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Tax or Clean Technology? Measuring the True Effect on Carbon Emissions Mitigation for Sweden and Norway

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Abstract: Studies of carbon emissions typically focus on price and tax effects or technology. We argue that the two are closely linked within an economy in disequilibrium. Our goals are twofold: (1) to examine the combined role of: low CO_2 technology, fuel taxes and CO_2 tax on taming CO_2 emissions and (2) to build a counterfactual analysis by capturing anything else that causes emissions to diverge from the trend such as renewable energy, energy laws and the state of the economy. The equilibrium correction model (EqCM) suggests that emissions have a long-term relationship with economic growth, fossil fuel use, taxes and clean power sources. Both oil and gas extraction and economic growth raise Norway's emissions, offsetting the mitigating effect of taxes. Sweden´s carbon fuel tax elasticity is 20%, a value far above Norway´s elasticity, even though these carbon taxes were phased-in under a period of macroeconomic instability, weakening their effectiveness. The income elasticity of emissions is negative for Norway and positive for Sweden. Emission cuts require (a) de-growth, (b) a higher tax on transport fuels and (c) electrification of transport. The effects of tax, technology, economic growth and those for the pre- and post-carbon tax era differ strongly in the two nations.

Keywords: carbon tax; error correction model; energy economy model; economy wide carbon emissions; mitigation of CO_2 emissions; transport fuels

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1. Introduction

The literatures on the economic valuation of carbon emissions (CO_2) have rarely used a disequilibrium framework for econometric analysis to explain the role of tax and technology in carbon emission mitigation strategies.

The Swedish economy has recorded rising carbon dioxide (CO_2) emissions in the years 1960–1976, but then saw falling emissions in 1976–2015. The rapid decline in emissions continued into the 2010–2019 period. In contrast, Norway´s emissions have steadily grown since the 1960s and only fell in 1990–1995, before rising again in 2005–2010, since then emissions have fallen until 2019. To control this growth, both countries introduced a carbon tax (price) in the 1990s (Sweden 1991; Norway 1991), an event which occurred under macroeconomic instability (low economic growth in Sweden in the 1990s), a new energy technology policy (nuclear energy in Sweden in the early 1970s; hydropower in Norway) and a cap on emissions. To unravel the emission factors, this study assesses whether emissions, the economy, fuel (carbon) taxes and consumer behavior (fossil fuel use), as well as the technology and the policy regime (including that of energy efficiency standards and clean technology programmes), are cointegrated and, if so, if there is a long-term equilibrium in CO_2 emissions. In the paper, a comparison is made of Norway and Sweden in order to observe the extent to which a fossil-fuel-rich economy like the former is better able to mitigate emissions than a fossil-fuel-poor economy such as Sweden. Cointegration is defined as a long-term equilibrium in the economy. We use an equilibrium correction model (EqCM) to find the long-term equilibrium among these economic and policy (tax) factors. The EqCM is defined as one (a) which has a well-defined equilibrium, and (b) in which adjustment takes place towards that equilibrium [1].

An equilibrium is a state from which there is no tendency to change [1]. The EqCM estimates both the short-term (cycle) and the long-term trend (permanent) of CO_2 emissions, which are subject to many influences aside from price. The EqCM based on the cointegration method breaks macroeconomic time series (emissions, economic growth, prices, electricity use, oil use) into a secular component and a cyclical component. Since the cyclical component dissipates over time, any long-term movement is attributed to the secular component [2].

To achieve macroeconomic stability, a control is needed [3–5], such as a target, i.e., a desired value of real consumption associated with cutting emissions which, in turn, is achieved by adjusting an instrument (i.e., taxation, government expenditure, subsidies, fraction of low-CO_2 electricity,). Changes in emissions, emission levels and cumulative past errors all need to be included in the rule to stabilize the target variables [1]. Adjustment of the instrument effect (tax) can be carried out within the EqCM. In the paper, we propose a new analytical method to explain emissions, building on the work of References [6–8].

This cointegration system assesses the combined effect of taxes and the announcement effect of a tax, defined as "an action taken to reduce the environmental impact that is the target of the tax, between the time of the announcement of the tax and its implementation, when this action would not have been taken in the absence of the tax had it not been announced" [9]. A CO_2 tax is a form of explicit CO_2 pricing, directly linked to the level of CO_2 emissions. It is expressed as a value per tonne of CO_2 tonne equivalent (per T-CO_2e). Energy taxes work as implicit CO_2 taxes and thus determine CO_2 prices. Taxes on CO_2 and on energy have been either endogenous or exogenous to induce technical change. This is the only paper that (a) develops disequilibrium macroeconomic models of CO_2 abatement, spanning decades, for the cases of Sweden and Norway, and (b) examines efforts to decarbonise an entire national economy since the effects of the tax should be seen in relation to other policy measures [10].

Our study extends the literature on emission pathways by assuming that short-term CO_2 emission responses to economic growth, prices, energy technology and hydrocarbon extraction are distinguishable from long-term responses. Emission cuts result from a decline in fossil energy use, including petroleum, gasoline and cuts in electricity generated by fossil fuels. These are CO_2-intensive sources of energy that are often central to major economic sectors such as industry, transport and households.

Many studies on CO_2 emissions rely on ex-post evidence, making it difficult to attribute the decline in CO_2 emissions only to tax rises. There are a variety of factors that dynamic macroeconomic models incorporate, often based on large-scale Computable General Equilibrium (CGE) models [7] or on dynamic optimization and macroeconometric models [11]. In recent years, econometric and other quantitative analysis of CO_2 abatement has expanded, including [12] a study of the Finnish economy; [13,14] of the U.S.; [15] and a study of the Canadian economy. The authors of [7] also carried out a statistical study on Europe.

Taxes are levied on fossil fuels for industrial processes, on transport fuels, on household fuels and on the power sector. Evaluation studies on tax do not consider the mutual interactions between pre-existing fuel taxes and CO_2 tax and policy instruments such as the low CO_2 standards for industrial equipment, transport and households. These mechanisms, along with that of the ETS allowance price "the actual spot price of CO_2 emissions", affect the CO_2 price. The CO_2 price is a factor in determining the volume of emissions, and this price is determined by the supply and demand of CO_2 emission allowances. Similarly, the level of energy tax is determined by the energy content for each fuel but not by the CO_2 content of fuels. There are three taxes that affect fossil fuel use and emissions: energy taxes on fuels, direct CO_2 taxes, and the CO_2 prices determined within the ETS. The sum of these three taxes can be seen as a surrogate for the real effective price of CO_2 and other externalities.

Evaluation of the true tax effect is further complicated by fuel efficiency standards (this lowers the CO_2 content of final fuel use) and other taxes such as the energy tax. Before the introduction of CO_2 taxes in the 1990s, significant theoretical and empirical work was developed [16–18]. The latter favours a carbon tax to a cap-and-trade system (ETS), since the climate change damage curve is flat. Cap-and-tax can provide CO_2 price stability, which facilitates investments in low-CO_2 technology.

Literature Review

In this section, we discuss the CO2 mitigation studies, as well as those on the environment and the economic growth nexus.

CO_2 mitigation models can be broadly classified into three categories: the first are models of dynamic optimisation [19], such as the Global 2100 model by the authors of [20] and the Poles model by the authors of [21]. The second are CGE models based on the concept of equilibrium in the market, with price and wage clearing to match supply and demand. Thirdly, there are macroeconometric simulations, such as that in this paper, which are estimated based on time series data (see also [7,22,23]). These models produce tax (price) and output effects. Recent advances in the approach have evolved from simple regression models to cointegration systems that capture disequilibrium.

Studies largely focus on changes in emissions, which result from changes in prices and in GDP. Studies on the environment and growth mostly rely on macroeconomic models with a static approach that ignores the dynamics of the macroeconomic system. Macroeconomic studies in the 1990s for energy planning in Norway and Sweden used the CGE framework [24], which assumes fixed prices and output and fixed substitution elasticities. These studies indicate that the costs of reducing emissions range from 169 to 700 US tonne-CO_2 (2000 USD prices) with GDP (welfare) losses ranging from a gain of 3.2 % to a loss of −1.3% of GDP (Ibid.). These methods focus on a single nation, but recent models use panel techniques based on data on many economies, such as as in Reference [25], or in Reference [11]. More recent models use evidence from interviews to determine whether the CO_2 price changes have induced cuts [26].

Studies can be further subdivided into (a) direct tax on CO_2 and (b) "Cap and Trade" for an emissions trading (ETS) scheme or "Cap and Tax". A global CO2 tax is sometimes considered a necessary tool to control emissions [19], while other studies find that the effectiveness of the tax depends on how fast a consumer reacts to a price change [27]. In Norway´s case, the CO_2 tax effect was found to be modest [8], while for the Swedish case, taxes are a powerful tool in cutting emissions [28]. Further positive evidence suggests that the carbon tax elasticity of demand for gasoline is three times larger than its price elasticity [6]. Evidence at the company level has established that a carbon tax reduces the carbon intensity of production for the Swedish economy [29–31].

After examining a high number of ex-post studies on CO_2 taxes for Scandinavian cities [32], three problems can be seen to explain the tax effect: frequent changes in tax rates, tax exemptions and "the too many variables" problem.

Four further studies on various types of CO_2 taxes support the argument for their effectiveness. A large-scale study confirms that many CO_2 tax systems do cut emissions around the world [33] and it is claimed that direct carbon pricing is the cheapest policy measure. A second study on UK manufacturing covering the 1970–2014 period confirms the effects of the tax in cutting sector-based emissions [9]. A study of Danish firms in [34] found that the effects of the CO_2 tax, the energy tax and the energy efficiency agreement were effective in reducing energy use and emissions. Studies by the OECD [35] favour CO_2 taxes and argue that the technology-based mitigation efforts are more expensive than price-based measures (tax or ETS).

An alternative method to price CO_2 is through the "Cap and Trade" system, which determines CO_2 prices to meet CO2 emissions targets [36]. However, both the energy price (tax) and the level of CO_2 tax (prices) will range from sector to sector. A cap-and-trade study on CO_2 price effects within the EU concludes that "what is available indicates that CO_2 emissions were reduced by an amount that was probably between 50 and 100 million tonnes" in 2006 and 2007 [37]. At the microeconomic level, studies on CO_2 emissions' mitigation use both dynamic panel models (e.g., Reference [38] and error correction models applied on CO_2 prices [39]) that reveal that emissions decline with those prices. In short, most studies agree on the success of the tax in cutting CO_2 emissions, but sector- and fuel-based evidence is lacking: The transport and household sectors face the largest level of CO_2 tax rates which defies the theory of carbon tax.

The above review shows that most studies support the use of CO_2 taxes; however, studies on Sweden found no effect of carbon pricing (tax) on investment in energy efficiency or carbon reduction [40,41]. This lack of effectiveness for the tax is explained by the fact that the tax does not cover all emissions (around 40% of total GHG emissions for Sweden) and covers more than 60% for Norway [42]. A recent study (Ibid.) reports that the aggregate CO_2 tax (implicit and explicit types) is too low, but it is increasingly used in many countries, with a total of 57 initiatives.

In addition to using CO_2 prices to cut CO_2 emissions, cuts can also result from a lower electricity demand and lower fuel prices, offsetting higher CO_2 prices as in Reference [43]. Another study [44] echoes the finding of Reference [43]: the financial crisis was the key factor in lowering CO_2 emissions rather than the effects of the ETS (or CO_2 prices), that is, the assumption is made that the financial crisis reduced the demand for electricity and oil products. It is entirely feasible that cuts in CO_2 emissions also occur under conditions of lower income growth, changes in fuel taxes, carbon tax and the ETS-based CO_2 prices for the Scandinavian economies under study.

In Section 2, we discuss the evolution of economy-wide CO_2 emissions and mitigation policy in the period of 1960–2018, the practice of pricing CO_2 for the two countries, the theory and methods and the key hypothesis underlying the modelling work. In Section 3, we present the EqCM model; in Section 4, we discuss the results of the time series analysis of the carbon tax. Section 5 concludes.

2. Materials and Methods

In the section, we describe the trends of CO_2 emissions for both countries and the estimation method.

2.1. Materials: Trends Emissions of CO_2 of Sweden and Norway

In this section, a description of the data input is given for the macroeconomic relationships and the EqCM for the cases of Sweden and Norway for the years from 1960 to 2019. CO_2 emissions from the transport sector have not declined in Sweden and Norway, but some sectors have a seen a downwards shift in the growth path of CO_2 emissions as a result of (1) CO_2 tax, (2) the changes in energy mix within the industrial sectors, and (3) the diffusion of low-CO_2 electricity based on nuclear (in Sweden) and hydropower generation (in Norway). The energy systems of these two nations have recorded substantial fuel switching in the last 20 years, and this has supported CO_2 mitigation efforts. In contrast, the transport sector of both countries has recorded a steady growth in the CO_2 emissions path along with that of the household sector (Figures 1 and 2), even though these sectors face the highest level of CO_2 tax rates. Diesel use continues to grow, despite higher fuel prices and taxes, while gasoline use is falling in both countries, with Sweden supporting biofuels and Norway supporting electric transport (Figures 1 and 2).

Table 9 (Section 3.2) shows the list of all taxes currently levied in Sweden and Table 10 (Section 3.2) shows the climate policy decisions for transport and renewable energy sec-tors for Sweden: Green taxes in Sweden are overwhelmingly transport related; the Swe-dish government does not present a quantitative impact assessment of the effectiveness of those taxes.

Tables 1 and 2 depict the change in Sweden's and Norway´s CO_2 emissions. Swedish emissions in some years follow those in GDP, while, in the 1980s, CO_2 emissions were decoupled from GDP changes after the adoption of nuclear power. The noticeable change is that, for Sweden, the rate of improvement (lower emissions) declined after 1990–1995 until 2000. After 2000–2005, the rate of CO_2 emitted began to increase, but only slowly. In recent years, emissions have continued to decline whilst GDP continues to grow. We can detect a general decoupling of CO_2 emissions from GDP.

Table 1. Annual changes in Sweden's CO_2 emissions and changes in GDP: 1960–2019. Average annual growth rates in %. Source: [45–49].

Years	GDP (%/Year)	CO_2 Emissions (%/Year)
1960–1965	5.18	4.94
1965–1970	4.05	8.08
1970–1975	2.59	−2.64
1975–1980	1.34	−2.35
1980–1985	1.99	−2.76
1985–1990	2.4	−3.9
1990–1995	0.71	−0.15
1995–2000	3.57	−0.38
2000–2005	2.62	0.7
2005–2010	1.59	0.37
2010–2019	1.31	−2.72

Table 2. Annual changes in Norway's CO_2 emissions and changes in GDP: 1960–2019. Average annual growth rates in %. Source: Statistics Norway [47,48].

Year	GDP (%/year)	CO_2 Emissions (%/Year)
1960–1965	4.63	4.6
1965–1970	3.75	11.29
1970–1975	4.84	1.15
1975–1980	4.53	3.38
1980–1985	3.33	−0.09
1985–1990	1.7	−2.1
1990–1995	3.73	2.16
1995–2000	3.68	2.14
2000–2005	2.2	1.8
2005–2010	0.76	6.15
2010–2019	2.86	−1.91

Table 11 (Section 3) tabulates the list of green taxes and the dates on which these were introduced in Norway. The oldest green tax was introduced in 1917 (annual tax on motor usage) and the newest in 2016 (road usage tax levied on LPG). As in Sweden, Norway´s taxes are dominated by the transport sector via petroleum fuels.

Norway's emissions first grew in tandem with the growth in GDP in the early 1960s, then grew much faster than GDP to the end of that decade, but were far bw GDP growth in the 1970s and 1980s until this reversed again in the 1990s. Early in the century, emissions grew at a significantly higher level than GDP growth but they declined in recent years, although GDP growth is strong. The decoupling of CO_2 emissions from GDP is not as strong in Norway as it has been in Sweden. (Table 2).

Figure 1 (Sweden) and Figure 2 (Norway) describe how macroeconomic variables changed after the adoption of the CO_2 tax in Sweden 1990 and in Norway in 1991. The changes in magnitude of the variables of interest are also shown (Figure 1). The scale was adjusted to make magnitude changes comparable. Each major increment increases by a factor of 10.

How much an energy (CO_2) tax can be raised will depend on the oil price level, personal income, inflation, the social cost of carbon or the business cycle. For example, the upward change in taxes (CO_2 and energy) follows the economic cycle: periods of recession (lower output relative to trend) are associated with higher taxes and tax reductions track periods of economic expansion (Figure 1). For Sweden, GDP does not pull up the CO_2 emissions trend post-1990, although GDP does pull up the changes in diesel use through time. GDP again pulls up the tax on gasoline; this is an indication that they are cointegrated. Emissions are pulled up by gasoline use and diesel use, while CO_2 prices (using gasoline cost data) are pulled up by emissions in our sample. In short, these variables are cointegrated.

Unlike Sweden, Norway exports oil and gas, which has led to three effects: it pulls up GDP, and increases both emissions and personal income growth. The data also reveal that the CO_2 price (using diesel cost data) is stable for recent years, but its changes do track income growth (Figure 2). Prior to the CO_2 tax, emissions grew by 1.69 times in Sweden and 1.85 times in Norway, while, after the tax, emissions grew 0.83 and 0.86 times, respectively. The statistical evidence is stacked in favour of emissions being cut with a tax. Overall, there is a cointegration relationship between the emissions, GDP and fossil fuel use (diesel, petrol, household fuels) through time.

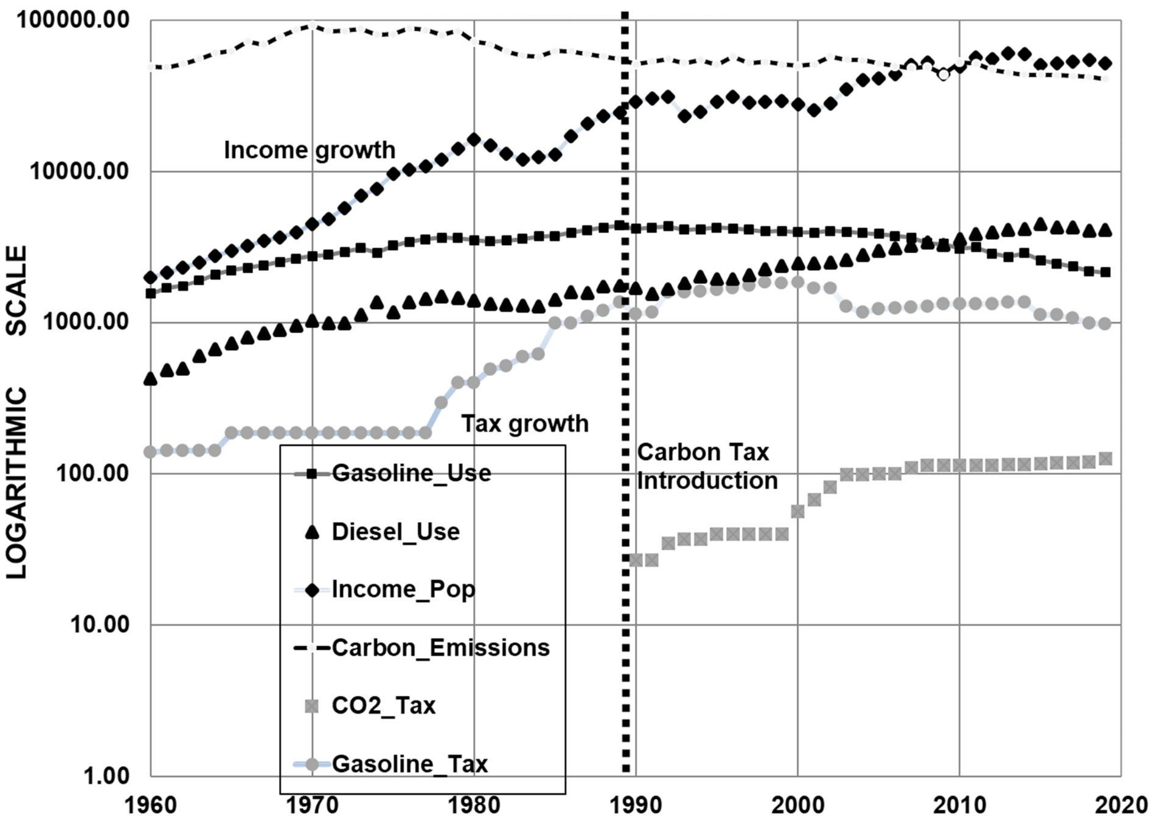

Figure 1. CO_2 emissions and other energy-use indicators: Sweden 1960–2019. Source: IEA [49] & UN data [47], World Bank (2020) [46].

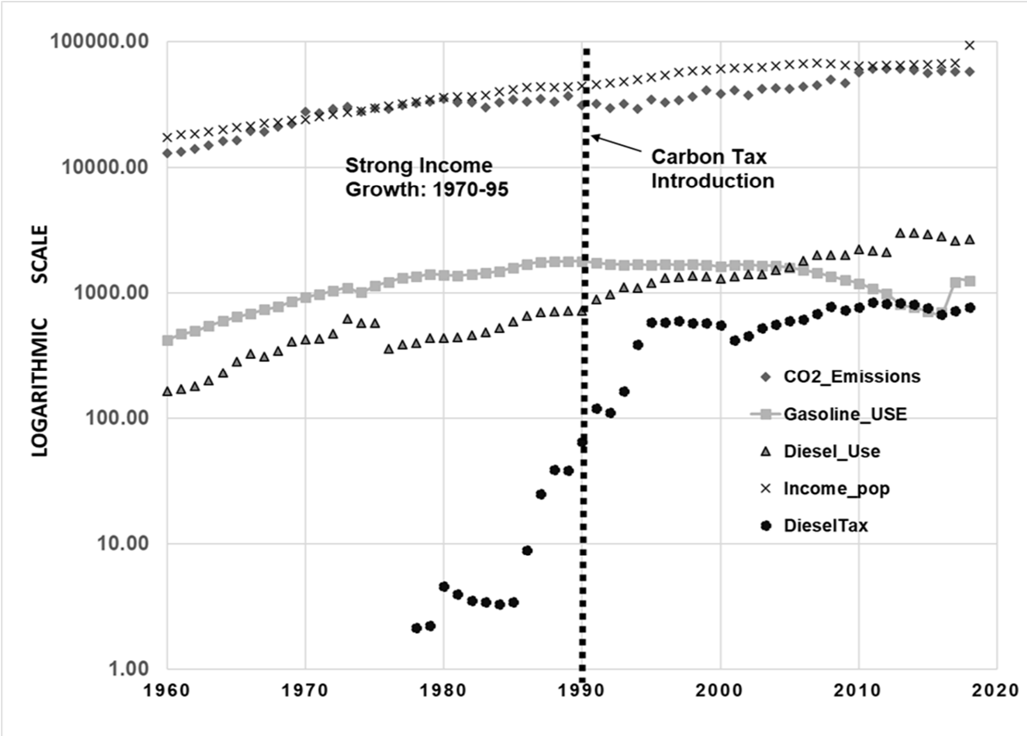

Figure 2. CO_2 emissions, income and taxes: Norway 1960–2019. Source: (various years), [47–49].

2.2. Key Relationships and Variables

This Section discusses (1) our hypothesis regarding the strongest effects on CO_2 emissions; (2) the description of the variables; (3) the model specification and 4) the error correction model.

2.2.1. Hypothesis of Equilibrium Relationships

The testing procedure is split into two areas. Firstly, we tested for unit roots for each of the variables to determine whether these were nonstationary (see Tables 7 and 8). Secondly, we tested whether the linear combinations of the variables were nonstationary or not. We proposed three hypotheses: (1) nuclear generation, hydropower for Norway and energy taxes for transport fuels both prompt rapid cuts in CO_2 emissions; (2) both fossil fuel use (mainly transport energy) and economic growth (measured by personal income before tax) are a cause of emissions for both countries; (3) a downward effect on emissions holds after the announcement effect and the adoption of the CO_2 tax. This is represented by the permanent effect dummy for the CO_2 tax policy. Hypothesis 1 is tested in Equation (1), Hypothesis 2 and 3 in Equations (1) and (4), while Hypothesis 3 is tested in Equations (1) and (4).

2.2.2. Data and Descriptive Statistics

For our analysis of CO_2 emissions, we defined the variables and present a data summary (Tables 3 and 4). Annual data on CO_2 emissions or GHG emissions are taken from [45] and [46]. The rest of the data series were taken from [45]: population, gasoline and diesel consumption by the transport sector, and nuclear electricity generation. Data for gasoline taxes (implicit CO_2 tax), motor diesel tax (implicit CO_2 tax), and CO_2 tax are found in Reference [50]. Data on annual GDP were taken from Reference [46].

Table 3. Definition of variables for Sweden in sample.

Variable (Sweden)	Definition
Income per population	000′s; Constant 2010 USD.
CO_2 Emissions	000′s Tonnes of CO_2 equivalent per year
Diesel use	000′s Tonnes of fuel
Gasoline use	000′s Tonnes of fuel
Nuclear electricity generation	GWh
Trend	1960–2018
Gasoline taxes (implicit CO_2 tax)	2014 Swedish Kronas per Tonne of fuel
Motor diesel Tax (implicit CO_2 tax)	2014 Swedish Kronas per Tonne of fuel
CO_2 tax (direct tax)	2014 Euro per Tonne of CO_2

Table 4. Definition of variables for Norway in sample.

Variable (Norway: 1960–2018; Except Otherwise Indicated)	Definition
Income per population	000′s, constant 2005 USD.
CO_2 Eq. Emissions (GHG)	000′s tonnes of CO_2 equivalent per year
Oil and gas extraction: Value added (1971–2018)	Million Krones, 2018
Fossil fuel energy use (coal, oil, petroleum, natural gas)	% of total energy supply
Diesel use (transport)	000′s Tonnes of fuel
Gasoline use	000′s Tonnes of fuel
Hydro power	GWh
Trend (1960–2018)	
Diesel taxes (1978–2018)	2014 Norwegian Krones per Tonne of fuel

Annual data on CO_2 emissions, GDP, and population were taken from Statistics Norway (2020). Data on diesel tax, and value added by oil and gas extraction, were from the same source and data on fossil fuel shares were from the World Bank [46]. Data on diesel use and hydropower generation were taken from Reference [48].

2.3. Estimation Procedure

We transformed the series into their natural logarithms to reduce their variability and obtain the long-term elasticity values of emissions and CO_2 taxes. Short-term elasticities were obtained in the first-differences models that we explain below (Equations (1)–(6)).

Data transformations for the variables are explained in Equation (1). By taking the first differences in non-stationary variables, we can achieve the stationary relationships of Equation (1).

Regressing variables that are non-stationary tends to produce spurious regressions results and, thus, unreliable t-statistics on the estimated parameters. The spurious regression problem indicates correlations that, in reality, do not hold. Cointegration techniques reduce this problem.

The key question is whether the variable *CO_2 emissions* and the other parameters described follow a long-term trend or not, and whether they deviate from it temporarily or permanently.

2.4. Testing for Stationarity of CO_2 Emissions

Two steps were taken to set up the EqCM model. In the first step, tests show the variables in levels with unit roots (non-stationary), and we can continue to take the differences of these to achieve stationarity. In Appendix A, we explain the basic logic used to test for unit roots. The results of these tests are reported in Section 3.2

In the second step, tests should show if the linear combinations of the variables are stationary. This is achieved by applying data to the EqCM application and testing the error correction term (Equations (1)–(6)). If the entire model is stationary, this is evidence of a long-term relationship among the variables in Equation (2).

2.5. Applying the Single EqCM to Establish Cointegration System

In this section, the EqCM was built to explain the macroeconomic relationships of CO_2 emissions, as described in Equations (1)–(6).

Equation (1) encapsulates the long-term model of emissions for Sweden. Equation (2) represents the short-term responses of emissions to a variety of macroeconomic factors, as explained above. To ease the interpretation of the coefficients, all the variables were transformed into natural logarithms.

$$\begin{aligned} CO_{2\,t} = Y + \beta_1 \quad & (Inc\_pop_{\,t}) + \beta_2(Nuclear_{\,t}) + \beta_3(Petrol_{\,t}) \\ & + \beta_4(Diesel\_U_{\,t}) \\ & + \beta_5(Tax : CO_2\_GasolineTax : CO_2\ Gasoline_{\,t}) \\ & + \beta_6(DummyCO_2\_Tax) + \beta_7(Trend) + \in \end{aligned} \tag{1}$$

where β stands for coefficients of the long-term models, b for short-term models, Δ for year-to-year changes or the first difference operator of the short-term model; "Dummy CO_2_Tax" is a dummy of the CO_2 tax with a value 1 of one for 1990–2018 and zero for the pre-tax period 1960–1989.

Transforming (1) to differences and using the error correction term EqCM in brackets delivers the short-term equation following the EqCM form:

$$\begin{aligned} \Delta(CO_{2\,t}) = \alpha \quad & + b_1\Delta(Inc\_pop_{\,t}) + b_1\Delta(Diesel\_U_{\,t}) + b_2\Delta(Petrol_{\,t}) \\ & + b_3\Delta(Nuclear_{\,t}) + b_4\Delta(Tax : CO_2\_Gasoline_{\,t}) \\ & - \phi EqCM_{t-1} + \in \end{aligned} \tag{2}$$

where k is year (k = 1,2) and "t" is the lag operator (1960–2018). *t-k* is a variable lagged by k year ΔCO_2 = Ln ($CO_2\ t/CO_{2\,k\,t,\,t\text{-}1}$).

The symbol Δ denotes first differences, e.g., ln CO_2 = ln ($CO_{2\,t}$) − ln ($CO_{2\,t\text{-}1}$). The EqCM coefficient ϕ varies between 0 and 1, which represents the long-term adjustment factor and should be negative in the regression.

When the change in CO_2 emissions ln Δ (CO_2) reaches zero, the short-term model (Equation (3)) and the long-term one (Equation (2)) converge, and these attain long-term equilibrium.

$$\begin{gathered} \text{EqCM} = \left(CO_2 - Y - \beta_1\left(Inc_{pop}\right) - \beta_2(Nuclear) - \beta_3(Petrol) - \right. \\ \beta_4(Diesel_U) - \beta_5(Tax : CO_2\_Gasoline) - \beta_6(DummyCO_2\_Tax) - \\ \left. \beta_7(Trend)\right) \end{gathered} \tag{3}$$

For the case of Norway, the following EqCM model is tested, where β_k stands for long-term coefficients.

$$\begin{gathered} CO_{2\,t} = Y + \beta_0(Inc\_pop_{\,t}) + \beta_1(Tax\_CO2Diesel_{\,t}) + \\ \beta_2(Oilextraction_{\,t} + \beta_3(FossilE\_Use_{\,t}) + \\ \beta_4(DummyCO_2\_Tax_{\,t}) + \beta_5(Trend) + \in \end{gathered} \tag{4}$$

The short-term equation for Norway is as follows, where "b" stands for short-term coefficients.

$$\begin{aligned} \Delta(CO_{\,2\,t}) = \alpha \quad & + b_0\Delta(Inc\_pop_{\,t}) + b_1\Delta(Tax\_CO_2\ Diesel_{\,t}) \\ & + b_2\Delta(FossilE\_Use_{\,t}) + b_3\Delta(Oil\ Extraction_{\,t}) \\ & + b_4\ (DummyCO_2\ Tax_{\,t}) - \phi EqCM_{t-1} + \in \end{aligned} \tag{5}$$

where

$$\text{EqCM} = (CO_2 \quad -Y - \beta_0(Inc\_pop) - \beta_1(Tax\_CO_2\ Diesel) - \beta_2(OilExtraction) - \beta_3(FossilE\_Use) - \beta_4(Dummy\_CO_2\ tax\ ) - \beta_5(Trend)) \tag{6}$$

3. Results: EqCM MODEL

3.1. Calculated Coefficients: Results

Table 5 depicts the econometric results of the EqCM for Sweden, confirming that the variables, i.e., per capita income, CO_2–gasoline tax, and oil use are cointegrated with CO_2 emissions. The EqCM term is statistically significant from zero, reflecting that, in the long-term, there is an economic link between these variables and these achieve equilibrium.

Table 5. Error correction model for CO_2 emissions: Sweden.

Long-Term Model. Dependent Variable: Log of CO_2 Emissions	**Observation Period: 1960–2018; Test Statistic (Critical Values in Brackets at 5% Significance Level)**	
All variable in natural logs.	Coefficient	t-values, probability value in brackets
Income per capita	0.136	−2.30 (0.025)
Nuclear power generation	0.005	1.61 (0.114)
Diesel Use	0.555	4.04 (0.000)
Gasoline Use	0.473	4.10 (0.000)
Tax: Gasoline and CO_2 (SEK/Tonne–CO_2)	−0.197	−4.05 (0.000)
Dummy_CO_2Tax (1960–1989: 0; otherwise, 1)	0.014	0.342 (0.733)
Time Trend	−0.013	−1.76 (0.084)
Adjusted R^2	0.90	
Observations: 56		
AR 1-2 test: F(2,46) = 2.0461 [0.1408]	Normality test: Chi^2(2) = 3.1151 [0.2107]	
ARCH 1-1 test: F(1,54) = 0.0089473 [0.9250]		
Hetero test: F(13,42) = 0.78204 [0.6739]	RESET23 test: F(2,46) = 6.3850 [0.0036] **	
Hetero-X test: F(28,27) = 0.66640 [0.8542]		
Short-Term Model (Critical Values in Brackets at 5% Significance Level)**		
Dependent variable: $\Delta CO_2 = \ln (CO_2/CO_{2\ t\text{-}1})$		
	Coefficient	t-values
Δ Income per capita	0.087	1.11 (0.274)
ΔNuclear	0.001	0.532 (0.597)
ΔDiesel_Use	0.453 **	3.61 (0.000)
ΔGasoline_Use	0.199 **	1.79 (0.079)
ΔGtax	−0.095	−1.53 (0.132)
EqCM $_{(t\text{-}1)}$	−0.715	5.18 (0.000)
Constant	−0.024	2.27 (0.027)
No. Observations: 55		
Adjusted R^2	0.45	
AR 1-2 test: F(2,46) = 0.22605 [0.7986]	Hetero test: F(12,42) = 0.71503 [0.7284]	Normality test: Chi^2(2) = 1.3351 [0.5130]
ARCH 1-1 test: F(1,53) = 0.025305 [0.8742]	Hetero-X test: F(27,27) = 0.77170 [0.7474]	
RESET23 test: F(2,46) = 2.6841 [0.0790]		

For Norway, the EqCM term (Table 6) is statistically significant from zero and shows two results: (1) the short-term model converges with the long-term one and (2) the emissions, per capita income, and the rest of the explanatory variables jointly achieve equilibrium.

Table 6. Error correction model: Norway.

Long-Term Model. Dependent Variable Log of CO_2 Emissions	**Observation Period: 1960–2018; Test Statistic (** Critical Values in Brackets at 5% Significance Level).**	
All variables in natural logs.	Coefficient	t-value
Income per capita	−0.182	−0.985
Fossil fuel use (Oil, Petroleum, Natural gas, Coal)	1.163 **	5.13
Oil and Gas Extraction (Value added)	0.029	4.71
Diesel tax (Indirect CO_2 Tax)	−0.035	−2.21
Dummy (Year I:50) 2009	−0.192	−2.59
Dummy_CO_2Tax (1960–1989 = 0; 1 1990–2018)	−0.113	−2.01
Time Trend	0.026	8.46
Adjusted R^2	0.95	
	Observations: 54	
AR 1-2 test: F(2,44) = 2.2604 [0.1163]	Hetero test: F(11,41) = 1.0476 [0.4250]	Normality test: Chi^2(2) = 3.0791 [0.2145]
ARCH 1-1 test: F(1,52) = 0.80326 [0.3743]	Hetero-X test: F(21,31) = 0.64780 [0.8488]	
	Short-Term Model	
	Dependent variable $\Delta CO_2 = \ln(CO_2/CO_{2\,t\text{-}1})$	
Independent Variables	Coefficient	t-value
Δ Income	−0.172	−0.880
Δ FossilUse	0.736	3.17
Δ Diesel tax	−0.028	−1.16
Δ Oil & Gas Extraction	0.0373	2.32
EqCM $_{(t\text{-}1)}$	−0.735	−4.89
	No. observations: 53	
AR 1-2 test: F(2,45) = 0.58673 [0.5603]	Hetero test: F(10,42) = 1.2719 [0.2769]	Normality test: Chi^2(2) = 6.7762 [0.0338] *
ARCH 1-1 test: F(1,51) = 2.2090 [0.1434]	Hetero-X test: F(20,32) = 1.0299 [0.4587]	
	RESET23 test: F(2,45) = 0.23639 [0.7904]	

3.2. Results: Sweden

Tables 5 and 6 tabulate the econometric results based on the estimated EqCM in Equations (1)–(6). We confirm three hypotheses of Section 3. The model achieved statistical significance for most of the variables. (Tables 5 and 6). The model performance of the EqCM is shown in Figures 3 and 4.

We now discuss results from the perspective of our working hypothesis. Firstly, as factors that explain decarbonization for Sweden, we confirm our first hypothesis: nuclear generation, as well as energy and CO_2 taxes, are associated with cuts in emissions (Tables 5 and 6). Secondly, we confirm a positive relationship between CO_2 emissions and fossil fuel use (mainly transport energy) for both the short- and long-term economic growth. Thirdly, the direct CO_2 tax failed to sufficiently cut transport sector emissions: gasoline and CO_2 tax elasticities are much higher than the equivalent value for nuclear power. Fourthly, the EqCM does not confirm a downward effect on emissions after the announcement effect and the adoption of the CO_2 tax, and the coefficient size is too small.

The third hypothesis was not confirmed, since the Dummy period (Dummy_CO_2Tax) showed a small positive value but lacks statistical power (the same dummy was negative for Norway). The Dummy shows that the impact of the direct CO_2 tax, other measures of energy efficiency and unobserved factors have all been less effective in cutting emissions than expected. The Dummy_CO_2 tax includes two periods (1960–1989), Dummy = 0; 1960–1989; dummy = 1, 1990–2018.

For the tax to be effective, it needs to be combined with gasoline taxes to capture the true cost of CO_2 emissions, since the gasoline tax works as an indirect tax on CO_2

emissions; however, the use of transport fuel continued unabated in the post-tax period due to economic growth and the slow fuel shift towards electricity. (Table 6; "Tax: Gasoline and CO_2 coefficient"). The tax dummy for the period reflects a modest upward shift in emissions and the gasoline tax shows that it is an effective tool to cut emissions.

3.3. Results: Norway

The various hypotheses we presented above were also confirmed for Norway. with a caveat. We introduced an additional effect: that oil and gas extraction produces emissions. The model performance of the EqCM for Norway is shown in Figures 5 and 6 (refer to Section 3).

First, for Norway, we confirm the first hypothesis: energy taxes produce cuts on CO_2 emissions. Secondly, we confirm a positive relation between CO_2 emissions and fossil fuel use (mainly transport energy); the coefficient on fossil fuel use dominates the Norway EqCM results on emissions, which signals the failure of the tax on transport fuels. As key inputs for economic growth, both fossil fuel use and oil extraction are linked to greater emissions, as the theory suggests. The third hypothesis is confirmed: the "Dummy_CO_2 tax" shifts the trend in CO_2 emissions downwards (Table 6) and the CO_2 tax period effect shows that firms and consumers abate emissions with the introduction of the CO_2 tax, the announcement effect and other energy-efficiency measures. The same variable also indicates the impact of other energy-efficiency technologies, i.e., renewable electricity generation. In short, the evidence confirms that the tax prompts cuts in emissions for the entire economy but the cuts are lower than expected.

The economic growth (income) coefficient reveals that emission cuts are driven by technological change. For the years 1960–2018, emissions did not grow with economic growth, and the effect is stronger in Norway than in Sweden, indicating that the former is becoming less carbon-intensive over time.

The emission response was positive after the profitability of oil and gas extraction grew, as more machinery and logistics are required to drill and extract large amounts of oil and gas. Norway generates 24% of its GDP from the oil and gas sector, fueling a higher rate of economic growth than Sweden, and clearly this factor influences its CO_2 emissions profile. Oil extraction rates increase emissions, which track higher oil prices, while lower oil prices decrease oil extraction. Norway benefits from oil export revenues, which fuel economic growth, and this explains the small effect of the diesel tax price on emissions in the model (Table 6).

Short-term coefficients (Tables 5 and 6) reveal key factors affecting CO_2 emission cuts: The direction of the impacts of the same variables as discussed above do not change from positive to negative. The models are dominated by fossil fuel use in both economies. These effects are not expected, however, to last long into the future.

Tax increases affect emissions more than tax decreases, and rising economic activity is a better predictor of emissions than price in recessionary periods. In periods of economic expansion, no corresponding increase is seen in emissions. Technological innovations considerably reduce emissions through fuel switching (greater electrification of industry) but substitution elasticities are low for nuclear or hydro-electricity, while transport fuels need to be phased out to electrify transport activity.

3.4. Results of Tests

The following tests are necessary to establish if the cointegration techniques described in Sections 2 and 2.5 can be used. The test for cointegration using the Sweden residuals rejects the null hypothesis of no cointegration by comparing the t-ADF statistic to the critical value of the Augmented Dickey Fuller (ADF) table, as the calculated value is lower than the critical value (See, First row, Table 7). These tests results confirm the use of cointegration methods.

Similarly, the ADF test for cointegration for the Norway residuals reject the null hypothesis of no cointegration, since the t-ADF value is smaller than the critical value (see first row, Table 8). These tests results confirm the use of cointegration methods.

3.5. Results for Unit Roots in Data Series: 1960–2018

For both countries, the DF and ADF tests generally fail to reject the null hypothesis of no unit root for variables in levels (in logarithms). Initially all variables of Tables 7 and 8 displayed non-stationarity. This implies that we can take differences in the variables to achieve stationarity and proceed to building up the cointegrated model. For both countries, the ADF test show that all variables in first differences (Δ) do not show unit roots in the variables, reflecting the fact that these variables are differenced and stationary. All tests are conducted with a trend and constant, with constant and without it (Tables 7 and 8). The ECM term for both Sweden and Norway equations shows that the ADF test is more negative than the critical value of the ADF table, which confirms that the data series are cointegrated.

Table 7. Sample: Sweden 1960–2018.

Augmented Dickey Fuller Test for Unit Root (in Levels and in First Differences). t-ADF Value. Test Statistic (** Critical Values at 1 % Significance Level; * critical value at 5% level). Includes Trend and Constant (IT), Constant (I), no Constant. WOL: Variable without a Time Lag				
Variable	**IT (A)**	**I (B)**	**Without a Constant (C)**	**Akaike Info Criterion (for Column A)**
ECM term (test for no cointegration)	−4.485 **	−4.212 **	−4.267 **	−5.451
WOL	−5.222 **	−5.027 **	−5.091 **	−5.482
Δ ECM	−6.19 **	−5.594 **	−5.660 **	−5.111
WOL	−9.619 **	−8.809 **	−8.908 **	−5.139
Log (CO_2)	−3.109	−0.8090	−0.1303	−5.239
WOL	−3.221	−1.112	−0.1397	−5.240
Δ CO_2	4.498 **	−4.147 **	−4.583 **	−5.005
WOL	−7.721 **	−7.705 **	−8.445 **	−5.026
Log (GDP per capita)	−1.885	−1.979	2.270	4.523
WOL	−1.397	−2.317	3.622	−4.474
ΔGDP_per capita	−5.430 **	−5.042 **	−3.916 **	−4.502
WOL	−5.643 **	−5.369 **	−4.521 **	−4.492
Log (CO2 tax and gasoline tax)	−0.6767	−1.331	2.598	-3.847
WOL	−0.8542	−1.315	2.618	−3.879
Δ (CO2 tax and gasoline tax) *	−5.628 **	−5.473 **	−4.448 **	−3.842
WOL	−7.872 **	−7.758 **	−6.766 **	−3.875
Log (Gasoline use)	−0.1964	−2.017	0.3196	−6.583
WOL	−0.3216	−2.440	0.6248	−6.566
Δ (Gasoline use)	−5.967 **	−5.285 **	−5.083 **	−5.116
WOL	−8.845 **	−8.266 **	−8.085 **	−5.142
Log (Diesel use)	−2.766	−0.6672	3.643	−5.575
WOL	−2.708	−0.7004	4.582	−2.708
Δ (diesel)	−5.396 **	−5.500 **	−3.794 **	−5.437
WOL	−7.097 **	−7.205 **	−5.524 **	−5.468
Log (Nuclear electricity generation)	−5.605 **	−6.026 **	0.2785	1.322
WOL	−5.645 **	−5.991 **	0.3391	1.292
ΔNuclear	−5.878 *	-5.106 **	-4.889 **	1.788
WoL	−7.689 **	−7.002 **	5.822 **	1.765

Table 8. Time series equation: Norway 1960–2018.

Augmented Dickey Fuller Test for Unit Root (in Levels and in First Differences). t-ADF Value. Test Statistic (** Critical Values at 1 % Significance Level; *critical value at 5% level). Includes Trend and Constant (IT), Constant (I), no Constant. WOL: Variable without Time Lag				
Variable	**IT (A)**	**I (B)**	**Without an Constant or Trend (C)**	**Akaike Information Criterion (for Column A)**
ECM Term (cointegration test: ADF) with lag	−4.426 **	−4.344 **	−4.350 **	−5.285
WOL	−5.592 **	−5.540 **	−5.559 **	−5.324
ΔECM	−6.249 **	−6.329 **	−6.390 **	−4.941
WOL	−10.13 **	−10.25 **	−10.35 **	−4.970
Log (CO2kt)	−2.633	−2.443	3.196	−5.266
WOL	−3.048	−2.083	2.229	−5.153
ΔCO2	−4.678 **	−4.523 **	−3.848 **	−5.200
WOL	−11.18 **	−10.94 **	−9.595 **	−5.175
Log (Income per pop)	−2.669	−0.007096	1.923	−6.226
WOL	−2.039	−0.7175	4.666	−6.173
Δ Income	−1.163	−1.919	−0.3832	−6.106
WOL	−0.9929	−1.749	-0.3867	−6.135
Log (Fossil Fuel use)	−2.147	−2.124	−0.3244	−6.575
WOL	−2.709	−2.690	−0.2997	
Δ (Fossil Fuel Use)	6.13 **	−6.191 **	−6.235 **	−6.495
WOL	−9.410 **	−9.499 **	−9.576 **	
Log (Oil & Gas: Value added)	−1.504	−2.209	0.6646	−1.225
WOL	−0.9964	−2.674	1.583	−1.086
Δ (Oil and Gas: Value added)	−4.977 **	−4.488 **	−3.920 **	−1.226
WOL	−4.910 **	−4.564 **	−4.126 **	−1.218
Log (Oil price)	−0.7437	−1.669	−0.7388	−0.8269
WOL	−0.9338	−1.620	−0.7467	−0.8633
Δ (Oil price)	−5.119 **	−4.948 **	−4.645 **	−2.571
WOL	−5.996 **	−5.871 **	−5.636 **	−2.595
Log (Diesel Tax)	−1.073 (lag)	−0.8977	−3.520 **	−2.032
WOL	−0.6841 (no lag)	−0.8831	−5.312 **	−2.015
Δ (Diesel Tax)	−4.059 *	−4.053 **	0.8335	−2.023
WOL	−5.911 **	−5.920 **	1.399	−2.046

By taking the first differences in emissions and the rest of the variables, we can reject unit roots at a high significance level, at the 1% probability level (Tables 7 and 8). Its t-value is smaller and (or more negative) than its critical value at the 1 or 5% level of significance. A high number of the individual variables are deemed to be a I (1) variable, and the series are cointegrated (see Tables 7 and 8). Unit root tests are calculated with and without a lag. Tables 7–11 report large sets of statistical tests for every variable and Figures 3–6 report model fitness for the Sweden and Norway equations.

3.6. Model Performance

The Figures 3–6 include model fitness for both the short- and long-term responses: the latter shows a better goodness of fit than the short-term models for both countries. The long-term model for Norway shows a better performance than that of Sweden: this more accurately explains the actual behavior of emissions (Figures 3 and 5), while the performance of the short model of Norway also shows a superior performance to that of Sweden (Figures 4 and 6).

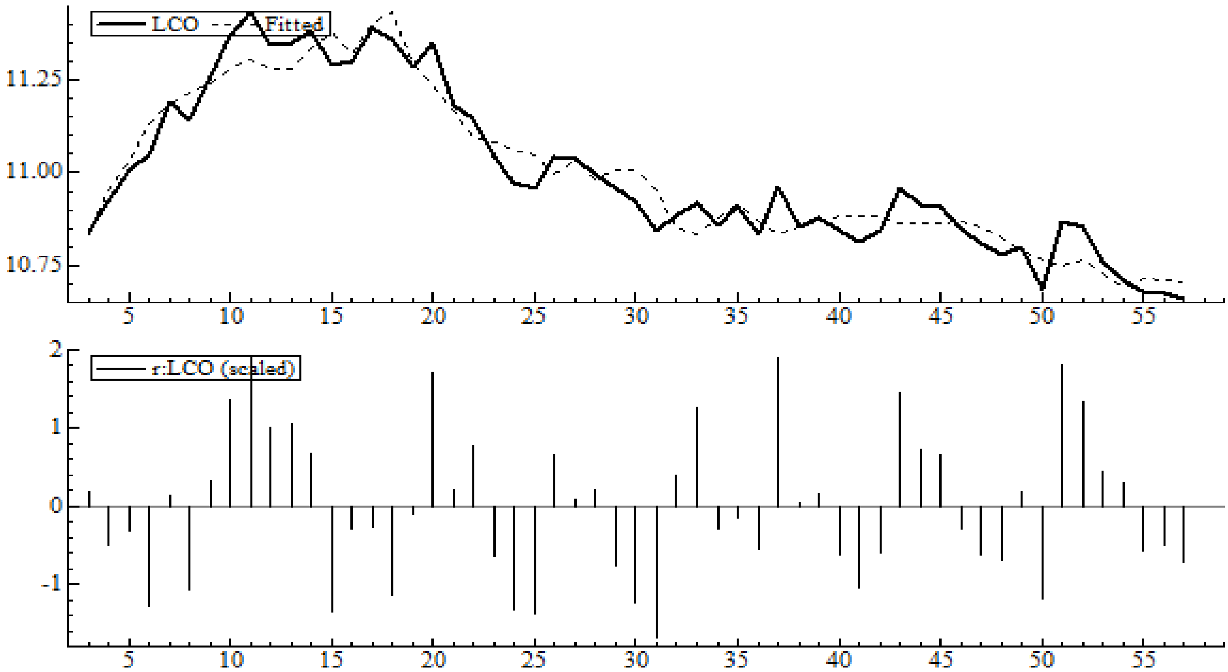

Figure 3. Results for the Sweden long-term model: 1. See Equation (1). Fitted model top graph, residuals bottom graph.

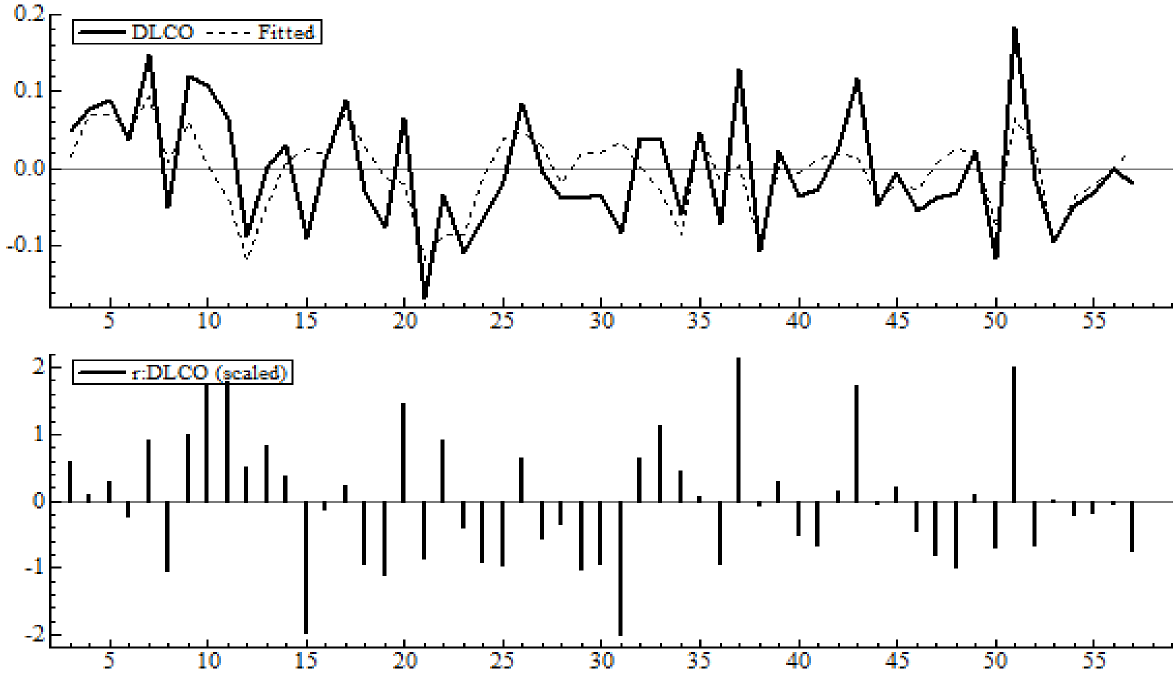

Figure 4. Results for the Sweden short-term model: 2. See Equation (2).

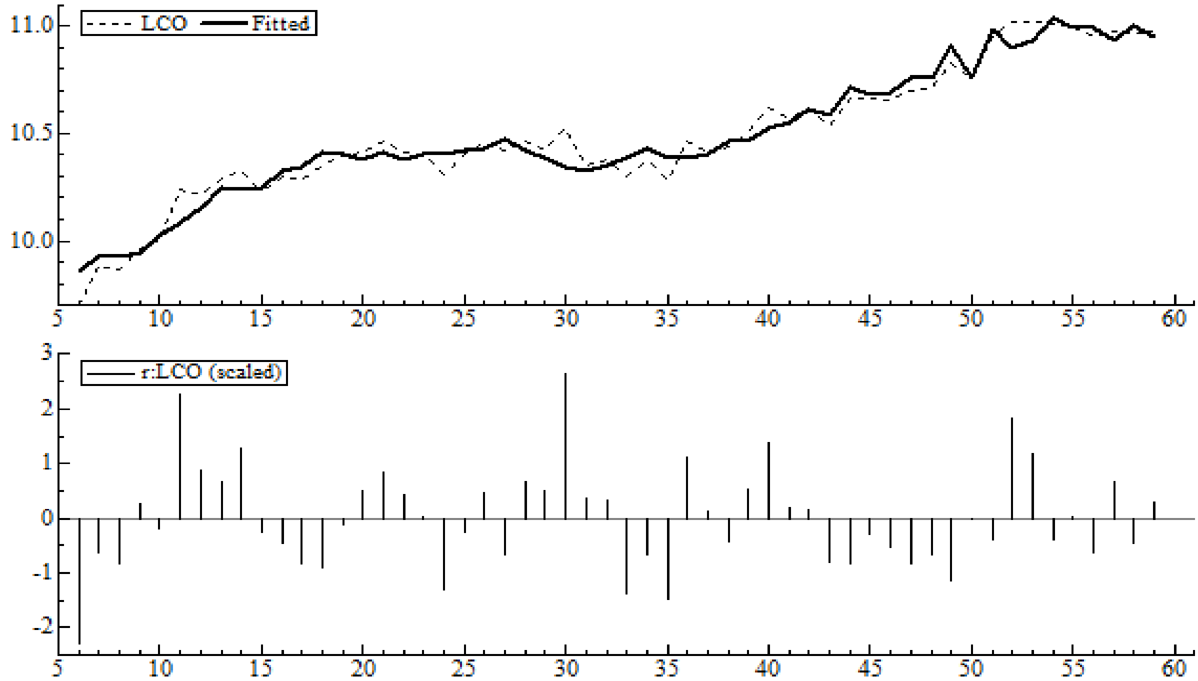

Figure 5. Results for the long-term model of CO_2 emissions (Norway): 3. See Equation (4). Fitted model top graph; residuals bottom graph.

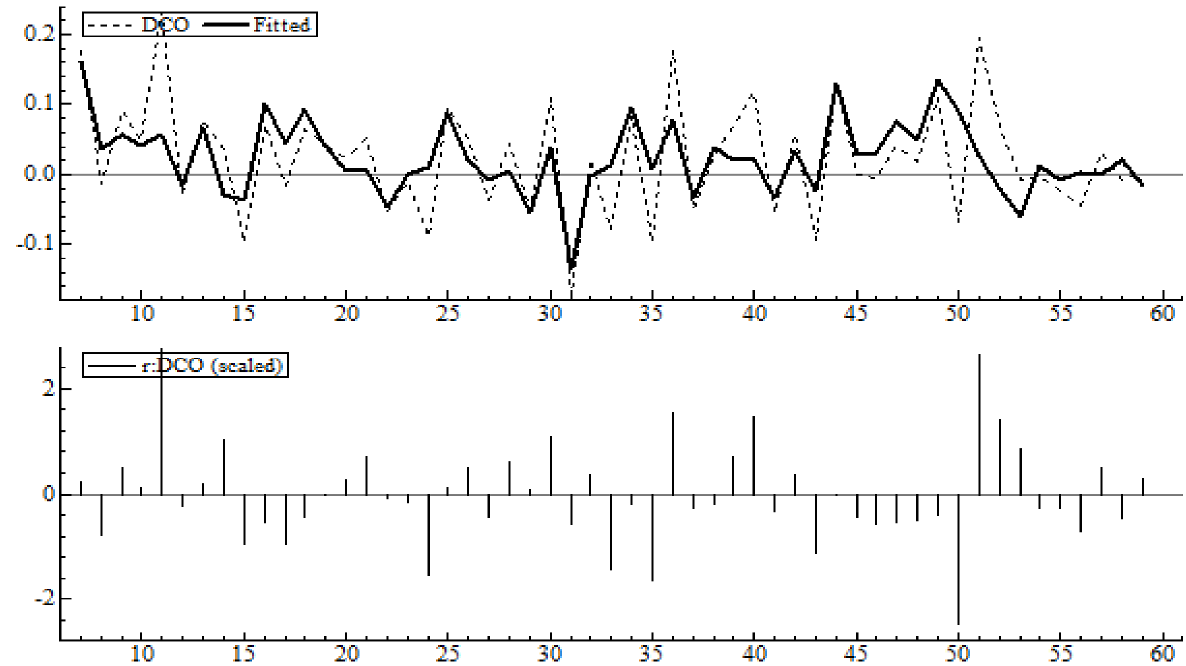

Figure 6. Results for the short-term model of CO_2 emissions (Norway): See Equation (5). Fitted model top graph; residuals bottom graph.

The elasticities reported above (Tables 5 and 6) can guide policy makers on how to design policy packages of both Sweden and Norway; the model results can help determine the right level of carbon and fuel taxes to cut emissions. However, our calculated elasticities are aggregated, while the taxes reported in Table 9 are disaggregated. The policy packages for cuts in GHG for both countries are discussed, with special emphasis on transport measures. Tables 9–11 tabulate the policy mix. The official policy mix (Table 9) does not include a quantitative analysis of the impacts of policy on CO_2 emissions.

To understand the role of green taxes (of which CO is the key one), it is essential to discuss the different tax instruments that are currently in use in both countries.

Table 9 shows the various green taxes for Sweden in 2019. The largest revenue comes from transport-related activity: rows for "Energy tax", "carbon dioxide taxes" for transport, and "tax On transportation". Transport-related taxes are high, i.e., ownership and road taxes. In sum, many green taxes mostly rely on transport-related taxes.

Table 9. Green taxes (revenue) for Sweden (2019). (Million Swedish Kronas). Source: Statistics Sweden [45].

Total	**100,811**
Energy tax	**75,704**
Tax on diesel oil	
Energy tax on fuels	26,617
Energy tax on electricity	25,510
Carbon dioxide tax	22,167
Nuclear power tax	n.a
Tax on thermal effect of nuclear power	n.a.
Sulphur tax	5
Emisson permits	1405
Hydroelectic power tax	n.a.
Tax on pollution	**2533**
Fee to the battery fund	4
Fee for chemical products	47
Tax on insecticides	126
Tax on chemicals	1468
Environmental protection fee [1]	
NOx fee	636
Tax on waste	252
Tax on insecticides and fertilizers	
Tax on commercial fertilizers	
Tax on natural resources	**138**
Natural gravel tax	138
Tax on transportation	**22,436**
Fee for vehicles	
Fee to the vehicle scrap fund	
Tax on air travel	1786
Vehicle tax	13,908
Sales tax on motor vehicles	
Kilometre tax	
Tax on road traffic insurance	2829
Congestion tax	2684
Road charges	1229

One key goal of the climate policy framework of Sweden is that first net zero emissions should be attained by 2045 and achieve negative growth after that year. The second emissions should be 85% lower than those of 1990 [51,52] (climate policy act; Climate Policy Council, 2020). To reduce emissions, the transport sector should be a key sector to decarbonize, since it is highly dependent on fossil fuels.

The Swedish Government has taken seven decisions, listed in Table 10, to mitigate climate change. A summary of these decisions for domestic transport, supported by the Climate Policy Act (Government Bill, 2019), are shown in Table 10. The government provides no quantitative assessment of several actions, i.e., carbon tax impacts, change in transport policy goals, funding for public charging infrastructure (renewable fuels and electricity sectors) and others. The "label "No" (in last Column) means that there is no government assessment of the measure listed in Table 10.

Table 10. Domestic transport and decisions taken in 2019 (Climate Policy Council, 2020) [51,52].

Area	Decision	Date Effective	Type of Decision	Government Presents Impact Assessment
Fossil-free and energy-efficient vehicles	Lower enumeration of the tax amount (petrol and diesel, 31 Dec. 2019)	July 2019	Change in tax	Partly
	Reduction in the CO_2 tax on petrol and diesel relative to the rate corresponding to the increase in the CPI and GDP	June 2019	Change in tax	No
Renewable fuels and electrification	Funding for non-public charging infrastructure, i.e., housing associations.	June 2019	New funding	No
	New fuel blend in 2019 and 2020.	1 January 2019	Change in blend levels	No
A transport-efficient society	Change in transport policy objectives	Budget Bill, 2020	Change in target formulation	No
	Amendment to urban environmental agreements	1 April 2020	Change in existing funding	No
	Municipalities given greater opportunities to introduce environmental zones	January 2020	Change in rules for existing instruments	No

Norway's green taxes that target climate change mitigation are tabulated in Table 11 based on [53]. The most important taxes are both the fuel tax and CO_2 taxes because of the volume of energy sold every year to power the transport sector. Some of these taxes are decades old, i.e., vehicle taxes date back to 1917 and road fuel taxes date to 1933. Vehicle taxes can complement CO_2 taxes to cut emissions.

Norway's government is required to cut GHG emissions by 30% compared to 1990 (base year) by 2020. A cut of 40% by 2030 is also a target compared to the base year. By 2050, Norway needs to achieve cuts of 90–95% compared to the base year. These targets are hard to achieve without (a) decarbonizing transport and (b) using higher fuel or carbon taxes, which are already high by world standards. Our estimates on fuel tax, income and clean power (Tables 5 and 6) can indicate how much these need to vary (Tables 9–11) to cut CO_2.

Table 11. Norwegian Green Taxes. Source: [53] Norway Ministry of Climate and Environment (2020).

Tax Type	Tax Rate	Date Introduced
CO_2 tax	Varies from 30 to 509 (NOK/t-CO_2)	1991
CO_2 tax on emissions in petroleum activities on the continental shelf.	Varies from 406 to 462	1991
Motor vehicle registration tax	Varies	1955
Annual tax on motor vehicles	Varies	1917
Annual weight-based tax on vehicles	Varies	1993
Road usage tax on petrol (NOK/Litre)		1933
Sulphur free	5.25	
Bio-ethanol	0 to 5.25	
Road usage tax on Diesel (NOK/Litre)		1993
Sulphur-free	3.81	
Bio-diesel	0 to 3.81	
Road usage tax on LPG (NOK/kg LPG)	2.98	2016
Lubricating Oil tax (NOK/Litre)	2.23	1998
Sulphur Tax (NOK/litre per 0.25 % Sulfur content above 0.05 weight %.	0.133	1970
Tax on health and environmentally damaging chemicals		2000
Trichloroethene (NOK/kg)	73.37	
Tetrachloroethene (NOk/kg)	73.37	
Tax on HFC and PFC (NOK/Tonne CO_2 eq.	508	2003
Tax on emissions of Nox (NOk/kg)	22.27	2007
Environmental tax on pesticides	varies	1998
Environmental tax on beverage packaging:		1973
Carton and cardboard	1.45	
Plastics (NOK/Unit)	3.55	
Metal (NOK/Unit	5.88	
Glass (NOK/Unit	5.88	
Electricity Tax (NOK/kWh)		1951
Standard Rate (NOK/KWh)	0.15	
Reduced Rate (manufacturing) (NOK/kWh)	0.005	
Base tax on minerals, etc. (NOK/Litre)		2000
Standard Rate, NOK/Litre)	1.665	
Reduced Rate (Pulp and paper, dyes, pigment industry) NOK/litre)	0.21	

4. Discussion

4.1. Discussion on Sweden

Our econometric results (Section 3) confirm previous research. For the Swedish case, taxes are a powerful tool in cutting emissions [28], and indeed, our results (Table 5) confirm that fuel taxes are effective and high. Further evidence suggests that the carbon tax elasticity of demand for gasoline is three times larger than its price elasticity [6] for Sweden. Unlike Reference [6], we found that the fuel tax elasticity is stronger than the carbon tax elasticity. The authors of [6], however, used a different technique to ours and this may explain the differences in the results.

4.2. Discussion on Norway

In Norway's case, the CO_2 tax effect was found to be modest in previous research [8]; however, we found that the CO_2 tax effect was larger than the fuel tax effect (Table 6, column one). For Norway, we found that the carbon price elasticity ("Dummy_CO_2tax") shifted the emissions path much more than fuel tax elasticity (diesel tax).

Regarding the GDP effect on emissions, the channel is the income effect, which is easily influenced by a drop in economic activity or a financial crisis. One study [44] echoes the finding of Reference [43]: the financial crisis was the key factor for lower CO_2 emissions rather than the effects of CO_2 prices; that is, the assumption is made that the financial crisis reduced the demand for electricity and oil products. We failed to capture the effect of a drop in GDP: a fall in emissions after a rise in the income per capita variable for Sweden (Tables 5 and 6). Instead, our results show that higher income is associated with higher emissions while, for Norway, a higher income is associated with technological change. The year dummy (Table 6) shows that the financial crisis of 2008–2009 significantly reduced emissions in Norway.

Macroeconomic studies for Norway and Sweden used the CGE framework [24], which assumes fixed prices and output and fixed substitution elasticities. Unlike these [24], our EqCM model does not assume fixed elasticities, or fixed prices. Instead, our models are based on time series datasets, which produce more realistic elasticity values. However, the high uncertainty in economic valuations of CO2 emissions and, thus, of taxes, remains [54,55], making it difficult to implement estimates from our EqCM analysis.

Our EqCM analysis captures the economic structure (the contribution of the manufacturing, services and primary sectors), explaining the differing path of emissions in both countries: Norway's economy is highly reliant on its oil and gas sector, which fuels its emission growth. This is a fossil-fuel-dependent economy that behaves totally differently to Sweden: its emissions decline more rapidly over time, although, in per capita terms, Norway's emissions are above the Swedish level. One lesson that can be drawn from the experience of these two nations is that high carbon and fuel taxes are insufficient to control the growth in fossil fuel use and a combination of measures is necessary to cut CO_2 emissions.

Since our model allows for a rough comparison between Sweden and Norway, we can say that the latter is an exception regarding the adoption of electric vehicles. Norway has become a global leader in the field of electromobility and the battery electric vehicle (BEV) market share is far higher than in any other country as a result of strong incentives promoting the purchase and ownership of BEVs. The role of incentives in promoting BEVs has been widely discussed in the literature, and makes Norway more of an outlier than a possible comparison.

Our econometric analysis faces three problems in the measurement of the effect of CO_2 taxes: the frequency of tax changes, tax exemptions and the "too many variables problem" [32]. However, since the analysis (Section 3) is estimated based on actual historical data, we can assume that some of these problems are partially solved. For example, the data on which our analysis is based ought to reflect the actual frequency of tax changes and exemptions; however, these exceptions would be indirectly captured in the fuel use levels.

Another notable comparison arising from our quantitative analysis of Sweden and Norway is that, in the future, both the fuel and CO_2 tax elasticities (Tables 6 and 7) are likely to decrease in absolute value as drivers increasingly shift away from gasoline (diesel)-powered cars to electric ones. This will particularly apply to Norway since Norway is further ahead in the adoption of Battery electric vehicles (BEVs) than Sweden. In fact, the low level of fuel tax elasticity of Norway is partly explained by the success of BEVs. The success in the electrification of the vehicle stock of Norway is a result of subsidies for batteries and BEVs [56–58]. The growing adoption of BEVS in Norway explains the recent decline in emissions in Norway.

Future policy on the taxation of fossil fuels and of carbon will need to consider the fall in fossil fuel revenues, especially for transport fuels; such revenues will need to be recouped from other sources and from the new electric transport sector.

5. Conclusions

Our evidence shows that Norway, for most of the period of analysis, was less able to mitigate CO_2 emissions than Sweden due to non-tax factors. However, Norway's adoption of BEVs implies that, in the future, the country will be well-placed to more easily cut emissions in the transport sector than Sweden.

Our quantitative and qualitative analysis confirms the three hypotheses based on an analysis of the cointegration of CO_2 emissions, fuel taxes, economic growth, and clean technologies of both countries. We found a cointegration relationship among variables for supply and demand, affecting CO_2 abatement efforts through the EqCM model and, since the series are cointegrated, we can confirm that there is an economic link among emissions and the other predictors. This new method allows for the determinants of emissions to be captured: a fast growth in emissions can be controlled with a target (a desired level of consumption) and an instrument (a tax).

Based on our model estimates, we found seven key outcomes for policy design.

- The first outcome of our considered policies is that the CO_2 tax has cut emissions in Norway more than in Sweden, but only in the first years following the introduction of the tax.
- Second the effect of the tax can be slow, since authorities use the tax as a revenue-raising device: in recessions, it will tend to rise, and in expansions it will decline. The tax will interact with (a) fuel taxes and (b) the rate of adoption of low-CO_2 technology. The tax's effect on emissions, however, must be seen in relation to other policy measures that are introduced. For these reasons, the shifts in CO_2 taxes will not necessarily track emission cuts.
- Third, in both nations, the cuts in emissions occurred as a result of energy supply-side policies through nuclear power or hydropower generation.
- Fourth, the EqCM analysis shows that the effect of the tax on emissions is negative and permanent; however, the effect of technology (nuclear, renewables and hydro-power) is also essential to reduce emissions. Unlike Reference [6], we found that the diesel tax was more effective in cutting emissions than the direct CO_2 tax in both countries, but Norway's diesel taxes were less powerful than those of Sweden, suggesting that higher taxes are needed in the former. The high personal income level explains the lower long-term price elasticity in Norway.
- Fifth, energy tax reform should also focus on other non-transport sectors; this reform will be needed since green tax revenue mostly relies on transport-related taxes, but the effectiveness of the latter may diminish after road electrification, which will lower tax revenue from transport energy (gasoline and diesel).
- Sixth, in Sweden, long-term emissions increase with economic growth. The response of emissions to fossil-fuel use is positive, as expected from a CO2-intensive energy source, but emissions respond negatively to (1) the CO_2 tax and fuel tax, (2) energy-efficiency measures, and (3) technology changes (i.e., nuclear power), as well as to (4) other unobservable effects. This is an R&D-led economy that is expected to produce lower growth rates of CO_2 emissions.
- Seventh, in Norway, emissions are still growing strongly despite enforced taxes on the supply side (oil and gas extraction) and the demand side. CO_2 emissions move in opposing directions: taxes, effective carbon prices and income effects and technological changes lead to cuts in emissions, while oil extraction activities and transport activities push up emissions. The long-term responses of emissions to economic growth, CO_2 prices and fuel taxes ensure that emissions decline.

- Future work is needed to examine further ways to cut emissions in the transport sector. Our analysis reveals that policy ought to focus on the greater electrification of transport for both nations, a reduction in energy use for road transport (Norway) and a removal of tax exemptions for industry, including carbon taxes.

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Appendix A

We tested the following relationship using the ADF and DF tests for all variables listed in Tables 7 and 8 in text:

$$\Delta X_t = \alpha + \varnothing X_{t-1} + \beta t + \beta 2 \mu_t \tag{A1}$$

if ∅ > 1 Xk variable is non-stationary. K is any regressor listed in Table 7.

if ∅ = 1 or −1 with values between Xk is stationary.

where t stands for time, U for residual errors, and X for k regressors.

We regressed each of our variables as a function of its past value and of a linear trend to test for unit roots.

Testing for unit roots should provide an indication of whether the data series is unstable, and thus drifts apart from time, or not. These tests indicate whether one can take differences in the model specification. In all likelihood, taking first differences in the dependent variable should render it stationary. Stationarity means equal mean and variance [59].

As Tables 7 and 8 show, we used the ADF test for unit roots. If Ho (null of no unit root) was rejected, we used the variable for the estimation of the ECM. The unit root test can be applied to the residuals too.

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