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– a price effect estimation approach

EU ETS - utsläppsrättsprisets inverkan på utsläpp från Sveriges industrier

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Abstract

Industries globally produced 50% of total CO_2 emissions in 2018, largely contributing to current climate changes. The efficiency of environmental policies is crucial for reaching necessary abatement goals. The EU ETS policy covers the most emission intensive industries, whereas it is imperative to repeatedly evaluate the policy efficiency. There is yet no consensus whether the price of EU ETS CO_2 allowances affects the emissions. Using a panel data regression analysis, this thesis examined the effect of the EU ETS allowance price on emissions of various Swedish industries. Overall, the results showed all independent variables to be statistically significant. The model estimated that a 1% increase in price is associated with a 12,73% decrease in emissions. However, the model contains certain limitations which may have caused biased results, hence the results should be interpreted with caution. The graphical analysis showed indications that all sectors except Iron & Steel has decreased their overall emissions and become more environmentally friendly due to the EU ETS carbon price. From these results, the study concludes that the allowance price of the EU ETS has a significant negative effect on the emissions of Swedish industries. It also concludes that the efficiency of the policy seems to vary among the different sectors, thus sector-specific adjustments of the policy may be relevant to optimize the overall efficiency of the policy.

Keywords: EU ETS, policy analysis, carbon pricing, emissions, industries, environmental policy

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Abbreviations

EU ETS	EU Emissions Trading System
EUA	EU Allowances
EEA	European Environmental Agency
GHG	Greenhouse gases

1. Introduction

The world faces an existential crisis in climate change (UNFCCC 2021). The emissions caused by humanity are currently exceeding the planet's ability of storage and preservation. According to the Emissions Gap Report 2020 the average fossil CO_2 emissions has increased with 1,3% each year during the period 2010-2019. This causes a surging surplus of greenhouse gases in the atmosphere contributing to increasing temperatures as the greenhouse effect rises. This has fatal effects on nature, not only constraining biological resources and harming the biodiversity, but also causing natural disasters such as extreme weathers, floods, and wildfires (Mirza 2003). To prevent escalating consequences, a global agreement is established to attain protection of the planet, known as the Paris-agreement. This alignment puts pressure on all participating countries to reach set emission-abatement goals to keep the global average temperature below 1,5 degrees Celsius. Several policies are applied in European economies to reach environmental goals, one of them being the EU ETS, a cap-and-trade policy covering energy intensive industrial and manufacturing producers. The energy sector and the industrial sector combined caused 50% of the total emissions from EU-27 countries in 2018 (EEA 2021). Due to the urgency of sustainable industrial production, this thesis will assess the effect of the EU ETS on industrial CO_2 emissions in Sweden.

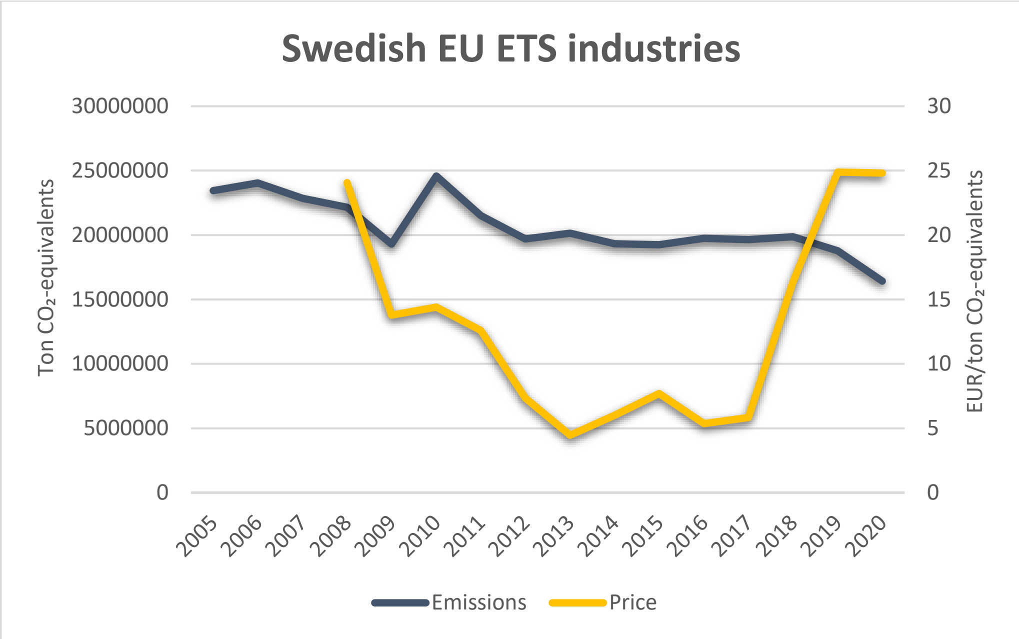

Figure 1 Trends of total emissions of Swedish EU ETS industries and allowance-prices. Source: Own processing 2021. Based on data from EEA 2021, Ember 2021.

The last few years the prices in the EU ETS allowance-market have shown a rapid increase, simultaneously as the emitted CO_2 from Swedish EU ETS industries has decreased, depicted in Figure 1. This provides reasons to evaluate how the changes of allowance prices are affecting CO_2 emissions from Swedish industries. Therefore, this thesis will carry out a policy analysis evaluating the effect of the allowance price on CO_2 emissions of EU ETS industries in Sweden. This will be done through a panel regression analysis which will include independent variables of allowance price and production, with the EU ETS emissions as dependent variable. The estimated coefficients of the variables will indicate how much a marginal change of the EU ETS allowance price changes the emissions.

The different industry sectors in Sweden are contributing with different multitudes to the total emissions (EEA 2021). The various sectors have also shown dissimilar trends in their year-by-year emissions the last few years. The occurrence of these differences could be an indicator that the various sectors are differently affected by the EU ETS allowance price. To reach a more sustainable industrial production, without altering the economic growth, the amount of emissions per produced output level needs to be lowered (Gillingham et al. 2009). In this thesis, the amount of emissions related to the industrial production output is considered as the emission intensity. This study will through a graphical analysis evaluate whether there are sector-specific differences in patterns of emissions and such emission intensities, and if these changes are due to the EU ETS allowance price. An assessment of how different sectors react to the policy may enable a clarification of possible variations in policy efficiency among sectors. This understanding could be valuable for policymakers when making sector-specific adjustments to reach an overall increase in policy efficiency.

1.1. Background

The EU has for the past 30 years aimed towards increasing the sustainability of consumption and production, using emission-abatement policies (European Union 2016). A recent report from CPLC (2017) shows that carbon pricing is an efficient, adaptable, and low-cost method to reduce greenhouse gases. The actuality of more frequent usage of carbon pricing harmonizes with these beliefs of effectiveness. Currently there are 31 emission trading schemes and 30 carbon taxes in the world which covers 22 percent of the total global emissions (World bank 2020).

The EU ETS was introduced in 2005 and is a cap-and-trade policy using emission permits to achieve emission reductions (EEA 2020). This policy constitutes a solution for emission reductions by using market-based instruments. This consists of supplied emission permits that European nations and their producers can trade if needed. Those firms emitting more than their level of permits can through the allowance market purchase more allowances to meet their individual needs, if not, heavy fines will be imposed. The firms using less permits can sell or reserve them for future use (ibid). This implies that the market creates additional gains for those firms who has low emission intensity in their productions. Given that the numbers of permits in the market are constrained, an indirect price is put on carbon emissions and by that works in similar ways as a carbon tax. As Hepburn (2006) is stating there is a simple but essential symmetry between control of quantities and prices. When using a quantity instrument, regardless of using a command-and-control regulation or by market creation, it always entails a related indirect price. Carbon taxes and the emission allowance schemes differ in several aspects (Green 2021). The carbon tax is a policy which includes a surcharge placed on energy or fuel use. This gives a certainty of cost as the price is set by the government of each country. In that sense there is no actual limit of the quantity of emissions, provided that the parties concerned are able and willing to pay the additional cost of the tax. In contrast, the ETS provide a certainty of quantity. This is set by the emission cap determined by deciding governments and establishes the upper limit of released greenhouse gases (ibid). As participating firms take part of a market, the price of allowances is affected and determined by the current supply and demand, creating daily spot-prices for allowances. It should be noted that the differences of the two policies are sometimes vague, since the ETS can hold a price floor which then gives it more resemblance of a tax (Hepburn 2006).

The EU ETS covers following industries: *Electricity and heat generation, oil refineries, steel works, production of iron, aluminum, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids, bulk organic chemicals,* and *commercial aviation* within the European Economic Area (EEA 2020).

The EU ETS has gone through different reforms through time, divided in the four time periods of 2005-2007, 2008-2012, 2013-2020, and 2021-2030 (European Commission 2015). The first phase was to be considered a pilot trial period, which was applied to test carbon-market prices and establishing necessary infrastructure for reporting, monitoring, and verifying emissions. Almost all allowances were allocated for free, and the caps were decided based on historic emissions, a practice called grandfathering. The second phase, 2008-2012, was used to refine the policy to make it more efficient. The EU imposed a tighter cap which reduced the total volume of allowances by 6,5% compared to 2005. In this phase the permits were generally no longer granted for free, more member states joined the EU ETS, and more types of greenhouse gases was included within the scope of the policy. The third phase of the EU ETS, 2013-2020, involved further modifications for several reasons. For example, the policy did not create such significant changes or progresses regarding renewable energy and low carbon technologies as was first anticipated. It also was not as cost-effective as first estimated. The allocation system was by that transformed from grandfathering to an auctioning principle. The auctioning platforms was made more transparent and accessible to any participating country of the EU ETS, to ensure openness and to be harmonized without discriminatory manners (ibid).

1.2. Aim, Research Question and Delimitations

This thesis aims to assess the effect of the EU ETS on emissions of Swedish industry sectors.

The project seeks to answer following question: *How has the EU ETS allowance-price affected the emissions of Swedish industries?*

The study contains certain limitations due to a constrained timeframe. Previous work is using a variety of methodologies when performing policy-evaluation, many of them being highly extensive, which is not within the scope of this analysis. This study is approaching the objective of the study merely by focusing on the price-effect of allowances. Another limitation is that the project only assesses the second and third trading-periods of the EU ETS, years 2008-2020. This is due to the grandfathered policy construction of phase 1 where the market effects were not considerable and therefore not of significance in this study. Furthermore, the study is limited to 6 industrial sectors: Refineries, Iron & steel, Non-metallic minerals, Pulp & Paper, Chemicals, and Electricity & Other combustion. The specific subsectors Primary aluminum, Non-ferrous metals, Nitric acid, and Bulk chemicals has been excluded from the dataset due to lack of complete data. Additionally, the study is limited to Swedish industrial production only, which is done with respect to the time-scope of the project, to find and prepare matching panel data for more than one variable.

1.3. Structure

The thesis is structured as follows: Section 2 presents a review of relevant literature of previous research. Section 3 describes the chosen method with the theoretical framework, data description, assumptions, and a presentation of the economic model. Section 4 presents the empirical results of the study. This is followed by a discussion in section 5 and brief conclusions in section 6.

2. Literature review

The previous literature has repeatedly assessed the influence of the EU ETS policy. Several methods have been applied and many viewpoints have been taken when evaluating the impact of the EU ETS on different industries and their emissions, resulting in different outcomes. There is a wide range of studies and models, many of them including other considerations in addition to assessing emission reductions, and sometimes even excluding the aspect of emissions. However, some of them are focusing on the effect of carbon pricing on emissions. Bayer and Aklin (2020) investigates the EU ETS carbon price's efficiency to reduce emissions. They argue that, despite low prices, the carbon markets can help reduce emissions. They use a statistical model with panel data, finding that the EU ETS have prevented more than 1 billion tons of emitted CO_2 in years 2008-2016. This quantity corresponds to 3.8% reductions of total EU-wide emissions compared to not applying the EU ETS in Europe. They claim that the price of carbon is not the only driving force of emission reductions, and that the policy is generally effective also during times of low carbon prices. Other studies also investigate whether carbon prices are a main driving force in emission reductions. For example, Haites (2018) studies the performance of carbon pricing policies with regards to emission abatements and cost effectiveness. He finds that carbon taxes overall in Europe has made reductions up to 6,5% over several years, he also notes that within countries where the EU ETS takes part the reduction moves more quickly than those with only a carbon tax. Another study focusing on possible factors influencing cap-and-trade policies' impact on emissions is Murray and Maniloff (2015). They use econometric models to quantify the emission reductions caused by the policy and reductions caused by other factors, such as additional environmental programs, recession and lowered natural gas prices. The result of their analysis shows that the emissions would have been 24% higher without the program, supporting that the policy is being efficient. They also argue that the emission reductions may have been due to institutional factors and not only to the permit price itself.

In a review of numerous ex-post analyses of the EU ETS and carbon pricing, Green (2021) reflects that the general results of the studies are that the prices of carbon are not high enough to cause significant decreases in emissions. She also concludes that for such a comprehensive policy there is seemingly little knowledge about its ex-post performance and emphasizes the need for more empirical work to assess the effect of carbon pricing on emission reductions. Many studies are assessing the first and second phases of the EU ETS policy, most of them with the results of low policy efficiency. In a firm-level perspective of the EU ETS, Jaraite-Kažukauske and Di Maria (2016) use data of Lithuanian firms between 2003-2010, assessing the impact of the EU ETS on the environmental performance before and after the implementation. Their results show that the EU ETS participation did not lead to a reduction in CO_2 emissions. Although, a slight decrease in emission intensity was identified. Kotnik et al. (2014) investigates the effect of the emission price on greenhouse gas emissions from industrial processes in 19 EU countries. They find that an increase in carbon price by 1 euro results in a 0,014 ton decrease in emissions per year in industrial processes. In a Swedish perspective of EU ETS evaluation, Sandoff and Schaad (2009) also assess the first trading period of the policy, examining the experiences of the actors in the trading sector of the at the time recently implemented ETS policy. Their study is based on a survey which gives an account of the attitudes and actions of the companies included in the Swedish emissions trading sector. The study reveals that Swedish companies show significant interest in reducing emissions, but without any close attention to the pricing mechanism of the market-based instruments (ibid). This could be an indicator of low efficiency of the trading system, which is a frequently stated result from assessments of the early EU ETS phases.

The ETS policy has also been implemented in other geographical regions than Europe, and these has also been assessed in various ways by previous works. In an Asian perspective of the ETS, Zhang et al. (2020) is evaluating the effect and efficiency of the ETS in reducing carbon emissions and the impact on economic growth in China, since its implementation in 2013. They carry out this assessment by applying a difference-in-difference method and a data envelopment analysis to evaluate the operating efficiency of the carbon emission trade market. The results showed that the ETS significantly reduced the emissions of industrial CO_2 in all emission trading pilots, and that the average emission intensity has decreased annually in China.

Overall, a lot of previous research can be found about the ETS policy. However, surprisingly few are assessing the policy's general effect on emissions. Furthermore, many studies are evaluating the impact of various factors' effect on allowance prices, but not many are assessing the price effect on emissions. Also, many articles are dated and covers the early phases of the EU ETS. Since no consensus about the EU ETS price effect on emissions is yet established, this project can further contribute to the literature with updated knowledge in the subject, using new data. It will support the literature with additional information about phase 2 and 3 of the EU ETS and how the policy has influenced CO_2 emissions of the Swedish industries, focusing on price effects. It can also contribute with further understandings of how the different sectors react to changes of carbon prices, which could indicate whether differences in policy efficiency are actual amongst industry sectors in Sweden.

3. Method

This section will describe the theoretical framework of the thesis, an empirical motivation of chosen method, and a hypothesis. This is followed by a data description, presentation of any assumptions, and an explanation of the econometric model.

3.1. Theoretical framework

This study is following a supply and demand theory, as the EU ETS policy is built on an auctioning principle. The policy has created an emissions trading market for CO_2 allowances which entails supply and demand conditions, creating a corresponding price for carbon emissions (Aatola et al. 2013). The supply and demand create a relationship between the price that suppliers are willing to offer, and the price buyers are willing to accept when purchasing a good (Snyder & Nicholson 2017). Economist Alfred Marshal (1842-1924) showed that supply and demand simultaneously operate to determine the price, just like scissors has two blades making the cut. The price is therefore determined by the equilibrium between supply and demand. When the demand for allowances grows larger than the supply, the price of allowances will increase (Aatola et al. 2013). In the same sense the price will decrease if the demand is less than the supply. As the allowance market works in an equilibrium model the price is determined by the occasional supply and demand of allowances.

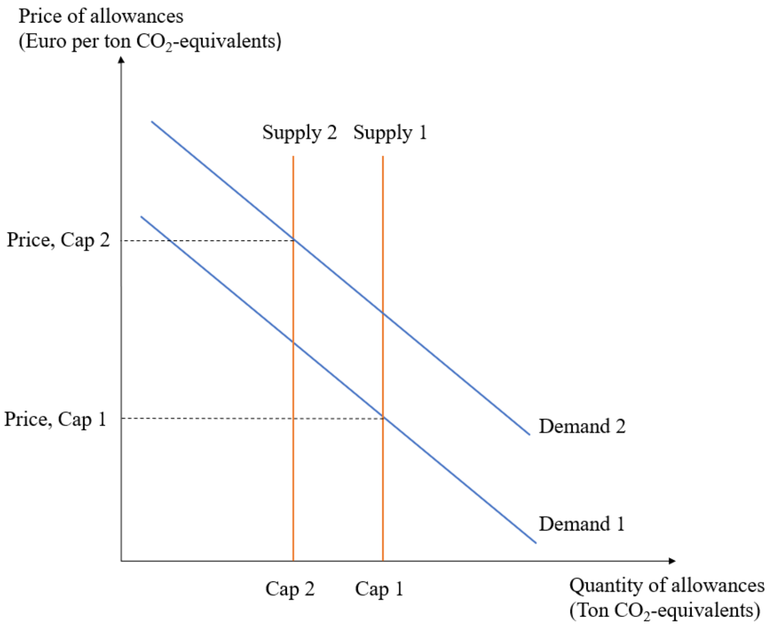

Figure 2 Market based system with inelastic supply. Source: Own processing 2021.

The level of supply of EU ETS allowances in the market is determined by policymakers as they decide the cap of allowed emissions (Figure 2). If the cap is lowered, the supply of allowances decrease, which entails a higher price. Also, the level of demand determines the price, if the demand of allowances is increased the price will also increase.

The price of allowances itself has an influence on purchasers (Aatola et al. 2013). If the price of allowances is lower than the cost of adjusting the production to emit less, the producers will choose to buy allowances instead of changing their production to be more environmentally friendly. At the point where the price of allowances exceeds the cost of making the green adjustment of production, the producers will choose to cut their emissions. Although, under the assumption that firms protect themselves against uncertain and volatile permit prices, they will also engage in forward trading. This is to administer their scope so that decisions involving abatements and productions can be made with regards to the expected value of the forward price of an allowance (ibid).

3.2. Empirical motivation & Hypothesis

There are various sorts of econometric models that can be used to assess how independent variables affect a dependent variable (Stock & Watson 2007). According to Zang and Wei (2010), statistical analyses such as multivariate linear regression models are often used when evaluating causes and effects of the pricing mechanism of the EU ETS. Also, Green (2021) reviews previously published EU ETS articles and lists several works where panel regression analysis is applied. Many have used this method to evaluate the impact of combustion in different industry sectors on emission allowance prices in various European countries. It has also been applied when assessing socio-economic effects (ibid). For instance, Chevalier et al. (2009) uses a multivariate linear regression analysis to shed light on any relations between macro-economic variables and the carbon market. Alberola et al. (2008) also uses a multivariate linear regression method to empirically study the interaction between the EU ETS carbon- and energy prices and shows that outside temperature had a significant effect on the carbon price during the first EU ETS time-period.

This project will use a panel regression analysis to investigate how the emissions of various Swedish industries are affected by the price of emissions. Since previous studies prove relevance of the use of regression analyses when evaluating various factors' effects on a variable, this is most likely an efficient instrument to answer the research question of this thesis. In this project, it is probable that the results will show a significant negative effect of allowance prices on emissions. This hypothesis is based on the observation of last years' negative trend of emissions related to the last years' positive trend of prices (Figure 1).

3.3. Data description

The data used is a panel data covering the period 2008-2020, limited to six Swedish industries, where the quantity of industry emissions is the dependent variable in terms of the logarithm of tons of CO_2 equivalents. The data of emissions from the various sectors was collected from the European Environment Agency, EEA (2021). The dataset originally included 18 industry activities for producing and manufacturing raw materials and goods in factories. From this initial dataset 4 activities were excluded due to a lack of complete data for the selected time-period. The remaining 14 activities has then been combined and regrouped into 6 higher-level sector groupings, with support from Table 6-3 in the EEA ETC/CME Working Paper descriptions of activities' sector belongings. This resulted in following industries:

1. Refineries
2. Iron & Steel
3. Non-metallic minerals
4. Pulp & Paper
5. Chemicals
6. Electricity & Other combustion

The data of allowance-prices was collected from Ember (2021) and covered weekly spot-price data of EU ETS Allowances in euros. This was manually adjusted into yearly mean prices.

Data of the Industrial production index (IPI) was collected from Statistics Sweden, SCB (2021). This dataset measures the real output of the industries and show the levels of production and capacity as a chain index, 2015=100, by industrial classification of NACE Rev. 2. The dataset is day- and seasonally adjusted and has manually been changed from monthly index to yearly index by calculating the yearly mean. This adjustment makes the base year of 2015 in some sectors take a marginally different value than 100. To enable a panel-regression analysis including variables of both emissions and production, a matching of the industry sectors of the EEA and the NACE Rev. 2 was necessary. This was done by comparing the Detailed Structure-tables of NACE Rev. 2 with Table 6-3 in the EEA ETC/CME Working Paper.

Table 1 Descriptive statistics of variables

Variable	Description	Units	Mean	Min	Max
Production	Industrial production output	Index	100.29	76.88	141.88
TotEmissions	Total GHG-emissions	Ton of CO_2-equivalents	3179340	55979	1.01e+07
Log-TotEmissions	Dependent variable, logarithm of total GHG-emissions	Logarithm of Ton of CO_2-equivalents	6.22	4.75	7.01
NewSectorID	Group variable, industry sectors: 1 – Refineries 2 – Iron & Steel 3 – Non-metallic Minerals 4 – Pulp & Paper 5 – Chemicals 6 – Electricity & Other Combustion		3.5	1	6
Year	Time variable	Years	2014	2008	2020

Price	Price of EU ETS emission-allowances	EUR/ton	12.89	4.46	24.89
LogPrice	Logarithm of price of EU ETS emission-allowances	Logarithm of EUR/ton	1.04	0.65	1.40

To investigate whether the dataset contains stochastic trends or random walks, unit-root tests will be applied (Bai & Carrion-I-Silvestre 2009). The presence of unit roots in the data are not optimal when doing a regression analysis. The unit roots are stochastic variations in the trends of the dataset, which may negatively influence the outcome of the estimated model and cause inaccuracy of the results. The variables in this project will be tested with the Levin-Lin-Chu unit-root test, a test especially appropriate for panel data, to evaluate if the data is stationary or contains unit-roots (Levin et al. 2002). The tests will be implemented to verify if the trending data should need to be differenced or regressed on determinative functions of time to make the data stationary. Due to the timeframe, implementation of such means will not be possible within the scope of this thesis. This is a possible weakness of the study which must be considered when analyzing the results. The results of these tests will be shown in Appendix 2 and briefly mentioned in the Results part of this thesis.

3.4. Assumptions

The production-index data covers all production in Sweden. However, not all producers in Sweden are included in the EU ETS policy. Although, since the chosen industries are considered as emission intensive industries (Brännlund & Lundgren 2010), an assumption has been made that the production data is covered by the EU ETS policy. This was done to enable an inclusion of a production variable in the model, as unitary production data among the industries cannot be elsewhere found and cannot manually be generated within the scope of this project. This assumption however brings a possibility of bias to the results and is to be considered a weakness of the study.

Due to the lack of availability of lower-level subsector data in the collected NACE Rev. 2 production data, usage of higher-level sector production data was necessary to enable an analysis. The lack of sophisticated data made it required to manually match the EEA-sectors' data with the NACE Rev. 2-sectors' data, which brought this study to making some assumptions. The production data sometimes included additional subsectors that the emissions data of EEA is not presenting. The EEA activities "Metal ore roasting or sintering", "Production of pig iron or steel" and "Production or processing of ferrous metals" are, according to the EEA ETC/CME Working Paper, subgroups of "Iron & Steel". This was therefore matched with the NACE Rev. 2 sector "Mining and Quarrying", due to its prominent contents being Iron & Steel production. However, other production-subsectors such as coal, lignite and other mining or quarrying sectors are also included in the "Mining & Quarrying" section. This is a weakness of the study, and the results should by that be analyzed with caution due to potential underlying bias. Similar assumptions have been made with the remaining sectors. The EEA activities "Production of cement clinker", "Production of lime, or calcination of dolomite/magnesite", "Manufacture of glass", "Manufacture of ceramics", "Manufacture of mineral wool" and "Production or processing of gypsum or plasterboard" are according to the EEA ETC/CME Working Paper subgroups of the "Non-metallic minerals"-sector. This was therefore matched with the "Industry for other non-metallic minerals"-section of NACE Rev. 2. "Refining of mineral oil" is a subgroup to the "Refineries"-sector and was matched with the NACE rev. 2 section of "Manufacture of coke and refined petroleum products". The EEA activities "Production of pulp" and "Production of paper or cardboard" are subgroups of "Pulp & Paper". This was matched with the production data of "Industry for pulp, paper and paperboard". The EEA activity "Production of carbon black" is a subgroup to the "Chemicals"-sector and was matched with the production data of "Industry for chemical, chemical products and pharmaceutical products". The EEA activity "Combustion of fuels" is, according to the EEA ETC/CME Working Paper, mainly covering electricity production, plus various manufacturing industries. Therefore, this has been matched with the "Electricity, gas, steam and hot water plants" production data.

3.5. Econometric model

This project will apply a panel regression analysis in its assessment. The model will evaluate the effect of the EU ETS carbon price on emissions of Swedish industries. It will do this by including an independent variable of the EU ETS carbon price in the model, with industrial emissions as the dependent variable. However, there may possibly exist additional factors affecting emissions of Swedish industries. One likely factor is the volume of production in each sector. It is possible that the size of emissions is in positive correlation with the size of industrial production. To account for this possible correlation in the analysis, a variable for industrial production output will be included in the model. It could be considered that the variable for production acts as a control variable for several possible factors influencing the emissions, whilst primarily affecting the level of production. This could for instance be market related shocks such as the 2008 financial crisis or the 2020 Covid-19 crisis, or general fluctuation of market prices or demands. It could also correct for the link between outside temperature and emission prices shown by Alberola et al. (2008), since outside temperature probably affects the output quantity of production in the energy market. No other control variable can be considered or included in the model within the scope of this study, which is a weakness of the study, and may entail omitted variable bias.

The econometric equation is specified as:

$$\log Y_{it} = \alpha + \beta_1 \log X_{1t} + \beta_2 X_{2it} + \beta_3 X_{3t} + \beta_4 X_{4i} + \varepsilon$$

Where Y is the total emissions, α is the constant, X_1 is the allowance-price, X_2 is the production index, X_3 a dummy variable for Year, and X_4 a dummy variable for Sectors. The variables Year and Sectors were tested as dummies in the model and the presence did change the coefficients and improve the significance of all variables in the model. The inclusion of the dummies also increased the R^2 value, as well did the inclusion of both variables Production and Price, whereas all 4 variables were considered valuable for a good model fit. As noted, the model will use the logarithm of total emissions and the logarithm of prices. The use of logarithmic variables in both left- and right-hand side is useful when interpreting the coefficients (Benoit 2011). This log-log relationship enables a clear explanation that when variable X_1 increases with 1%, the Y variable changes with β_1%. The coefficient of a logarithmic variable in a log-log relationship is commonly referred to as an elasticity. Since the variable for Production is an index of industrial production output, it will not be made logarithmic.

Econometric models are commonly used when applying panel data, two of them being the Fixed effects model and the Random effects model (Stock & Watson 2007). The Random effects model, unlike the Fixed effects model, assumes the variation across entities is random and uncorrelated with other independent variables in the model. Different tests can be applied to decide whether random effects model or fixed effects model is better applied. This project will perform a Hausman test to determine whether Random or Fixed effects model should be used.

When assessing a panel data, which includes a time aspect, it is essential to apply de-trended stationary data (Stock & Watson 2007). Otherwise, the variance and the mean will also increase, since the data in the series is constantly growing over time. The index of production in this model is seasonally adjusted and de-trended, yet the variables of price and emissions are not. However, these variables are made logarithmic in the model, which could contribute to de-trending the data. A measurement of stationary or non-stationary datasets is a homoscedasticity test, where homoscedasticity is a state with continuous residual variance throughout the dataset (Stock & Watson 2007). Although the applied price- and emissions data in this project is made logarithmic, they cannot with any confidence be considered homoscedastic. Heteroscedasticity is a state where the variance of the variables is non-constant throughout the dataset. Such occurrence could affect the accuracy of the model and should be controlled for. The model in this project will be tested for heteroscedasticity with a Breusch-Pagan test. If the test is shown to be significant, the null hypothesis is rejected, which indicates that heteroscedasticity is present and the model is not reliable. If this would be the case, Robust Standard Errors will be applied to correct for any heteroscedasticity.

4. Results

This section presents the results from the completed tests and the applied econometric model.

Table 2 Correlation between variables

	Production	TotEmissions	LogTotEmissions	NewSectorID	Year	Price
Production	1.00					
TotEmissions	-0.18	1.00				
LogTotEmissions	-0.20	0.83	1.00			
NewSectorID	-0.02	0.18	-0.26	1.00		
Year	0.47	-0.05	-0.03	0.00	1.00	
Price	0.15	-0.02	0.00	-0.00	0.13	1.00
LogPrice	0.10	-0.02	0.01	0.00	0.04	0.98

Table 2 shows the correlation between variables. The correlation can fall between -1 and 1 which indicates maximum linear dependences, while a value of 0 indicates independence between the variables (Stock & Watson 2007). The logarithmic variables show a large correlation with their original variables, which is not unexpected. The remaining variables does not show high correlation amongst each other, the highest value being 0.47 between Year and Production, indicating that when years passes the production overall in some extent also increases.

The Levin-Lin-Chu tests in Appendix 2 investigates the occurrence of unit roots in the datasets of the different variables. The tests indicate existence of unit roots in the variables of Price and Emissions, but not for the variable of industrial production output. This implies that the data in the variables of price and emissions are non-stationary and could contain stochastic trends or random walks, which may lower the credibility of the results.

The Breusch-Pagan test in Appendix 3 shows a chi-2 test for occurrence of heteroskedasticity in the model. The results indicate the test to be significant, a result saying that heteroskedasticity is present. This result entails that Robust SE will be applied in the regression model to control for heteroskedasticity, which will provide more reliable results.

Table 3 Hausman test for Random versus Fixed model

	Coefficients			
	(b) Fixed	(B) Random	(b-B) Difference	Standard Error
LogPrice	-12.73	-12.73	-1.58e-09	3.53e-05
Production	0.0026	0.0026	1.27e-13	3.00e-09
Year				
2009	-3.16	-3.16	-3.91e-10	8.73e-06
2010	-2.83	-2.83	-3.62e-10	8.06e-06
2011	-3.63	-3.63	-4.55e-10	1.01e-05
2012	-6.62	-6.62	-8.23e-10	1.84e-05
2013	-9.40	-9.40	-1.17e-09	2.6e-05
2014	-7.76	-7.76	-9.63e-10	2.15e-05
2015	-6.39	-6.39	-7.93e-10	1.77e-05
2016	-8.39	-8.39	-1.04e-09	2.32e-05
2017	-7.91	-7.91	-9.83e-10	2.19e-05
2018	-2.22	-2.22	-2.77e-10	6.17e-06
2019	0.09	0.09	1.24e-11	2.76e-07
Prob>chi2	1.00			

The Hausman test presented in table 7 analyses the differences between the coefficients of the Fixed effects and the Random effects models. If the differences of coefficients are systematic the null hypothesis will be rejected, and the Fixed Effects model is a better model fit for the dataset. In this case the results show a p-value of 1.00 which indicates that the test is insignificant and the differences in coefficients are not systematic. This result suggests that the Random effects model is better fitted for this dataset, which will be pursued in the regression analysis.

Table 4 Results of Panel Regression Analysis

Variables	Robust Coefficient	Standard Errors	P>|z|
LogPrice	-12.73***	4.25	0.003
Production	0.0026**	0.0011	0.016
Year			
2009	-3.16***	1.01	0.002
2010	-2.83***	0.95	0.003
2011	-3.63***	1.21	0.003
2012	-6.62***	2.20	0.003
2013	-9.40***	3.12	0.003
2014	-7.76***	2.59	0.003
2015	-6.39***	2.14	0.003

2016	-8.39***	2.80	0.003
2017	-7.91***	2.64	0.003
2018	-2.22***	0.73	0.003
2019	0.09**	0.05	0.037
2020	0	(omitted)	
NewSectorID			
2	0.19***	0.01	0.000
3	0.06***	0.00	0.000
4	-0.52***	0.00	0.000
5	-1.55***	0.01	0.000
6	0.45***	0.00	0.000
cons	23.84***	5.83	0.000

***, **, * indicates significance at 1%, 5% and 10% respectively

Table 8 shows the results of the Random effects panel regression analysis. The results show that all included variables are at 1% level of significance, aside from the variable of Production which is significant at 5% level. The logarithmic variable for price has a coefficient of -12.73 which implies that 1% increase in price is associated with a 12.73% decrease in emissions. The coefficient for Production is 0.0026. As the production variable in this case is an Index variable, which tells the percentage change of production related to a base year, it should be interpreted as any logarithmic independent variable in a log-log relationship. Therefore, the results indicate that for a 1% increase in production there will be a 0.0026% increase in emissions. The variables of Year and NewSectorID are non-logarithmic dummies. The results of these variables, being in a log-linear situation, need some adjustment before making interpretation. However, these coefficients will not be considered in this study since the different industries' portions of the total emissions can be graphically displayed from historical data. Such data is presented in Figure 2 and will further be graphically analyzed from there.

5. Discussion

In this section the results of the thesis will be discussed, along with a graphical analysis of illustrated data of EU ETS allowance prices, EU ETS emissions, and industrial production output. This will be put in relation to the reforms of the policy, to analyze the policy's effect on Swedish industrial emission reductions, as well as on any changes of the industries' production turning more environmentally friendly.

This thesis has measured the effect of the EU ETS carbon price on emissions of Swedish Industries. The findings may help understand sector-specific effects of the EU ETS carbon price and thus contribute to further knowledge about favorable sector-specific adjustments for increased policy efficiency. This could help improving the emission reductions, which would support reaching the goal of the Paris agreement.

5.1. Analysis of econometric results

The variables in the model all had high significances which indicate that they affect the emissions. The variables of price and emissions are non-stationary according to the unit-root tests. This is not surprising since both variables probably include random walks or trends due to external effects. Random happenings such as the economic crisis in 2008, the covid-19 crisis in 2020 or other market related fluctuations affecting the sectors probably have an impact on the Swedish industries. Nevertheless, the presence of unit-roots and heteroskedasticity may affect the accuracy of the estimated results. Also, the coefficients from the results of a random effects panel regression can be somewhat difficult to interpret since they include both within-entity and between-entity effects, having a weighted average of within and between estimators. This is important to have in mind when evaluating the results, knowing that the estimated coefficients may not be directly applicable to each sector. The different designs of the EU ETS phases could also affect the accuracy of the result due to structural breaks, making historical values not completely valid for predictions or estimations of today's market. Before 2013 the allowance trading market was not fully developed, which entails differences in market effects and price changes over time, and in the industries' reactions to such changes.

The coefficient of price declares that a 1% increase in price makes a 12,73% decrease in emissions. This variable is highly significant which confirms the stated hypothesis of this thesis; allowance-prices are having a negative effect on emissions. This is in line with previous research of the EU ETS (Kotnik et al. 2014; Haites 2018; Murray and Maniloff 2015). However, the coefficient value of 12,73 is considerably high compared to previous literature. For example, Kotnik et al. (2014) finds that an increase in carbon price by 1 euro results in a 0,014 ton decrease in emissions per year in industrial processes. When comparing the results of this thesis with Kotnik et al. (2014) it is favorable to adjust the units to similar units as theirs. As the yearly mean price in this thesis is 12,89 euro, a 1% price increase would equal an increase of 0,1289 euros per ton CO_2. The yearly mean of total emissions in this thesis is 3 179 340 ton CO_2-equivalents. A 12,73% decrease in emissions would then equal a decrease of 404 730 ton CO_2-equivalents. Therefore, the results of this thesis suggests that an average yearly increase in price of 0,1289 euro per ton is associated with an average yearly emissions decrease of 404 730 ton CO_2-equivalents. Evidently, Kotnik et al.'s (2014) estimated value is considerably smaller, and although a negative relationship is likely, the size of the estimated price-effect in this thesis is questionable. A likely explanation of the high estimate of price is the possibility of omitted variable bias in the model. Factors such as offshoring, emission-abatement costs, or other environmental policies could have large impacts on the emissions of Swedish industries. Sweden has ambitious environmental goals compared to other countries taking part of the EU ETS, meaning that additional policies, environmental goals, and measures for attaining emission abatements have been implemented in the Swedish economy lately (Naturvårdsverket 2020). This could have had a contributing part in the decreased emissions in Sweden and the exclusion of such important variables from the model have probably caused biased results in this thesis. Furthermore, it is questionable if industries really are quick adjusters of production processes, and whether they are agile enough to be able to respond to price changes simultaneously as the changes occurs. It is probable that some industries during previous years proactively have ventured for a more sustainable production to become more environmentally friendly, even before any substantial price increase, enabling simultaneously reduced emissions. Such possible venturing could be caused by several reasons, such as previous supports for environmentally friendly investments, cost fluctuations of abatement measures through time, or the producers' estimations of future policy changes. The allowance price itself could then perhaps not be considered the only causal factor of the decreased emissions in Sweden, even though there is a statistically significant price effect showed by the results of this thesis. As Bayer and Aklin (2020) state, the EU ETS has been effective even during times of low allowance prices. Similarly, Haites (2018), and Murray and Maniloff (2015) argues that the price effect of the EU ETS allowances is significant, but that the policy has been more effective than simple price-controlling policies such as carbon taxes. This confirms a probability of additional dimensions within the policy, other than price effects, causing emission reductions. In future research, the eventuality of such additional causal effects of the EU ETS, and the eventuality of additional factors affecting industrial emissions, needs to be considered and further evaluated to obtain more reliable results.

5.2. Co-movement between Emissions, Allowances and Price

This section will assess whether the rapid price increase following 2017 is due to market effects, relying on the theory of supply and demand.

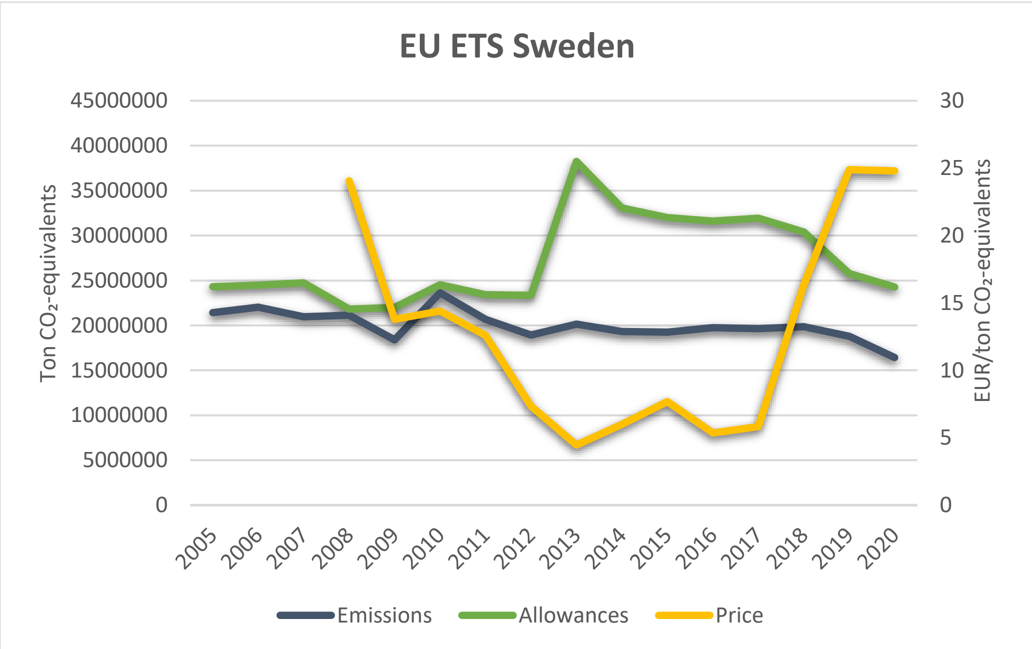

Figure 3 Allocated emissions and allowances in Sweden. Yearly average price changes. Source: Own processing 2021. Based on data from EEA 2021, Ember 2021.

Figure 2 shows the allocated allowances in Sweden since the implementation of the EU ETS. It also shows all verified emissions from industries covered by the EU ETS in Sweden. The yellow line presents the fluctuations in allowance-price over time. The emissions initially show a generally consistent level, apart from the fluctuations following year 2008 most likely reflecting the effects of the financial crisis. The drop in price following 2008 may also reflect the financial crisis, lowering the demand of allowances in some sectors. It could also reflect the EU ETS reform in 2008, making the policy more transparent whereas a large surplus of allowances in the market became visible. Such noted market-based relationships of price fluctuations are in accordance with the theory of supply and demand presented by Snyder and Nicholson (2017). The emissions appear to remain relatively stable between 2013 and 2018 where it then subsequently decreases. The allowances show a rapid increase in 2013, which is a result of the policy reform entering phase 3. The market then progressively became more transparent, and the auctioning principle was more thoroughly applied, which enabled the policy to attain more of a genuine market context. The emissions-cap was gradually lowered throughout phase 3 and a clear decrease is observed after 2017, turning even more distinct after 2018. The rapidly increasing allowance price after 2017 reflects this lowered level of allowances, a relationship indicating that the auctioning principle of the policy sets in. This reaction is in line with Hepburn's (2006) statement of symmetry between regulation of quantities and prices, as the use of quantity instruments always entails a related indirect price. It also agrees with the supply and demand theory described by Snyder and Nicholson (2017), stating that lowered levels of supply entail an increased price. Hence, it is probable that the auctioning principle of the EU ETS and the supply levels of allowances decides the allowance price.

5.3. Sector-level differences

This section will graphically analyze and discuss any differences between the Swedish sectors regarding emissions and the year-by-year co-movements of emissions and industrial production output. Sector-level emissions over time are presented in Figure 4 together with the price of allowances over time.

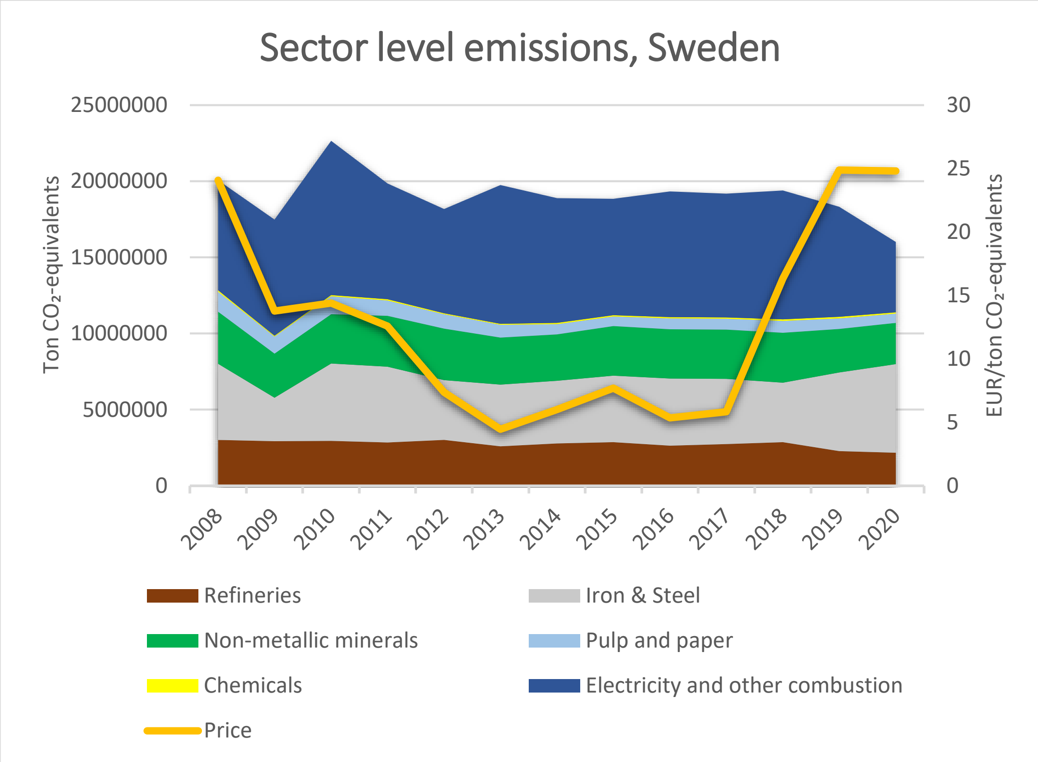

Figure 4 Swedish industrial emissions from different sectors. EUA price. Source: Own processing 2021. Based on data from EEA 2021, Ember 2021.

Large overall fluctuations in emissions can be observed after the financial crisis 2008, where the sector of Iron & Steel has a substantial part of the changes in emissions (Figure 4). The levels of emissions in the industries then remained rather stable between years 2013 and 2017. Various changes can be observed after year 2017 when the price rapidly increased. The overall emissions decreased after that point, where all sectors took part of this reduction, except for the Iron & Steel sector where the emissions instead increased.

An important objective of an environmental policy is to induce lowered emissions without a decrease in industrial production output, since the global emissions must be lowered whilst not hindering economic growth (European Parliament 2015). If industries can enable more production and less emissions, they are considered as less emission intensive, and thus more environmentally friendly in their production. The different sectors' emissions and production outputs are illustrated in Figure 5 – Figure 10, as indexes with base year 2015=100.

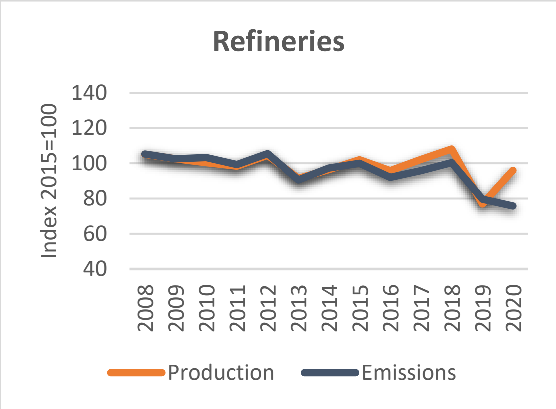

Figure 5 Production and emissions of Refineries. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

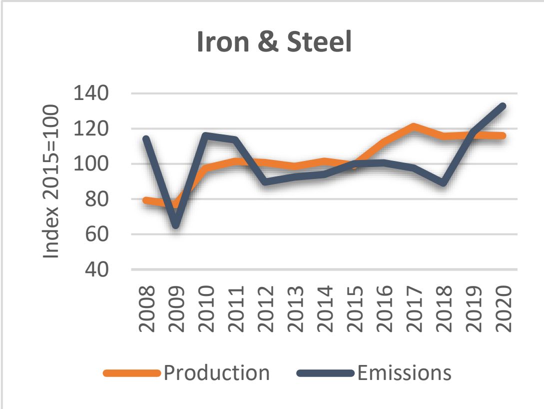

Figure 6 Production and emissions of Iron & Steel. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

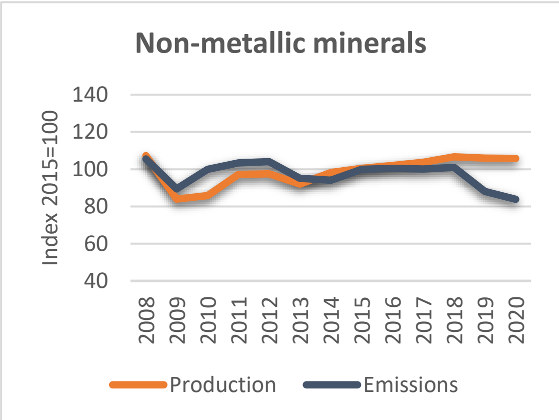

Figure 7 Production and emissions of Non-metallic minerals. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

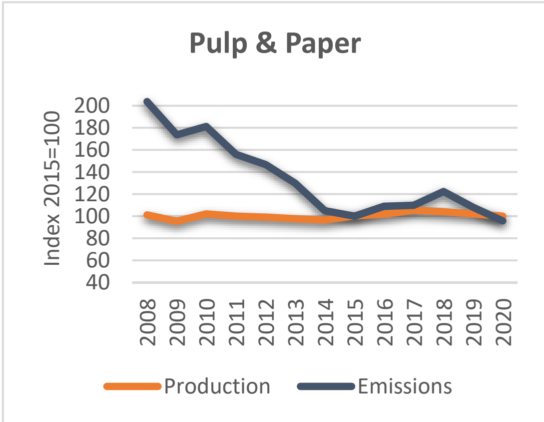

Figure 8 Production and emissions of Pulp & Paper. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

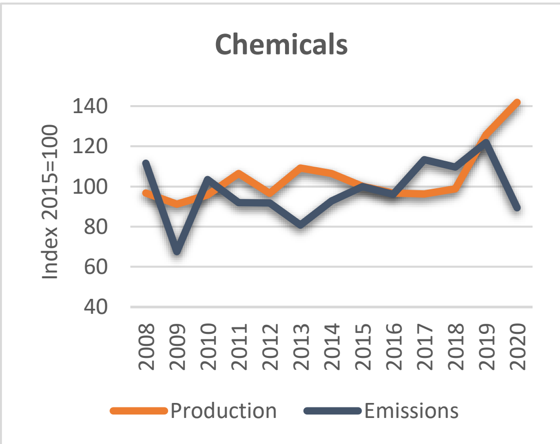

Figure 9 Production and emissions of Chemicals. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

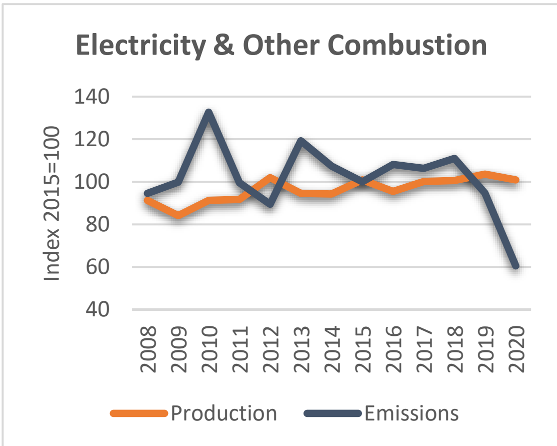

Figure 10 Production and emissions of Electricity & Other combustion. Source: Own processing 2021. Based on data from SCB 2021, EEA 2021.

The occurrence of an overall increased environmentally friendly production is indicated by the negative correlation between Production and Emissions in Table 2. The correlation of -0,20 is not high, but it is a negative correlation, indicating that for an overall increasing production, emissions decrease. This is notably visible in Figure 8, presenting the Pulp and Paper sector, which shows that the emissions were initially high but then decreased over time although production output is held relatively constant. Similar developments can be observed in most sectors. The Electricity and Other combustion sector presented in Figure 10 shows that the level of production appears to be kept relatively consistent, and over time indicates a slightly increasing trend. In contrast, the emissions show a rapid drop after year 2018, a relationship indicating that the emitted CO_2 per produced output has decreased in the Electricity- and Other combustion sector. This is a signal that the policy is being effective and that the price increase after 2017 enhanced incentives to adapt less emission intensive methods in the production. The Non-metallic minerals sector in Figure 7 indicates this pattern as well, where the trends of emissions and production tends to correlate throughout time, until year 2018 where the emissions started decreasing despite production being held constant. The Chemical-sector in figure 9 is also showing a break of pattern after year 2018. The production is seemingly held constant until 2018 where it then shows a rapid increase. The emissions of this sector show an overall increasing trend after 2013 until 2019, where it then rapidly drops year 2020 even though production is increasing, a reaction indicating that the emission intensity is lowered. The Refineries sector in figure 5 show a large drop in emissions after 2018, although also a large drop in production. However, the year of 2020 is showing a recovery of production, whilst the emissions keep decreasing. This is also indicating a decreased emission intensity, implying that a more environmentally friendly production is achieved.

The pattern of a more environmentally friendly production after year 2018 is demonstrated by all sectors in this thesis except for the Iron & Steel sector, presented in figure 6. Furthermore, the industry of iron and steel is the only one not showing a decrease in emissions after 2018. This is an important actuality since it might indicate a lack of policy efficiency concerning this specific industry sector. In contrast, there is a distinctive response from the Electricity & Other combustion sector, which indicates a large policy efficiency. Perhaps the various sectors need to be approached differently due to their different preconditions, characteristics, and circumstances of production. As Aatola et al. (2013) argues, the producers will not choose to cut emissions until the point where the allowance price exceeds the costs of making green adjustments. This argument tells me that the Iron & Steel sector probably faces higher abatement costs than for instance the sector of

Electricity & Other combustion, a possible actuality causing the differences of policy efficiency among the sectors.

Considering that all sectors except one are showing similar changes in patterns after year 2018, when a rapid price increase simultaneously occurred, it is likely that the allowance price is having an effect on the lowered emission intensity. This is supported by the statistically significant variable of price in the results of this thesis's econometric model. It also agrees with the findings of Jaraité-Kažukauske and Di Maria (2016), who noticed a lowered emission intensity among industries due to the EU ETS. However, the price effect on the emission intensity has not been statistically tested in this thesis, neither has actual ratios of emissions per production output been calculated and assessed. Other factors of the policy than the allowance price could have an effect on emission reductions or increased environmentally friendly production, as Bayer and Aklin (2020), Haites (2018) and Murray and Maniloff (2015) show. Such additional factors have not been considered in this evaluation and needs to be further investigated.

6. Conclusions

The aim of this study was to investigate the effect of the EU ETS allowance price on emissions of different industries in Sweden. This has been done by assessing the price effect of allowance prices on emissions, using a random effects regression analysis. All variables in the model were shown to have a statistically significant influence on emissions, where price has a negative effect on emissions, and the output of production has a positive effect on emissions. The coefficient for price was shown to be relatively high; a 12,74% overall decrease in emissions for a 1% increase in price. This large estimate is likely due to underlying bias from the limitations within the dataset and the model. Other factors and circumstances not included in this analysis may have an impact on emission reductions of Swedish EU ETS industries. Consequently, more research about additional contributing factors of emission reductions is needed. Nevertheless, the results of this thesis are making relevant contributions to the scientific debate. The findings of a significant negative effect of the EU ETS allowance price on industrial emissions are contributing to the discussion about price effects in this field of study, where no consensus have yet been reached.

The graphical year-by-year analysis of the emissions and the co-movements of emissions and industrial production outputs reveals heterogeneity between industry sectors. These findings specifically acknowledges that the Iron & Steel industry does not seem to be affected by the changes of the EU ETS allowance price. All other sectors show decreased emissions after 2017 when a rapid price increase occurred, and also appears to carry a less emission intensive production since then. These findings suggest that most Swedish industries are becoming more environmentally friendly due to the policy, but that there are differences in how well the policy perform in the various sectors. The findings of such differences in policy efficiency between sectors could significantly contribute to and be of relevance for policy makers. More comprehensive research is needed to evaluate these sector-specific differences, as well as further discussions about possible favorable sector-specific adjustments of the EU ETS, which could help reach an overall increase in policy efficiency. Such increased policy efficiency could help decrease the emissions further, and thereby contribute to reaching the goal of the Paris agreement.

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Appendix 1

Complete data (SCB 2021, EEA 2021, Ember 2021).

Year	Production (Index)	TotEmissions	Emissions (Index)	LogTotemissions	NewSector	NewSectorID	Price	LogPrice
2008	105,1417	3018116	105,3351	6,479736	Refineries	1	24,07	1,381476
2009	102,5667	2939159	102,5795	6,468223	Refineries	1	13,78	1,139249
2010	100,325	2957670	103,2255	6,47095	Refineries	1	14,41	1,158664
2011	98,425	2847035	99,36424	6,454393	Refineries	1	12,59	1,100026
2012	104,4833	3023274	105,5152	6,480478	Refineries	1	7,36	0,866878
2013	91,525	2596336	90,61461	6,414361	Refineries	1	4,457411	0,649083
2014	96,39167	2786094	97,23735	6,444996	Refineries	1	6,002972	0,778366
2015	102,0917	2865251	100	6,457163	Refineries	1	7,69351	0,886125
2016	95,78333	2637710	92,0586	6,421227	Refineries	1	5,353721	0,728656
2017	102,2167	2745232	95,81122	6,438579	Refineries	1	5,83724	0,766208
2018	108,15	2875171	100,3462	6,458664	Refineries	1	16,34051	1,213266
2019	76,95	2281280	79,61885	6,358179	Refineries	1	24,8878	1,395986
2020	96,05	2172035	75,8061	6,336867	Refineries	1	24,80441	1,394529
2008	79,275	4999042	114,2059	6,698887	Iron and Steel	2	24,07	1,381476
2009	76,875	2847030	65,042	6,454392	Iron and Steel	2	13,78	1,139249
2010	97,49167	5073654	115,9105	6,705321	Iron and Steel	2	14,41	1,158664
2011	101,3667	4974667	113,6491	6,696764	Iron and Steel	2	12,59	1,100026
2012	100,75	3925106	89,67125	6,593851	Iron and Steel	2	7,36	0,866878
2013	98,59167	4053727	92,60967	6,607854	Iron and Steel	2	4,457411	0,649083
2014	101,5	4115323	94,01686	6,614404	Iron and Steel	2	6,002972	0,778366

2015	99,20833	4377218	100	6,641198	Iron and Steel	2	7,69351	0,886125
2016	112,325	4399098	100,4999	6,643364	Iron and Steel	2	5,353721	0,728656
2017	121,2417	4275433	97,67466	6,63098	Iron and Steel	2	5,83724	0,766208
2018	115,5667	3900477	89,10858	6,591118	Iron and Steel	2	16,34051	1,213266
2019	116,375	5162189	117,9331	6,712834	Iron and Steel	2	24,8878	1,395986
2020	115,925	5813576	132,8144	6,764443	Iron and Steel	2	24,80441	1,394529
2008	107,2833	3416644	105,5192	6,5336	Non-metallic minerals	3	24,07	1,381476
2009	83,95833	2895841	89,43478	6,461775	Non-metallic minerals	3	13,78	1,139249
2010	85,84167	3236037	99,94135	6,510013	Non-metallic minerals	3	14,41	1,158664
2011	97,2	3348443	103,4129	6,524843	Non-metallic minerals	3	12,59	1,100026
2012	97,45	3367060	103,9878	6,527251	Non-metallic minerals	3	7,36	0,866878
2013	92	3081168	95,1584	6,488715	Non-metallic minerals	3	4,457411	0,649083
2014	98,25	3046083	94,07484	6,483742	Non-metallic minerals	3	6,002972	0,778366
2015	100,4667	3237936	100	6,510268	Non-metallic minerals	3	7,69351	0,886125
2016	102,0333	3250524	100,3888	6,511953	Non-metallic minerals	3	5,353721	0,728656

2017	103,6417	3240855	100,0902	6,51066	Non-metallic minerals	3	5,83724	0,766208
2018	106,725	3272031	101,053	6,514817	Non-metallic minerals	3	16,34051	1,213266
2019	106,0417	2850551	88,03605	6,454929	Non-metallic minerals	3	24,8878	1,395986
2020	105,7417	2715348	83,86046	6,433825	Non-metallic minerals	3	24,80441	1,394529
2008	101,325	1310964	203,7896	6,117591	Pulp and paper	4	24,07	1,381476
2009	95,43333	1118356	173,8486	6,04858	Pulp and paper	4	13,78	1,139249
2010	102,0833	1166424	181,3208	6,066856	Pulp and paper	4	14,41	1,158664
2011	100,2167	1003083	155,9294	6,001337	Pulp and paper	4	12,59	1,100026
2012	99,33333	943184	146,6181	5,974596	Pulp and paper	4	7,36	0,866878
2013	97,825	836819	130,0836	5,922632	Pulp and paper	4	4,457411	0,649083
2014	96,475	675928	105,0731	5,8299	Pulp and paper	4	6,002972	0,778366
2015	100,3917	643293	100	5,808409	Pulp and paper	4	7,69351	0,886125
2016	101,7	701968	109,121	5,846317	Pulp and paper	4	5,353721	0,728656
2017	105,3917	707186	109,9322	5,849534	Pulp and paper	4	5,83724	0,766208
2018	104,2167	787218	122,3732	5,896095	Pulp and paper	4	16,34051	1,213266
2019	102,1083	696323	108,2435	5,842811	Pulp and paper	4	24,8878	1,395986
2020	100,075	616606	95,8515	5,790008	Pulp and paper	4	24,80441	1,394529
2008	96,70833	92363	111,5105	4,965498	Chemicals	5	24,07	1,381476
2009	91,21667	55979	67,58382	4,748025	Chemicals	5	13,78	1,139249
2010	95,725	85647	103,4022	4,932712	Chemicals	5	14,41	1,158664

2011	106,5083	76123	91,9038	4,881516	Chemicals	5	12,59	1,100026
2012	96,64167	76031	91,79273	4,880991	Chemicals	5	7,36	0,866878
2013	109,1583	66885	80,7507	4,825329	Chemicals	5	4,457411	0,649083
2014	106,45	76806	92,72839	4,885395	Chemicals	5	6,002972	0,778366
2015	100,15	82829	100	4,918182	Chemicals	5	7,69351	0,886125
2016	96,78333	79668	96,1837	4,901284	Chemicals	5	5,353721	0,728656
2017	96,28333	93921	113,3914	4,972763	Chemicals	5	5,83724	0,766208
2018	98,84167	90816	109,6428	4,958162	Chemicals	5	16,34051	1,213266
2019	125,7833	100937	121,8619	5,00405	Chemicals	5	24,8878	1,395986
2020	141,875	74108	89,47108	4,869865	Chemicals	5	24,80441	1,394529
2008	91,21667	7231315	94,6535	6,859217	Electricity and other combustion	6	24,07	1,381476
2009	84,125	7631025	99,88545	6,882583	Electricity and other combustion	6	13,78	1,139249
2010	91,21667	10137260	132,6905	7,005921	Electricity and other combustion	6	14,41	1,158664
2011	91,66667	7601811	99,50306	6,880917	Electricity and other combustion	6	12,59	1,100026
2012	102,0083	6834517	89,45965	6,834708	Electricity and other combustion	6	7,36	0,866878
2013	94,60833	9113110	119,285	6,959667	Electricity and other combustion	6	4,457411	0,649083
2014	94,35	8198087	107,3079	6,913713	Electricity and other combustion	6	6,002972	0,778366
2015	100,8583	7639776	100	6,883081	Electricity and other combustion	6	7,69351	0,886125
2016	95,55833	8264494	108,1772	6,917216	Electricity and other combustion	6	5,353721	0,728656
2017	100,15	8124800	106,3487	6,909813	Electricity and other combustion	6	5,83724	0,766208

2018	100,5917	8474800	110,93	6,928129	Electricity and other combustion	6	16,34051	1,213266
2019	103,6	7233379	94,68051	6,859341	Electricity and other combustion	6	24,8878	1,395986
2020	100,925	4625242	60,54159	6,665134	Electricity and other combustion	6	24,80441	1,394529

Appendix 2

Unit-root test for Production.

	Levin-Lin-Chu test, Production	
	Statistic	**p-value**
Unadjusted t	-10.98	
Adjusted t*	-4.52	0.00

Unit-root test for LogPrice.

	Levin-Lin-Chu test, LogPrice	
	Statistic	**p-value**
Unadjusted t	-3.14	
Adjusted t*	-1.59	0.06

Unit-root test for LogTotemissions.

	Levin-Lin-Chu unit-root test for LogTotemissions	
	Statistic	**p-value**
Unadjusted t	-5.58	
Adjusted t*	0.13	0.55

Appendix 3

Breusch-Pagan test for heteroskedasticity.

	Breusch-Pagan test
chi2(18)	38.66
Prob > chi2	0.0032