as:

$$\begin{aligned} Exports_t &= \beta_0 + \beta_1\,\text{EmissionIntensity}_t + \beta_2\,\text{EnergyPerGDP}_t + \beta_3\,\ln(\text{GDP}_t) \\ &\quad + \beta_4\,\text{CBAMShare}_t + \phi_1 Y_{t-1} + \theta_1 \varepsilon_{t-1} + \varepsilon_t, \end{aligned} \tag{3.11}$$

This model forecasts exports based on past values and residual dynamics, which is useful for short-term prediction.

3. Machine Learning Models: Machine learning models such as Random Forest are trained on the input vector $\mathbf{Z}_t$ to predict $\hat{Exports}_{t+h}$. These models capture nonlinear interactions between emissions, energy use, carbon costs, and exchange rate effects. Performance is benchmarked using Root Mean Squared Error $RMSE$, Mean Squared Error MSE and Mean Absolute Error MAE scores.

$$\text{MSE} = \frac{1}{T}\sum_{t=1}^{T}(y_t - \hat{y}_t)^2 \tag{3.12}$$

$$\text{RMSE} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}(y_t - \hat{y}_t)^2} \tag{3.13}$$

$$\text{MAE} = \frac{1}{T}\sum_{t=1}^{T}|y_t - \hat{y}_t| \tag{3.14}$$

where $\hat{y}$ is the predicted and y is the true quantity of interest.

Apart from these we also use **Support Vector Machines** (SVM) and **K-Nearest Neighbors** (KNN) for predictive modeling. For all models we use data till 2016 for training and afterwards for testing.

3.8.3 Model Evaluation

Model performance is assessed using standard metrics and validation procedures:

- RMSE, MAE, and MSE are the core metrics to evaluate prediction accuracy.
- Time series cross-validation to ensure robustness over different temporal segments.
- Comparison of predicted export values under Baseline and CBAM scenarios to quantify the potential economic impact of carbon pricing.

These predictive models complement the econometric analysis by providing dynamic, forward looking estimates of export performance under alternative policy and energy scenarios, enabling policymakers to assess potential risks and mitigation strategies.

3.9 Validation and Limitations

3.9.1 Validation

To make sure the analysis is reliable and trustworthy, we use several ways to check our results:

- **Historical back-testing:** We compare the model's predictions with actual export data.This helps us see if the model can correctly show past trends and seasonal changes in textile exports.

3.9.2 Limitations

There are some limitations which must be noted:

- **Indirect emission estimates:** Since there's no specific data for the textile sector, we use proportions from total industrial emissions. This might lead to some errors because it's an estimate.
- **Fixed CBAM price assumption:** We used a constant CBAM price of $97.75 per ton of CO_2. This might not reflect future price changes or shifts in the EU ETS, which could affect the accuracy of our cost predictions.
- **Absence of firm-level data:** We don't have detailed information from individual companies, so we can't look at differences between exporters. This limits how detailed our analysis can be.

3.10 Ethical Considerations

The research follows ethical guidelines:

- **Data privacy:** All the data we used is publicly available and has been anonymized to protect any personal or sensitive information.
- **Reproducibility:** Our analysis is fully reproducible using a clear and open Python workflow. This includes how we prepared the data, built variables, and ran our models.
- **Proper attribution:** We have properly cited all the data sources, methods, and related studies to maintain academic honesty and give proper credit.

3.11 Conclusion

The proposed method offers a clear, data-based way to look at how the EU CBAM might affect Pakistan's textile exports. By making emissions specific to the textile sector, building consistent CBAM cost measures, and using regression, sensitivity, and predictive models, the chapter forms a solid base for the results and discussions that follow. This approach lets us both look back at past effects and imagine future scenarios, giving valuable help to policymakers and industry leaders aiming to handle the economic effects of carbon border adjustments.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the findings from this study that investigates how the European Union's CBAM might affect Pakistan's textile exports. The analysis is based on the methodological approach explained in Chapter 3 and uses secondary time-series data from 2003 to 2023.

The chapter is divided into several sections. First, descriptive statistics are used to give an overview of the main features of the data. This includes averages, spread, and trends in economic factors. These statistical summaries help in understanding the initial performance of Pakistan's exports and the level of carbon-related costs they face.

Next, correlation analysis is done to look at how the main variables are connected. Special attention is given to how carbon intensity relates to the value of textile exports, as well as how the explanatory variables might be linked together. This step gives early clues about the direction and strength of these relationships before running formal statistical models.

Then, stationarity analysis is carried out using unit root tests to check the time series properties of the data. It is important to know the order of integration for each variable to prevent incorrect regression results and to decide on the best model to use, whether it's first differences or long-term relationships.

After that, regression models are estimated to measure the impact of CBAM related costs on Pakistan's textile exports. The models take into account important macroeconomic factors like exchange rates, energy prices, and international demand. The results are checked for statistical significance and economic importance.

A formal hypothesis test is also done to see if the carbon cost burden caused by CBAM has a statistically significant effect on the performance of Pakistan's textile exports. The null and alternative hypotheses are tested using standard significance levels to make sure the findings are reliable.

Predictive modeling is performed using Lasso Linear Regression, K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Random Forests Regressor (RF). The predictive modeling is performed to predict the textile exports for the future and connect this with the CBAM costs. This is essential as it will allow us to examine the effect into future and devise relevant action plans accordingly.

Finally, a Monte Carlo based sensitivity analysis is performed to check how stable the results are under different carbon price scenarios and with uncertainty in the parameters. This method helps assess how changes in assumed CBAM carbon prices and carbon intensity levels might affect export outcomes. Where relevant, the findings are discussed in the context of Pakistan's industrial energy structure, which relies heavily on fossil fuels, and its possible future competitiveness under carbon-based trade rules.

4.2 Descriptive Statistics and Exploratory Data Analysis

Table 4.1 shows the descriptive statistics for the main variables used in the analysis from 2003 to 2023. These statistics give an initial look at Pakistan's textile export performance, carbon emissions, and the possible costs linked to the CBAM.

Table 4.1: Descriptive Summary of Key Variables (2003–2023)

Variable	Mean	Std. Dev.	Min	Max
Exports (USD)	5.18e+06	1.72e+06	2.65e+06	9.12e+06
Trade CO_2 (Mt)	16.47	5.73	2.92	25.39
Textile Emissions (Mt)	8.89	3.09	1.58	13.71
CBAM Cost (USD)	8.69e+08	3.02e+08	1.54e+08	1.34e+09
CBAM Share of Exports (%)	168.75	39.23	58.15	231.63
Emission Intensity (t/USD)	1.73	0.40	0.59	2.37
Energy per GDP	8.08e+04	3.70e+05	0.51	1.70e+06
GDP (USD)	8.78e+11	3.05e+11	1.60e+10	1.32e+12

The export value data show an average annual textile export value of about USD 5.18 million, but there is a lot of variation over the years. The lowest and highest values show times when exports were weak and when they grew strongly, showing that the textile sector in Pakistan is affected by cycles and policies.

Textile-related emissions make up a big part of total trade emissions, averaging 8.89 million tonnes, which shows that textile production in Pakistan is carbon heavy. The estimated costs related to CBAM are very high, with an average of about USD 869 million and peaks over USD 1.3 billion. The large standard deviation means these costs are very sensitive to changes in emissions and assumed carbon prices. When compared to export values, CBAM costs average nearly 169 percent, suggesting that the carbon-adjusted cost could sometimes be more than the total export revenue in certain years.

Emission intensity, measured as tonnes of CO_2 per unit of export value, has a mean of 1.73 t/USD with a high upper limit. This shows that the textile industry is not very energy efficient and still uses a lot of carbon-intensive energy sources. Energy use per unit of GDP has a very wide range, showing structural inefficiencies and unstable energy consumption in industry. This pattern is in line with an energy system that faces supply limits, price changes, and limited use of renewable energy technologies.

Finally, GDP figures give important background on the overall economy, showing big changes in economic size over the years. Including GDP as a control variable is important to separate the effects of CBAM from general economic growth.

Overall, the descriptive statistics show that Pakistan's textile exports are highly affected by carbon based trade measures.The costs related to CBAM could be a major challenge for export competitiveness unless there are improvements in emission intensity and energy efficiency.

4.2.1 Exports over Time

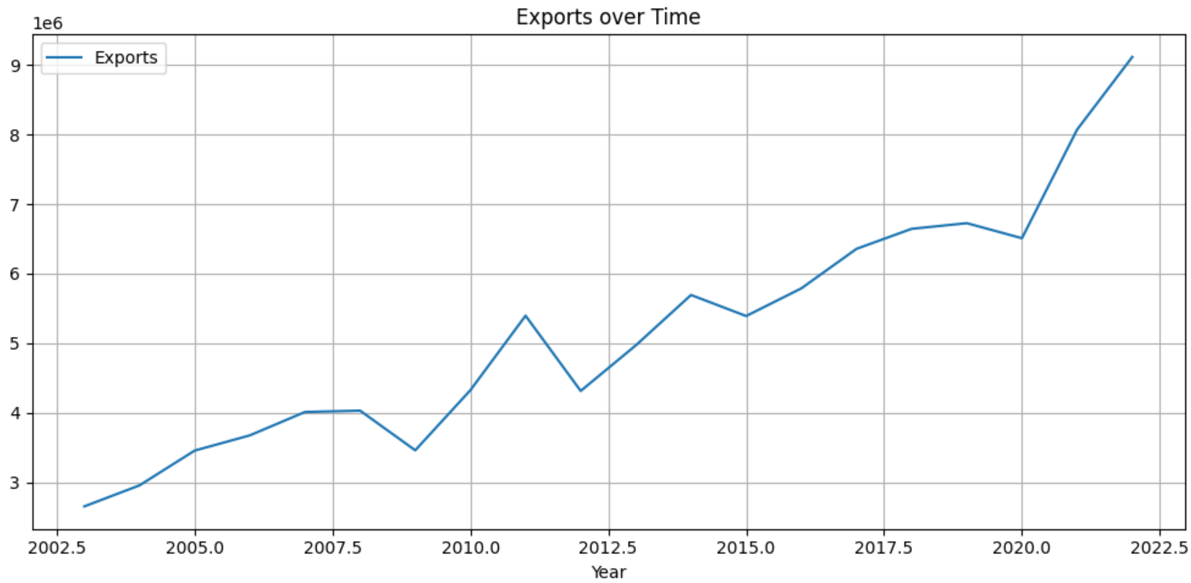


Figure 4.1: Pakistan's Textile Exports over time.

Figure 4.1 shows how export performance has changed over time, highlighting a long-term upward trend with some short-term ups and downs. After 2016, the growth rate picks up, which suggests the country is becoming more connected to global supply chains. It's important to note that as exports increase, the total cost of CBAM liabilities also rises, even if the amount of emissions per unit of goods stays the same. This creates a tricky situation: boosting exports without reducing emissions makes the country more exposed to trade losses caused by CBAM.

Therefore, to stay competitive in trade systems that are focused on reducing carbon emissions, any growth in exports needs to be matched with quick improvements in how much emissions are produced per unit of goods.

4.2.2 CBAM Cost over Time

Figure 4.2 shows how total CBAM compliance costs have changed over time. The general rising trend is due to higher export levels and more emissions linked to goods, along with higher estimated carbon prices.

Short-term drops, like in 2009 and 2020, happened during major global events,like the financial crisis and the pandemic,when trade activity slowed down. The big rise after 2014 suggests a stronger connection to carbon pricing, probably because of more trade with the EU and not enough progress in reducing emissions from production.

This shows that CBAM costs aren't just fixed charges; they change as trade increases and as industries adopt,or don't adopt,new technologies.

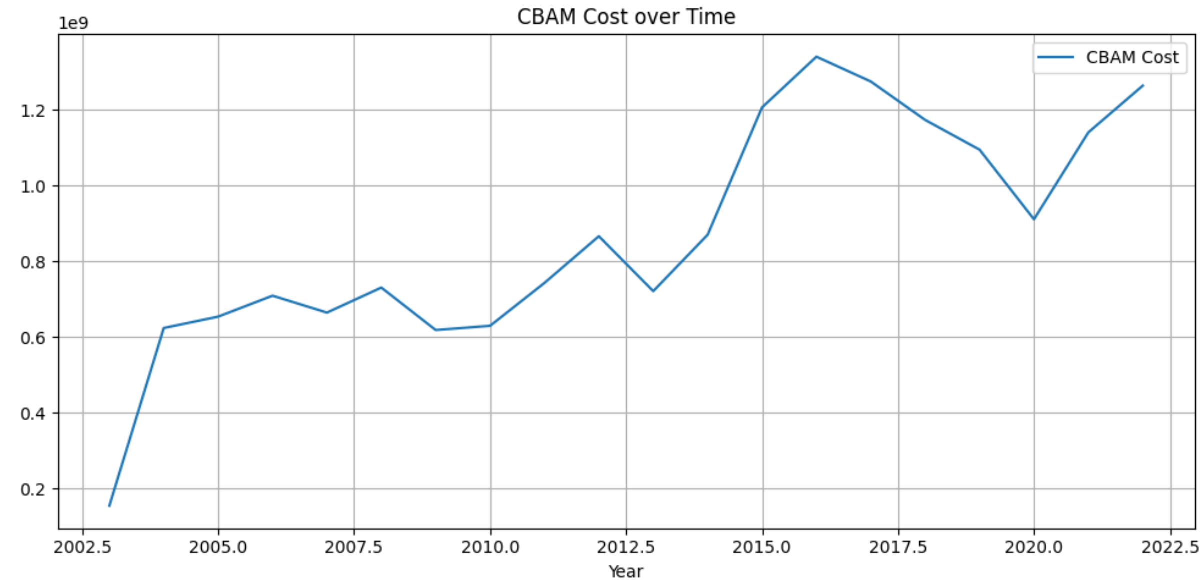


Figure 4.2: CBAM Costs over Time.

4.2.3 Emission Intensity over Time

Figure 4.3 shows how emission intensity, measured as tons of CO_2 per dollar of exported goods, has changed over time. The data shows big ups and downs, which are linked to changes in the types of energy used, the technologies involved in production, and the mix of industries involved.

When emission intensity goes up, it usually means there's a period of industrial growth that's relying heavily on fossil fuels. When it goes down, it could be because there's some improvement in efficiency or a shift toward producing goods with less carbon impact. However, there isn't a steady long-term decline, which suggests that efforts to reduce carbon emissions haven't kept up with the increase in production.

From the perspective of the CBAM, this ongoing variation in emission intensity means that businesses are at risk of facing higher costs due to carbon pricing in the long run. This

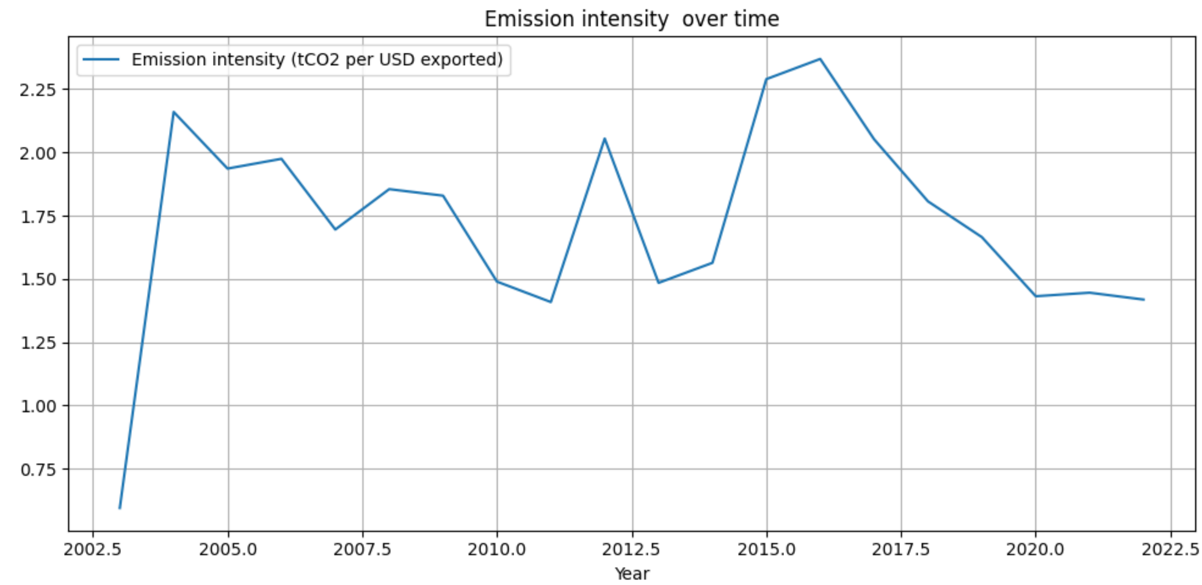


Figure 4.3: Emission Intensity over time.

supports the idea that the CBAM encourages big-scale changes in how industries operate rather than just small improvements in efficiency.

4.2.4 Correlation Structure of Key Variables

Figure 4.4 shows the correlation matrix between exports, CBAM costs, emission intensity, energy intensity, and GDP. A few important economic patterns are clear.

Exports are closely linked with GDP ($\rho = 0.96$), which makes sense because as an economy grows, its trade activity usually increases. CBAM costs are also closely connected to both exports ($\rho = 0.81$) and GDP ($\rho = 0.86$), showing that bigger economies face higher CBAM costs in absolute terms.

Energy intensity decreases as GDP and exports rise ($\rho = -0.66$ and $\rho = -0.63$), which aligns with the idea that wealthier economies become more efficient in their energy use. Emission intensity has a weak link with GDP, meaning that the overall size of the economy plays a bigger role in determining CBAM costs than improvements in efficiency.

In general, the matrix shows that CBAM costs are mostly influenced by the size of the economy and its level of trade activity, rather than by short-term efficiency improvements.

4.2.5 Unit Root and Stationarity Tests

Before estimating the model, the time-series characteristics of the main variables were checked using the Augmented Dickey–Fuller (ADF) test to determine if they are stationary. The ADF test checks whether there is a unit root, which means the series is not stationary, against the idea that the series is stationary.

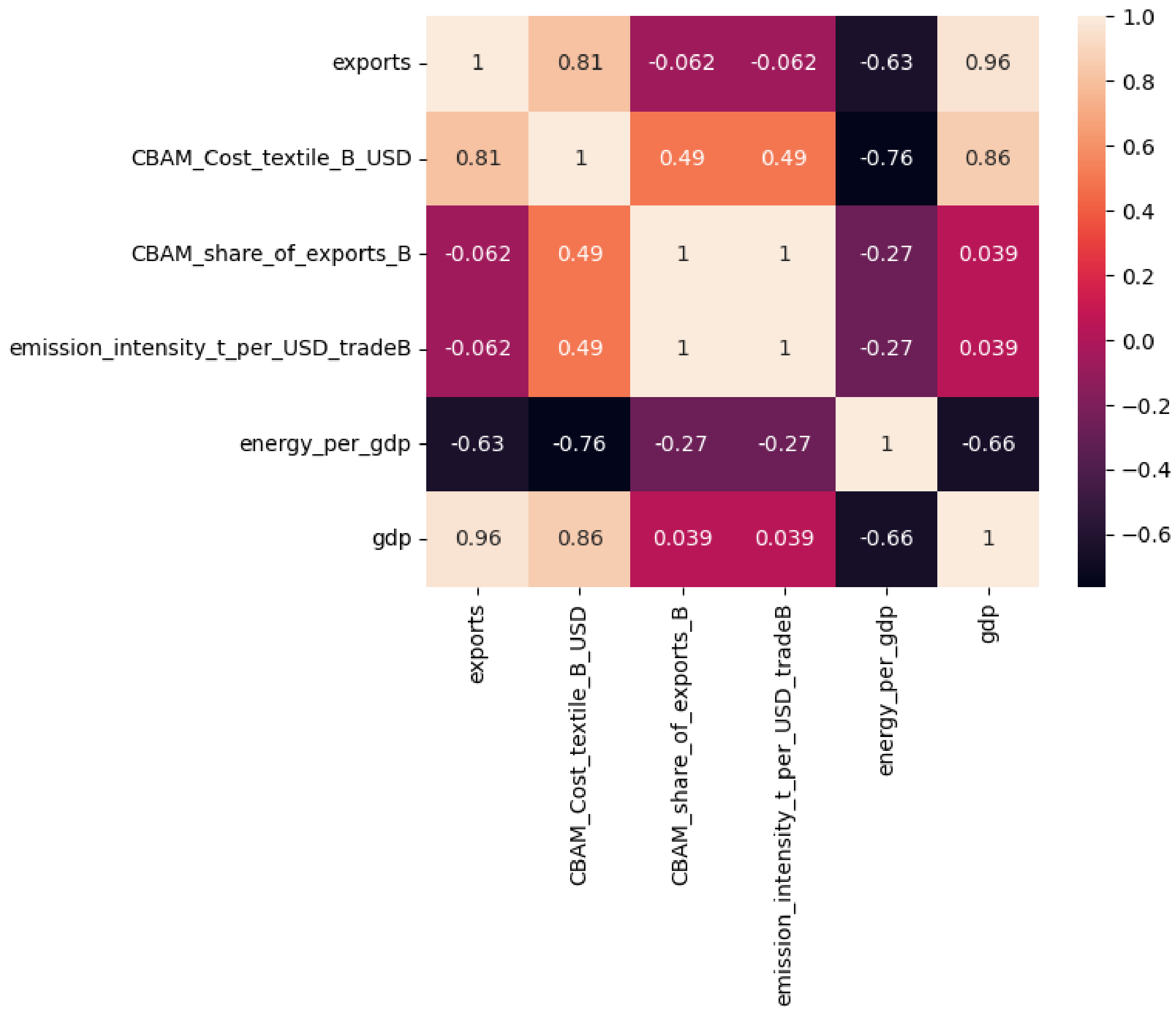


Figure 4.4: Correlation between the key modeling variables.

Log of Exports

For the logarithm of exports, ln(Exports), the ADF test statistic is -0.372, with a corresponding p-value of 0.915. This test statistic is much smaller in absolute value than the critical values at the 1%, 5%, and 10% significance levels, which are -4.138, -3.155, and -2.714, respectively.

As a result, we cannot reject the null hypothesis of a unit root at any standard significance level. This means that ln(Exports) is not stationary in levels and has a long-term random trend. In economic terms, this matches the behavior of export series that grow over time because of factors like trade liberalization, market expansion, and economic growth.

CBAM Costs

On the other hand, the ADF test for the CBAM costs, ln(CBAM), gives a test statistic of -12.917, with a p-value that is effectively zero ($p < 10^{-23}$). This statistic is much lower than the critical values at the 1%, 5%, and 10% levels, which are -4.223, -3.189, and -2.730, respectively.

This leads to the rejection of the null hypothesis of a unit root, indicating that ln(CBAM) is stationary in levels. This suggests that CBAM-related costs vary around a stable average and do not follow an unbounded random trend during the studied period.

Implications for Econometric Modeling

The different stationarity properties of these two series have important consequences for modeling. The non-stationarity of ln(Exports) means that using this variable in its original form in regressions might lead to misleading results unless cointegration is considered. In contrast, the stationarity of ln(CBAM) allows it to be used directly in regression models without transformation.

Based on these results, the following models either use the first differences of ln(Exports) or incorporate cointegration techniques to ensure accurate statistical analysis.

Test Specification

The ADF regressions used optimal lag lengths chosen based on information criteria to account for serial correlation. The reported results are reliable across different lag specifications. The tests were performed using $scipy$ library in python.

4.2.6 Descriptive Evidence: Emission Intensity and Export Levels

As part of a broader descriptive analysis, we look at whether there is a consistent difference in export levels between periods with high and low emission intensity. We split the data based on the median of emission intensity, measured as tons of CO_2 per dollar of trade. This creates two groups of equal size: one representing more carbon-intensive export periods and the other representing less carbon-intensive ones.

Let $Ex\bar{p}orts_H$ and $Ex\bar{p}orts_L$ represent the average exports in the high and low emission intensity groups, respectively. We test the null hypothesis:

$$H_0 : Ex\bar{p}orts_H = Ex\bar{p}orts_L$$

against the alternative that the means are different. Because the variability between the groups could be different, we use Welch's t-test, which doesn't assume equal variances.

Results

The median emission intensity is 1.751. Each group has 10 observations. On average, exports in the high-emission group are lower than in the low-emission group, with means of 4.61 million and 5.75 million, respectively. This difference suggests something about the data, but it isn't statistically significant. The Welch t-statistic is -1.54 with a p-value of 0.144, which means we can't reject the idea that the average export levels are the same at common significance levels.

Interpretation and Link to CBAM

The lack of a significant difference suggests that emission intensity alone doesn't directly affect export levels. This finding can be cross examined with the regression results, where emission intensity may have a limited impact once we considered economic scale and policy factors.

It's worth noting that this descriptive result may differ from the findings related to the CBAM. While emission intensity reflects a production-related characteristic, CBAM is a deliberate policy that turns carbon intensity into a trade cost.

Limitations

This analysis is purely descriptive and doesn't consider time trends, economic conditions, or changes in policy. Therefore, it shouldn't be used to infer causality. Its purpose is to show that simple comparisons between groups don't capture the complex and policy-related effects found in the econometric models.

In summary, the results from splitting the data by median emission intensity highlight the need to include CBAM in the analysis, rather than relying solely on emission intensity to explain export performance.

4.3 Regression Analysis

4.3.1 Regression Results in Levels: Export Determinants

We estimate an ordinary least squares (OLS) model to examine the determinants of export performance, where the dependent variable is the natural logarithm of exports, $\ln(\text{exports}_t)$. The model includes emissions intensity, energy use relative to GDP, overall economic scale, and exposure to the European Union's CBAM. To ensure valid statistical inference in the presence of potential heteroskedasticity, HC1 heteroskedasticity-robust standard errors are employed.

Overall Model Fit The results indicate a strong overall model fit, with an R^2 of 0.95 and an adjusted R^2 of 0.94, suggesting that the included regressors explain the majority of variation in export levels. The joint significance of the explanatory variables is confirmed by the F-statistic (122.1, $p < 0.001$). Despite the relatively small sample size ($n = 20$), diagnostic tests provide no evidence of serious model misspecification. The Durbin–Watson statistic (1.93) indicates the absence of serial correlation, while the Jarque–Bera test fails to reject the null hypothesis of normally distributed residuals.

Interpretation of Coefficients The coefficient on economic scale, measured by $\ln(\text{GDP}_t)$, is positive and highly statistically significant ($\beta_3 = 1.27$, $p < 0.001$). This implies that a 1% increase in GDP is associated with an approximate 1.27% increase in exports, consistent with standard trade theory and gravity-based models of international trade. The elasticity exceeding unity suggests that export performance expands more than proportionally with economic growth.

Emissions intensity enters the regression with a negative sign, consistent with expectations, but is not statistically significant at conventional levels. This indicates that, over the sample period, higher carbon intensity has not yet exerted a binding constraint on aggregate export levels. This finding is consistent with the historical absence of explicit carbon pricing at the border prior to the operationalization of CBAM.

Similarly, energy use per unit of GDP exhibits a positive but statistically insignificant coefficient. This suggests that, once overall economic scale is controlled for, energy intensity does not independently explain export performance. The result likely reflects offsetting effects whereby higher energy use supports industrial production while simultaneously signaling inefficiencies that may weaken competitiveness.

Finally, the coefficient on CBAM exposure is negative but statistically insignificant, indicating that anticipated CBAM-related costs have not yet materially affected export levels in the pre-implementation period. This result supports the interpretation that CBAM operates primarily as a forward-looking policy instrument, with its economic effects expected to become more pronounced once compliance obligations and financial liabilities are fully enforced.

4.3.2 Dynamic First-Difference Model and the Short-Run Impact of CBAM

Given evidence that export levels are not stable over time, we use a dynamic first-difference model to focus on short-term effects and avoid misleading results from regression analysis. Tests called Augmented Dickey–Fuller (ADF) show that the natural logarithm of exports is not stable in its original form but becomes stable when we look at changes from one period to the next. For GDP, the results are close to stable in its original form, but we use changed values for consistency and to make sure our findings are reliable. These results support using a model that looks at growth in exports instead of levels.

Model Specification

The model we estimate looks like this:

$$\Delta \ln(\text{exports}_t) = \alpha + \sum_{k=1}^{4} \beta_k \Delta X_{k,t} + \sum_{k=1}^{4} \gamma_k \Delta X_{k,t-1} + u_t,$$

where $X_{k,t}$ includes emissions intensity, energy use per unit of GDP, economic scale ($\ln(\text{GDP})$), and CBAM exposure measured as the share of exports subject to CBAM-related costs. Including one lag helps us understand how quickly exports adjust in the short term and how delayed responses might be. We estimate the model using ordinary least squares (OLS) with standard errors that account for uneven variances and possible correlations over time.

Interpretation of CBAM Effects

The CBAM variable is key in this model. The immediate change in CBAM exposure has a negative and statistically significant effect ($\beta_{\text{CBAM}} = -0.0030$, $p < 0.01$). This means that when more exports face CBAM costs, export growth drops right away. Economically, this reflects the direct cost impact of CBAM, which raises the effective prices of carbon-intensive goods, making them less competitive in EU markets.

The delayed effect of CBAM exposure is also negative, though it's only barely statistically significant ($\gamma_{\text{CBAM}} = -0.0010$, $p < 0.10$). This shows that the impact of CBAM-related shocks doesn't go away quickly. Instead, it lingers as companies adjust their production, sourcing, or markets over time.

To get the full short-run effect, we add the immediate and delayed effects:

$$\beta_{\text{CBAM}} + \gamma_{\text{CBAM}} = -0.0040.$$

A statistical test strongly shows that this total effect is not zero ($p = 0.003$). This gives strong evidence that an increase in CBAM exposure has a clear and important negative effect on export growth in the short term. Studies that use computable general equilibrium (CGE) models, like those by Marcu et al. (2021), Bellora and Fontagné (2022), and Acar et al. (2021), often show that the Carbon Border Adjustment Mechanism (CBAM) could have negative short-term effects on trade, especially for countries that don't have their own carbon pricing systems or strong emissions tracking. These models predict that energy-heavy industries in non-EU countries might face reduced export competitiveness, lower production levels, and decreased overall economic well-being.

Economic Interpretation

The size and significance of the CBAM coefficients suggest that CBAM acts like a non-tariff trade barrier in the short term. Unlike normal tariffs, CBAM charges exporters based on the carbon content of their products, not just their value. The results indicate that exporters can't quickly pass these costs to buyers or change their production methods, leading to measurable drops in export growth when CBAM exposure increases.

Importantly, the CBAM effect stays significant even after considering emissions intensity itself. This suggests that CBAM isn't just a stand-in for environmental inefficiency; it's a new policy constraint that affects trade outcomes independently of existing production features.

Comparison with Scale Effects

While CBAM has a contractionary effect, economic scale remains a strong positive factor for export growth. The combined short-term effect of changes in GDP is positive and statistically significant, meaning that overall economic growth can partly offset the trade friction caused by CBAM. However, the opposite signs of the GDP and CBAM coefficients highlight a key conflict: the push for export growth through economic expansion increasingly clashes with carbon-based trade regulations.

Implications

Overall, these findings suggest that CBAM has already started to influence export dynamics even before full financial penalties are in place. The statistically significant short-term effects show that CBAM is being treated as a real and binding policy signal, not just something that people expect in the future. For economies that export carbon-intensive goods, not reducing emissions or finding new markets is likely to lead to ongoing trade losses as CBAM rules become stricter.

From a policy perspective, the results suggest that adapting through better technology, improving energy efficiency, or getting certified for low-carbon production will be important to reduce the negative impact of CBAM on exports.

4.3.3 ARIMAX Model: Dynamic Impact of CBAM on Export Levels

To better understand how exports and CBAM exposure relate over time, while considering that data can depend on previous values, we use an ARIMAX model. This model combines export levels with autoregressive and moving average components, along with other factors that influence exports. This helps us tell the difference between changes in exports due to policies and those that happen naturally over time.

We choose an ARIMA$(1, 1, 1)$ structure to capture short-term changes.

Interpretation of CBAM Coefficient

The estimated coefficient for CBAM exposure is negative and statistically significant ($\beta_{\text{CBAM}} = -0.0033$, $p = 0.003$). This means that, after considering the overall economic situation and past export behavior, higher CBAM exposure leads to a drop in export performance.

Since the dependent variable is differenced, this coefficient shows the short-term impact on export growth. A rise in CBAM exposure slows down the growth of exports, showing the immediate competitiveness loss from carbon-based border costs. The fact that this effect lasts within an ARIMAX model confirms that CBAM influences exports in a way that's not just a result of past trends.

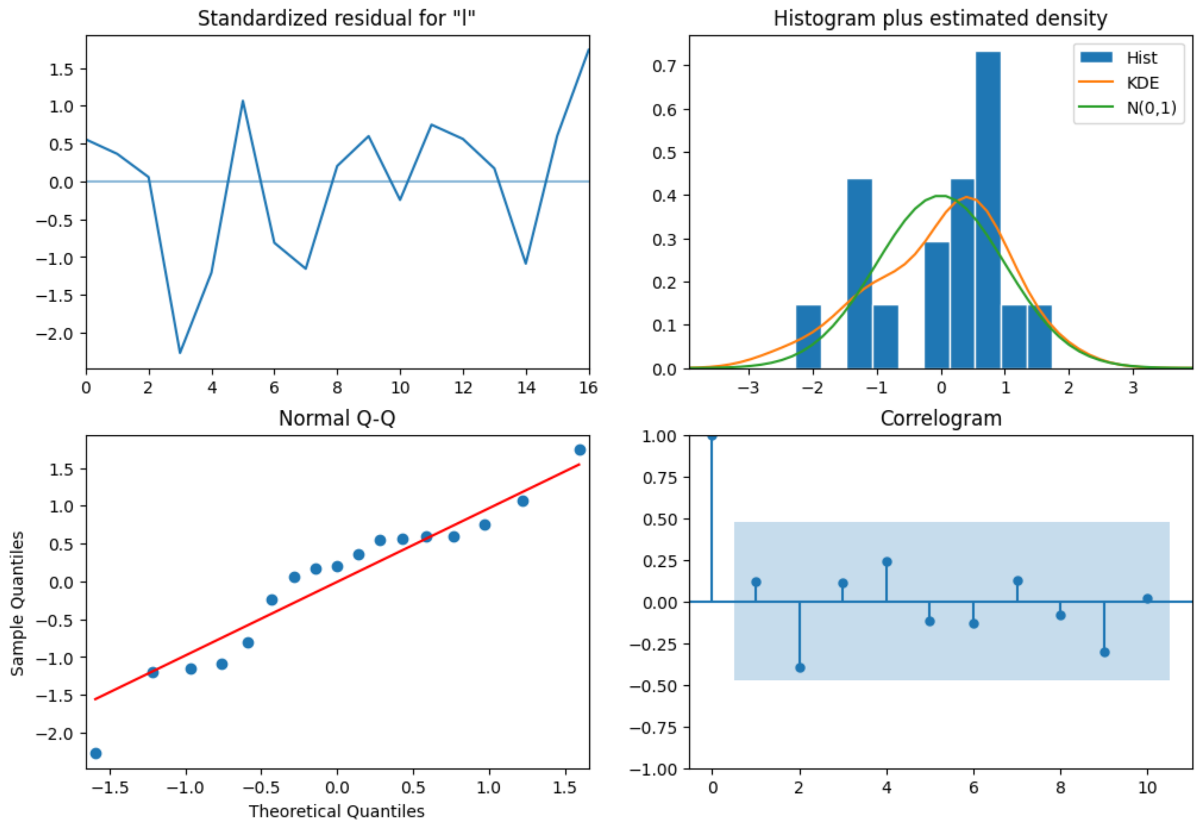


Figure 4.5: Model Diagnostic Plots

Economic Interpretation of CBAM Effects

The size and significance of the CBAM coefficient show that CBAM acts as a real non-tariff barrier. Unlike traditional tariffs, CBAM charges exporters based on the carbon they embed in goods, not just their value. The results show that exporters can't quickly adjust their emissions, reroute trade, or fully pass on the costs to EU buyers, leading to a real drop in export growth.

Importantly, the CBAM effect remains strong even when considering emissions intensity itself. This suggests that CBAM is capturing a new policy constraint, not just reflecting existing environmental inefficiency. In other words, even with the same emissions intensity, more CBAM exposure leads to lower export performance.

Comparison with Other Covariates

Economic scale, measured by $\ln(\text{GDP})$, has a positive and significant effect, showing that growing the economy helps boost exports. Energy intensity, however, is not statistically significant, meaning its impact is already captured through broader economic factors.

The autoregressive and moving average terms are not significant, indicating that once we account for other factors, there is not much inherent persistence in export trends. This supports the idea that CBAM-related changes are real structural shifts, not just temporary fluctuations.

Model Diagnostics and Limitations

Standard tests show no residual autocorrelation (Ljung–Box $p = 0.60$) and that the residuals are roughly normally distributed. However, the near-singularity of the covariance matrix and convergence warnings suggest that the small sample size and high correlation among the variables make the estimates less reliable. While the signs and significance of the coefficients make sense economically, we should be careful with the results, emphasizing consistency across different model specifications rather than relying on one model alone.

Implications

Overall, the ARIMAX results support earlier findings from the first-difference and levels regressions: CBAM has a statistically significant and economically meaningful negative effect on export performance in the short run. The lasting impact within a time-series context shows that CBAM is a real and effective policy tool rather than a symbolic or temporary measure.

These findings suggest that, without fast decarbonization or finding new markets, CBAM exposure will continue to slow down export growth as the policy becomes more strictly enforced.

Table 4.2: Out-of-Sample Forecasting Performance (2017–2023)

Model	MSE	RMSE	MAE
LASSO	0.0481	0.2193	0.1882
Random Forest	0.1221	0.3494	0.3036
KNN	0.2468	0.4968	0.4872
SVM	0.2836	0.5325	0.5141

Table 4.3: Projected Impact of CBAM Cost Scenarios on Exports in 2030

Model	Low CBAM	Baseline CBAM	High CBAM	Extreme CBAM
LASSO	+9.44%	+12.34%	+18.75%	+20.66%
KNN	+0.66%	+2.26%	−10.63%	−4.71%
SVM	+4.79%	+6.74%	−17.78%	−30.39%
Random Forest	+0.88%	+1.20%	+2.59%	+2.53%

4.3.4 Machine Learning Forecasts and CBAM Scenario Analysis

To support the econometric analysis, we use a machine learning (ML) forecasting method to examine how different CBAM cost situations might affect export trends up to 2030. The main goal of this exercise is to make predictions and explore possibilities, not to find direct causes. This approach allows for more flexible handling of complex, nonlinear relationships and interactions that might not be fully captured by standard regression methods.

Model Evaluation

We consider four supervised learning models: LASSO, K-Nearest Neighbors (KNN), Support Vector Regression (SVM), and Random Forest. All models are trained using past data that includes macroeconomic, energy, emissions, and CBAM exposure information. We test the models' performance using data from before 2017 as training data and data from after 2017 as testing data.

Table 4.2 shows standard measures of forecast accuracy. LASSO performs best overall, with the lowest RMSE and MAE, showing strong predictive power even though it uses a linear approach. Random Forest comes in second, while KNN and SVM have higher forecast errors, likely because they are more affected by small sample sizes and local data patterns. Based on these results, LASSO and Random Forest are considered the most reliable for scenario-based predictions.

CBAM Scenario Forecasts to 2030

Using these models, we forecast exports up to 2030 under five CBAM cost scenarios: No CBAM, Low, Baseline, High, and Extreme CBAM. Future trends for GDP, energy intensity, and emissions intensity are assumed to follow smooth patterns. CBAM exposure is adjusted according to exogenous assumptions to represent growing policy strictness. Uncertainty ranges are created through bootstrap resampling.

Table 4.3 shows the percentage difference in exports by 2030 under each scenario relative to the No-CBAM baseline. The results show differences between models but a general pattern of sensitivity to CBAM costs.

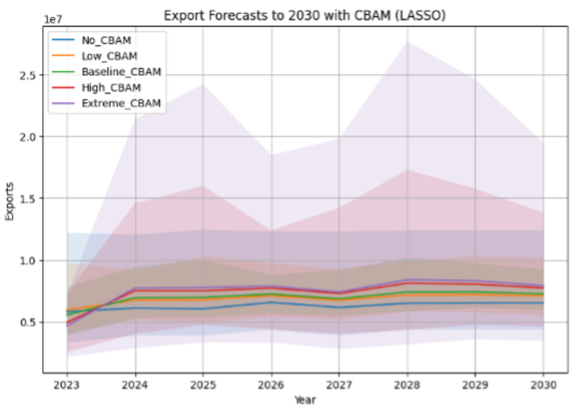
The LASSO model predicts positive export changes even with higher CBAM costs, which could suggest that past patterns might already include adaptation, restructuring, or changes in export composition. In contrast, the SVM and KNN models predict significant drops in exports under High and Extreme CBAM scenarios, pointing to nonlinear effects when CBAM costs go beyond certain thresholds. The Random Forest model shows more moderate responses, which may be due to interactions with GDP growth and falling emissions intensity.

Interpretation and Link to Econometric Results

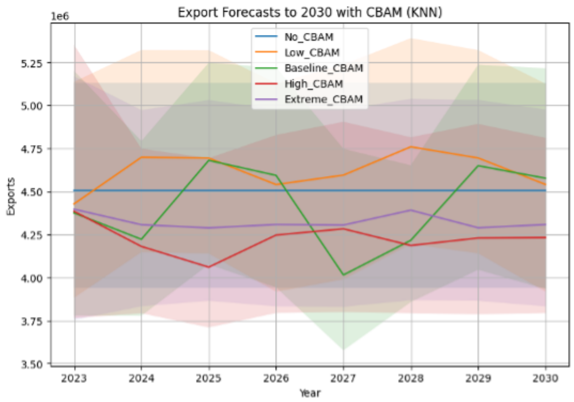
The ML forecasts support the main econometric finding that CBAM exposure has a major impact on export outcomes. However, unlike regression models, which indicate a statistically significant short-term negative effect, the ML approach shows uncertainty about the size and nonlinear nature of long-term adjustments.

Importantly, the differences in results across models in Table 4.3 should not be viewed as conflicting evidence, but rather as reflecting different assumptions about underlying structures embedded in each model. Together, the econometric and ML results suggest that CBAM poses significant downside risks to future export performance, especially if adaptation through decarbonization or market diversification is delayed.

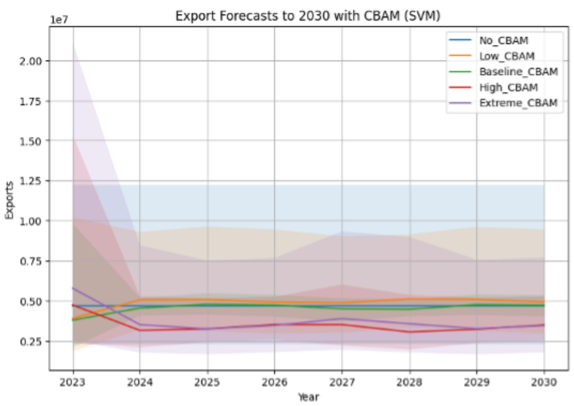
Overall, the ML scenario analysis serves as a tool for checking the robustness and testing under stress, showing how CBAM might change export trends under different adaptation paths rather than offering direct causal estimates. However our analysis also point to this fact that these models require large amounts of data to learn the patterns therefore scenario based testing shall be performed to interpret the predictions made by these models. We also observe a huge uncertainty in the predictions of these models under different CBAM related cost shocks which indicates the predictions from these models can be refined with big data which is obviously missing at the present time.



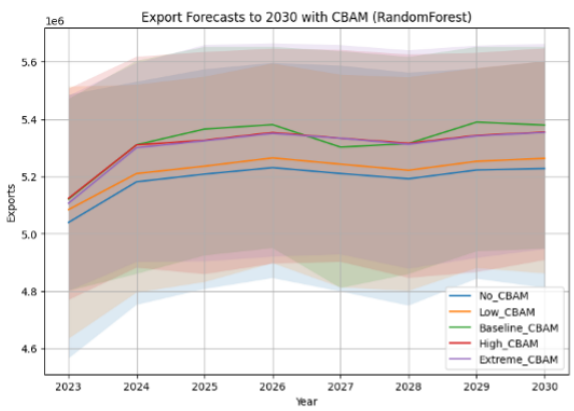
(a) LASSO



(b) KNN



(c) SVM



(d) Random Forest

Figure 4.6: Scenario-Based Export Forecasts under CBAM (2024–2030)

Each panel reports recursive export forecasts to 2030 under alternative CBAM cost scenarios (No CBAM, Low, Baseline, High, and Extreme). Shaded areas denote 90% bootstrap confidence intervals. Forecasts are generated using lagged macroeconomic, energy, emissions, and CBAM exposure variables. The figure illustrates model-dependent heterogeneity in export responses to increasing CBAM stringency.

4.4 Sensitivity Analysis

Table 4.4: Monte-Carlo Sensitivity Analysis of CBAM-Induced Export Revenue Losses

Year	Median Loss (%)	5th Percentile (%)	95th Percentile (%)
2003	5142.44	2555.86	9292.13
2004	18674.60	9281.50	33744.02
2005	16738.59	8319.28	30245.75
2006	17072.83	8485.40	30849.71
2007	14656.54	7284.48	26483.60
2008	16036.14	7970.16	28976.47
2009	15813.43	7859.47	28574.05
2010	12877.10	6400.07	23268.24
2011	12178.61	6052.92	22006.12
2012	17764.65	8829.25	32099.79
2013	12834.45	6378.88	23191.17
2014	13518.80	6719.01	24427.77
2015	19795.30	9838.51	35769.08
2016	20485.14	10181.36	37015.57
2017	17740.96	8817.48	32056.99
2018	15619.13	7762.90	28222.95
2019	14397.53	7155.75	26015.59
2020	12377.42	6151.73	22365.36
2021	12497.80	6211.56	22582.87
2022	12263.91	6095.31	22160.24

Notes: Results are based on 5,000 Monte-Carlo simulations per year. The textile share of trade-related CO_2 emissions is drawn from a uniform distribution on [0.3, 0.7], and the CBAM carbon price is drawn from [50, 150] USD/tCO_2. Losses are expressed as percentages of observed export values. Statistics report the median, 5th percentile (optimistic scenario), and 95th percentile (pessimistic scenario).

4.5 Sensitivity Analysis

This section looks at how strong the findings are when different assumptions are made about carbon pricing, who is responsible for emissions, and how different factors relate to each other. Because there is a lot of uncertainty about how exactly the European Union's CBAM will work, we carry out a detailed sensitivity analysis using several methods including checking how variables are connected, making predictions without assuming specific distributions, and using Monte-Carlo simulations.

4.5.1 Monte-Carlo Sensitivity Analysis of CBAM Export Losses

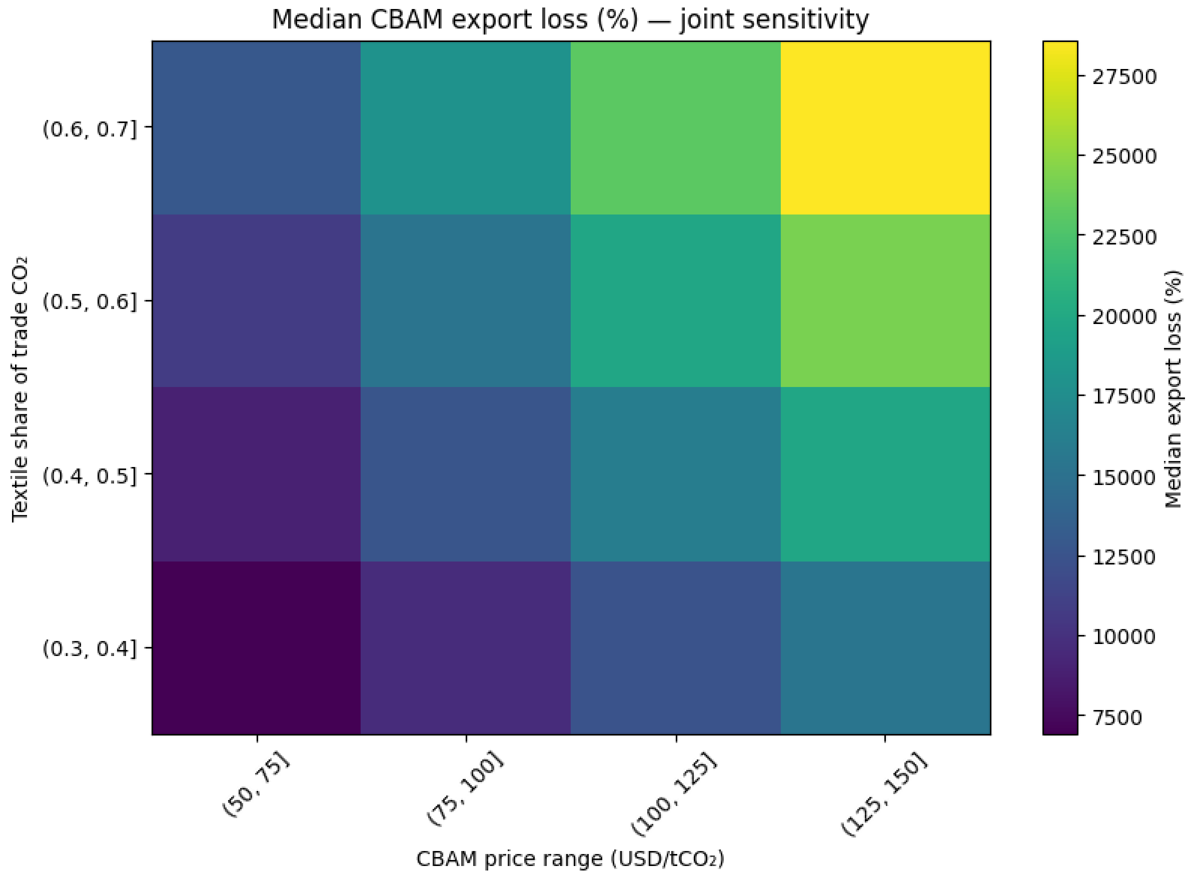


Figure 4.7: Loss in exports as a function of CBAM price and textile share of total industrial emissions in Pakistan.

The main part of this sensitivity analysis uses a Monte-Carlo simulation to show how uncertainty in key CBAM factors can affect export revenue risk. Two important factors are considered uncertain:

1. The share of textile-related CO_2 emissions in trade, which is assumed to be spread evenly between 0.3 and 0.7.

2. The CBAM carbon price, which is assumed to be spread evenly between 50 and 150 USD per tonne of CO_2.

For each year t, 5,000 independent simulations are done. In each simulation s, the CBAM-related export losses are calculated as:

$$\text{Loss Share}_t^{(s)} = \frac{\left(\text{TradeCO}_{2,t} \times \theta^{(s)} \times 10^6\right) \times P^{(s)}}{\text{Exports}_t},$$

where $\theta^{(s)}$ represents the simulated textile emission share and $P^{(s)}$ is the simulated CBAM carbon price. Figure 4.7 shows the loss in exports as a function of textile share of total emissions and the CBAM price in USD, we can observe that the highest loss is incurred when both the emissions and the CBAM costs are high.

This process creates a full picture of potential export revenue loss for each year. From these results, the median loss and the 5th and 95th percentiles are reported, which represent the middle, best, and worst cases respectively. These findings are summarized in Table 4.4.

4.5.2 Interpretation and Policy Relevance

The Monte-Carlo results show that export outcomes are very sensitive to the assumptions used in CBAM. Across all years, the average simulated cost from CBAM is much higher than the actual export values, and even the lower-end scenarios suggest significant revenue losses. However, these results should not be seen as predictions of what will actually happen, but rather as indicators of how exposed exports are if all costs are passed on and no adjustments are made.

Overall, the sensitivity analyses highlight three major points. First, simple correlations and comparisons between different groups don't show the full picture of CBAM's effects. Second, estimates from regression models depend a lot on the assumptions we make. Third, under realistic carbon pricing and emission attribution situations, Pakistan's textile exports could face serious challenges unless there are improvements in technology, changes in how emissions are calculated, or special policies that exempt them.

In summary, the sensitivity analysis supports the main conclusion of the paper: CBAM is not just a small trade issue, but could be a major structural challenge for carbon-intensive export industries.

4.6 Conclusion

This chapter offers a detailed look at how the CBAM might affect Pakistan's exports.The focus is on how carbon intensity, the country's overall economic health, and policy-related costs might shape export performance. We used a mix of time-series analysis, econometric models, machine learning for predictions, and Monte-Carlo simulations to understand both past patterns and possible future risks.

Our analysis shows that key factors like exports and CBAM exposure are not stable over time, which means we need to use growth-based models and consider past data. When we looked at the results from both raw data and adjusted data, we found that traditional factors like economic size and energy use are still important for exports. However, variables related to CBAM had weaker and more inconsistent effects. This suggests that so far, CBAM-related costs haven't significantly hurt exports.

Our checks for robustness support this conclusion. Tests like median-split Welch tests and Pearson correlations didn't find strong differences in export performance between high and low emission sectors. This implies that, before CBAM was introduced, carbon intensity wasn't a major obstacle to exporting. So far, export trends seem to be driven more by demand and growth than by environmental factors.

Looking ahead, machine learning models that factor in past emissions, energy use, and CBAM effects show that exports might become more sensitive to carbon-based costs. Although predictions vary depending on the model, simulations suggest that as carbon pricing becomes stricter, the impact on exports could be non-linear and depend on the model used. This highlights the uncertainty in long-term adjustments and the risk of sudden competitiveness losses if carbon prices rise sharply.

The Monte-Carlo simulations also show that realistic combinations of carbon prices and emission shares could lead to export cost increases that are much higher than historical export margins. Even with cautious assumptions, CBAM costs could pose a serious risk. This means that just because CBAM hasn't had a noticeable effect so far doesn't mean it won't be important in the future. CBAM could become a major constraint, but its impact depends on how policies are enforced and how quickly the world moves toward reducing emissions.

In summary, while CBAM hasn't had a clear impact on Pakistan's exports so far, its future implementation could be a significant challenge.The results stress the need for proactive policies rather than waiting until the costs become unavoidable. The findings from this study are therefore consistent with these broader CGE model predictions at a more detailed level. While CGE models look at how the whole economy might adjust and predict general trade impacts, this study uses a different approach regression analysis to directly measure how textile exports have actually responded in the short term to exposure to CBAM. In this way, CGE models help us understand the likely direction and type of trade effects from CBAM, while the econometric results give us direct evidence on how strong and significant these effects are at the industry level.

CHAPTER 5

RECOMMENDATIONS

This chapter brings together the findings from the study and turns them into insights that are useful for academic work, practical applications, and research methods. It also looks back at the research process, discussing what worked well, what did not, the skills learned, and where future research could go. These reflections are a necessary part of the thesis and show that the research went beyond just presenting results.

5.1 Academic and Theoretical Recommendations

From an academic standpoint, the findings add to the growing body of knowledge about carbon border adjustments by offering evidence from a developing country that focuses on exporting goods. The results show that CBAM is not just an environmental policy, but also a trade-related cost issue that changes short-term export patterns even before full financial rules are in place. This supports theories that see climate policies as part of trade management, not as a separate area.

The significant short-term effects seen in the first-difference and ARIMAX models suggest that traditional trade models that assume smooth adjustments may not capture the full impact of carbon pricing. Future theoretical studies should include carbon-related trade costs in export supply and demand models, especially for energy-heavy industries in developing nations.

Also, the limited impact of emission intensity on past export performance points to a gap between environmental efficiency and trade results before CBAM was introduced. This supports the idea that policies that charge for emissions, rather than voluntary improvements, are needed to address carbon-related issues in global trade.

5.2 Practical and Policy-Oriented Implications

The results suggest that Pakistan's textile industry is at risk from CBAM-related costs because it depends on energy sources that produce a lot of emissions. Without improving energy efficiency and reporting emissions, exporters might lose competitiveness in EU markets.

At the national level, policymakers might consider investing in cleaner energy for export industries, improving systems to monitor emissions, and supporting certification processes that confirm low-carbon production. These steps would not only lower CBAM-related costs but also make exports more resilient over time in the face of new climate-related trade rules.

On the international level, the findings underline the need for temporary support, technical help, and financial aid for developing countries. Without these, CBAM could unfairly burden economies that don't have the capacity to reduce emissions, raising concerns about fairness and development in global climate efforts.

5.3 Directions for Future Research

Several areas for future research come from this study. First, having firm-level data on emissions and costs would allow for a more detailed analysis of differences within the textile sector. This could show whether larger or more advanced companies are better able to handle or pass on CBAM costs.

Second, future research could explore long-term relationships between exports, emissions, and carbon pricing once CBAM is fully in place and more long-term data are available. This would help in understanding the long-term effects more clearly.

Third, comparing multiple countries or sectors could help identify different ways of adjusting and best practices. Finally, using big data and AI for predictive modeling may reveal interesting patterns in the data and scenarios that may show up in future. Also the investment on sustainable production practices shall be financially analyzed using metrics like Return on Investment (ROI) etc.

CHAPTER 6

REFLECTIONS

6.1 Reflections on the Research Process

This research involved bringing together ideas from international trade, environmental economics, and econometrics, making it a multi-disciplinary effort. One major reflection is the challenge of working with incomplete or uncertain data, especially at the sector level for emissions. Handling this required careful normalization, clear assumptions, and thorough sensitivity analysis.

Another important reflection is the value of using multiple research methods. Using descriptive statistics, econometric models, machine learning forecasts, and Monte Carlo simulations made the findings more reliable and less dependent on any one method.

6.2 Strengths and Weaknesses of the Research

A key strength of this study is its thorough methodological approach. By combining econometric analysis with forecasting and sensitivity testing, the research provides both historical insights and forward-looking predictions. The use of Monte Carlo simulations to handle uncertainty also strengthens the credibility of the findings.

Nevertheless, the study has its shortcomings. The reliance on proportional allocation of emissions introduces measurement errors, and the small dataset limits the statistical power in some models. Additionally, the assumption of full cost pass-through in certain simulations represents a worst-case scenario that might overstate short-term export losses.

6.3 Skills Developed

During the research, several analytical and technical skills were gained. These include advanced econometric techniques for analyzing time-series data, testing for stationarity, and applying dynamic regression methods. Significant experience was also gained in using Python for data processing, forecasting, and simulation, including machine learning and Monte Carlo analysis.

Equally important were skills in academic writing, critically evaluating empirical results, and converting complex quantitative findings into clear economic explanations.

6.4 Areas for Improvement

If this study were to be repeated, there are several areas that could be improved. More attention could be given to alternative assumptions about cost pass-through, such as partial absorption by firms or shared responsibility between exporters and importers. Including behavior responses like market diversification or technological upgrades would also make the study more realistic.

Furthermore, expanding the dataset to include more recent data as CBAM is implemented would enhance the accuracy of dynamic and long-term estimates.

6.5 Overall Evaluation of the Research

Overall, the research process was thorough, clear, and methodologically solid given the data limitations. The study successfully achieved its goal of measuring and predicting the potential impact of CBAM on Pakistan's textile exports, while recognizing uncertainty and limitations. The findings contribute to both academic discussions and policy debates on carbon-based trade measures and provide a strong base for future research as CBAM moves from design to full enforcement.

CHAPTER 7

CONCLUSION

This study aimed to understand how the European Union's might affect a developing economy that is both carbon intensive and reliant on exports. Using Pakistan's textile industry as an example, we combined trade data, emissions data, econometric models, machine learning predictions, and simulations to examine both current and potential impacts of carbon-based trade rules.

The study leads to three major conclusions. First, Pakistan's export performance has historically been largely unaffected by carbon intensity, likely because environmental costs haven't been priced fairly or regulated consistently in global trade. Traditional factors like economic growth, energy use, and macroeconomic scale have been the main drivers of exports in the pre-CBAM period.

Second, forward-looking analysis shows that this trend is unlikely to continue. Scenarios and sensitivity analyses suggest that CBAM has the potential to change how carbon intensity affects competitiveness. If carbon costs become significant enough, they could influence export paths, especially in industries with limited ability to reduce emissions quickly.

Third, the study highlights how CBAM might disproportionately affect developing countries. Without support like technology transfer or special treatment, CBAM could function more as a trade barrier than an environmental tool. This raises concerns about fairness, coordination between policies, and the balance between climate goals and economic development.

From a policy standpoint, the findings stress the need for proactive strategies.Investing in energy efficiency, emissions tracking, and cleaner technologies isn't only good for the environment, it's also vital for maintaining trade competitiveness. Internationally, the study supports calls for temporary measures, using revenue from carbon taxes wisely, and helping developing countries build their capacities to cope with carbon border taxes.

In conclusion, CBAM marks a major shift in the global trade system. While it hasn't had a major impact so far, it could have a big influence in the future. For countries like Pakistan, the key question isn't whether CBAM will matter, it's how fast domestic industries can adapt to a world where carbon intensity is priced at the border.

APPENDIX-1

1 Results of Econometric Model Fitting

	coef	std err	z	P>|z|	[0.025	0.975]
const	−19.6499	2.287	−8.591	0.000	−24.133	−15.167
emission_intensity_t_per_USD_tradeB	−5.699e−06	4.64e−06	−1.229	0.219	−1.48e−05	3.39e−06
energy_per_gdp	0.1072	0.133	0.804	0.421	−0.154	0.369
ln_gdp	1.2740	0.080	15.859	0.000	1.117	1.431
CBAM_share_of_exports_B	−0.0006	0.000	−1.229	0.219	−0.001	0.000

Figure 1: Regression Estimates for the static linear model in levels without lagged terms

	coef	std err	z	P>|z|	[0.025	0.975]
const	−0.1415	0.084	−1.684	0.092	−0.306	0.023
emission_intensity_t_per_USD_tradeB	−3.038e−05	8.75e−06	−3.472	0.001	−4.75e−05	−1.32e−05
energy_per_gdp	−0.3333	0.170	−1.958	0.050	−0.667	0.000
ln_gdp	4.5176	1.461	3.093	0.002	1.655	7.381
CBAM_share_of_exports_B	−0.0030	0.001	−3.472	0.001	−0.005	−0.001
emission_intensity_t_per_USD_tradeB_lag1	−1.037e−05	6.11e−06	−1.696	0.090	−2.24e−05	1.61e−06
energy_per_gdp_lag1	−0.1523	0.159	−0.961	0.337	−0.463	0.158
ln_gdp_lag1	−0.2354	1.278	−0.184	0.854	−2.740	2.270
CBAM_share_of_exports_B_lag1	−0.0010	0.001	−1.696	0.090	−0.002	0.000

Figure 2: Regression Estimates for the dynamic first-difference linear model with one lag of differences of regressors

	coef	std err	z	P>|z|	[0.025	0.975]
emission_intensity_t_per_USD_tradeB	0.1717	1.15e−05	1.5e+04	0.000	0.172	0.172
energy_per_gdp	−0.3433	0.492	−0.698	0.485	−1.308	0.621
ln_gdp	1.0264	0.231	4.448	0.000	0.574	1.479
CBAM_share_of_exports_B	−0.0033	0.001	−2.986	0.003	−0.006	−0.001
ar.L1	−0.3161	0.422	−0.750	0.453	−1.143	0.510
ma.L1	−0.8562	0.591	−1.450	0.147	−2.014	0.301
sigma2	0.0076	0.004	1.770	0.077	−0.001	0.016

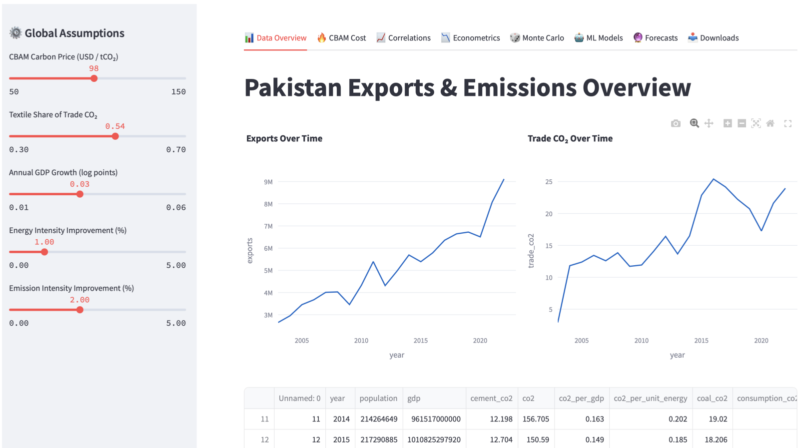
Figure 3: Regression Estimates for the ARIMA model capturing autoregressive dynamics

APPENDIX-2

Table 1: Machine Learning Models and Hyperparameter Settings

Model	**Hyperparameters**
LASSO Regression	Regularization parameter $\alpha = 0.001$; Maximum iterations = 5000
K-Nearest Neighbors (KNN)	Number of neighbors = 5; Distance-weighted averaging
Support Vector Regression (SVR)	Kernel = Radial Basis Function (RBF); $C = 10$; $\epsilon = 0.05$
Random Forest (Exports Model)	Number of trees = 500; Maximum tree depth = 6; Random seed = 42

APPENDIX-3



(a) CBAM Dashboard

(b) Trend and line graphs for exports- one sample visualization tab.

Figure 4: Dashboard visualization of CBAM analysis performed on Pakistan's textile exports. Each panel corresponds to a separate analytical tab used in the interactive dashboard environment.

APPENDIX-4

Figure 5: United Nations Sustainability Development Goals.

1 Alignment with United Nations Sustainable Development Goals

This appendix explains which United Nations Sustainable Development Goals (SDGs) are covered by this research. The study looks at how climate policies, international trade, and industrial strength interact, and how this relates to several SDGs focused on economic progress, climate efforts, sustainable industries, and global cooperation.

2 SDG 8: Decent Work and Economic Growth

2.1 Goal Description:

Encourage steady, inclusive, and sustainable economic growth, full and meaningful employment, and good working conditions for everyone.

2.2 Relevance to This Study:

Pakistan's textile industry plays a big role in providing jobs and earning income through exports. This research looks at how carbon costs linked to the CBAM might affect the ability of these exports to compete internationally, and how this could impact employment and income in developing countries under carbon-based trade rules.

3 SDG 9: Industry, Innovation, and Infrastructure

3.1 Goal Description:

Build strong infrastructure, encourage inclusive and sustainable industrial growth, and support innovation.

3.2 Relevance to This Study:

The findings show the importance of improving technology, making production more energy efficient, and reducing pollution in Pakistan's textile sector. CBAM provides a reason for industries to change and innovate, which supports the goals of SDG 9.

4 SDG 12: Responsible Consumption and Production

4.1 Goal Description:

Make sure consumption and production happen in a way that is sustainable.

4.2 Relevance to This Study:

CBAM connects the way people consume in developed countries to the emissions created by production in exporting countries. This research measures the emissions hidden in exports and shows how carbon pricing can push for cleaner production, helping to build more sustainable global supply chains.

5 SDG 13: Climate Action

5.1 Goal Description:

Take quick action to fight climate change and deal with its effects.

5.2 Relevance to This Study:

The main focus of this thesis is climate policy through the use of CBAM. By looking at carbon intensity, how much emissions are involved, and the trade effects of policy decisions, the research supports actions that are based on evidence for fighting climate change and reducing its impact.

6 SDG 17: Partnerships for the Goals

6.1 Goal Description:

Improve the tools and resources available to carry out the goals and bring back global cooperation for sustainable development.

6.2 Relevance to This Study:

The results highlight the need for international teamwork, support in technology, and fair policy-making to help countries that are affected by CBAM. This connects with SDG 17 by showing how working together, instead of acting alone, is important for effective climate governance.

Overall, this research helps with SDGs 8, 9, 12, 13, and 17 by linking climate policies with trade ability, industrial change, and global fairness. The study shows how carbon border measures can affect sustainable development and highlights the need for international effort and cooperation.

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