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Tale of two shocks

Response of the Finnish economy to the European union carbon policy shocks between 2005 and 2021

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Contents

1 Introduction

The Finnish government has pledged to reduce carbon dioxide emissions in an ambitious timescale. In the Government Programme, the goal of carbon neutrality is set to be achieved by 2035 (Valtioneuvosto, 2019). For the goal to be completed, Finland would need to become one of the world's first countries with fossil fuel-free energy production. The energy sector's transition is in full force, as the total greenhouse emissions have decreased by twenty-one per cent since 1990 (Statistics Finland, 2022).

Additionally, for the Finnish government to meet the goals set by the Paris Agreement, it will need drastic and urgent measures. In contrast to the topicality of this subject, there has yet to research on the macroeconomic impacts on the Finnish economy by the previously implemented EU-wide carbon emission reduction policies. This is a

Research done by Känzig will be my thesis's main inspiration. I will quasi-replicate his findings on the effects of the carbon policy shocks, changing the target variables from a European-wide context to the Finnish economy. Additionally, I will extend the carbon policy shock time series to the end of the year 2021.

The concentration on the EU Emission trading system (EU ETS) is warranted as it is a policy tool implemented in a sizable economy, and it has reached maturity with several phases of policy development. This study aims to contribute to this growing area of research by exploring the effects of policy shocks produced by updating the framework of the EU ETS on the Finnish economy. The provide new descriptive results on the response of the Finnish economy.

2 Climate policy in Finland

In this chapter, I will briefly introduce Finland's climate policy before implementing the European Union emission trading system and briefly introduce the different phases of the European Union emission trading system. The effects of these regulatory updates are discussed in the following chapters. Still, a short synopsis of the regulatory evolution is necessary for the reader to fully appreciate the economic consequences of the policy shocks produced by these institutions.

2.1 Before the EU Emission trading system

Finland was the first country in the world to implement a tax on the sources of carbon emissions (Hallituksen esitys, 1989; Bavbek, 2016). The tax encompassed various emission sources, as it targeted transport fuels and the fuels used for energy production (Lin and Li, 2011; Ekins and Speck, 1999). The carbon tax was stringent as it was indifferent to the final user and buyer of the energy-producing fuels, as the tax policy did not differentiate between households and industrial users (Ekins and Speck, 1999). The only fuel source exempted from carbon tax was wood (Elbaum, 2021). The tax was initially modest, with a relatively low valuation of 1.12 € per CO2 equivalent tonne, and the tax was progressively increased to more substantial levels (Bavbek, 2016). Sweden followed the example laid out by Finland and enacted a carbon tax in 1991 (Andersson, 2019). In Chapter 3.1, I will elaborate on the effectiveness of the Finnish and Swedish carbon taxes. I will further discuss the literature and the evidence of the effectiveness of different policy choices.

The carbon tax was not implemented as a revenue-raising measure, as it was from the beginning argued from environmental grounds as it could price the externalities caused by the burning of fossil fuels. The government proposal was enacted as law in 1989 and entered into force at the beginning of 1990. (Hallituksen esitys, 1989).

The carbon tax policies of the 1990s Nordics might provide an explanation for my counterintuitive findings about the reaction of the Finnish economy to the carbon policy shocks of the European Union, which are discussed in Chapter 7.3. The Finnish economy had more time and a solid monetary incentive to use fossil fuel resources more efficiently and to invest in green infrastructure prior to the enaction of the European Union ETS. When compared to other European economies, which did not have such incentives. Even after the enaction of the EU ETS, the tax continues to affect sectors not subject to the trading system (Bavbek, 2016).

2.2 EU emission trading system

A new chapter in the Finnish climate policy began in 2005 as the European Union emission trading system (ETS) was established. The ETS is based on a cap-and-trade scheme that restricts the total emissions for the affected sectors (these will vary in the different phases) and lets the market participants trade with each other (García et al., 2021). Furthermore, a variety of allocation schemes have been implemented in the different phases of the EU ETS as the European Commission has updated the allocation strategy (Verde et al., 2019). The ETS has been operating in four phases: Phase I ran from 2005 to 2007 and served as an experimentation period, Phase II was operational from 2008 to 2012, Phase III from 2013 to 2020, and Phase IV will run from

2021 to 2030 (Ellerman et al., 2020; Joltreau and Sommerfeld, 2019; Verde et al., 2019).

Phase I of EU ETS is widely considered the experimentation period where the institutions of ETS were tested and refined. Additionally, in the first two phases, the national governments were left in charge of planning the allocation of these certificates to their respective industries (Verde et al., 2019). These national allocation plans (NAP) were after the submittal of the national governments scrutinised by the European Commission (Ellerman et al., 2020). Therefore, the verification procedure, including the submissions and verifications, of the NAPs, will be a significant source of the carbon policy surprise. Discussed further in Chapter 6.3 and the exact dates, in addition to the shocks' nature, are specified in Appendix B.

Phase II continued with a similar framework of submitted NAPs and their Commission approvals (Ellerman et al., 2020). In the second phase, the governments were allowed to auction up to 10 per cent of the allowances. A raise from the 5 per cent in Phase I (Ellerman et al., 2020). Industrial production slowed abruptly after the financial crisis, which made the cap non-binding, thus reducing the price of the allowances to near zero (Verde et al., 2019). The effects of the policy changes between the different phases on the prices of the emission trading allowances can be seen clearly in Figure 1.

The oversupply of ETS allowances in the latter stages of Phase II was the inspiration that led to the reforms in Phase III (García et al., 2021). The most substantial change to the ETS market was the abolition of NAPs and the resulting centralisation by adopting a single EU-wide cap (Verde et al., 2019). This cap was planned to reduce yearly by a linear amount that was

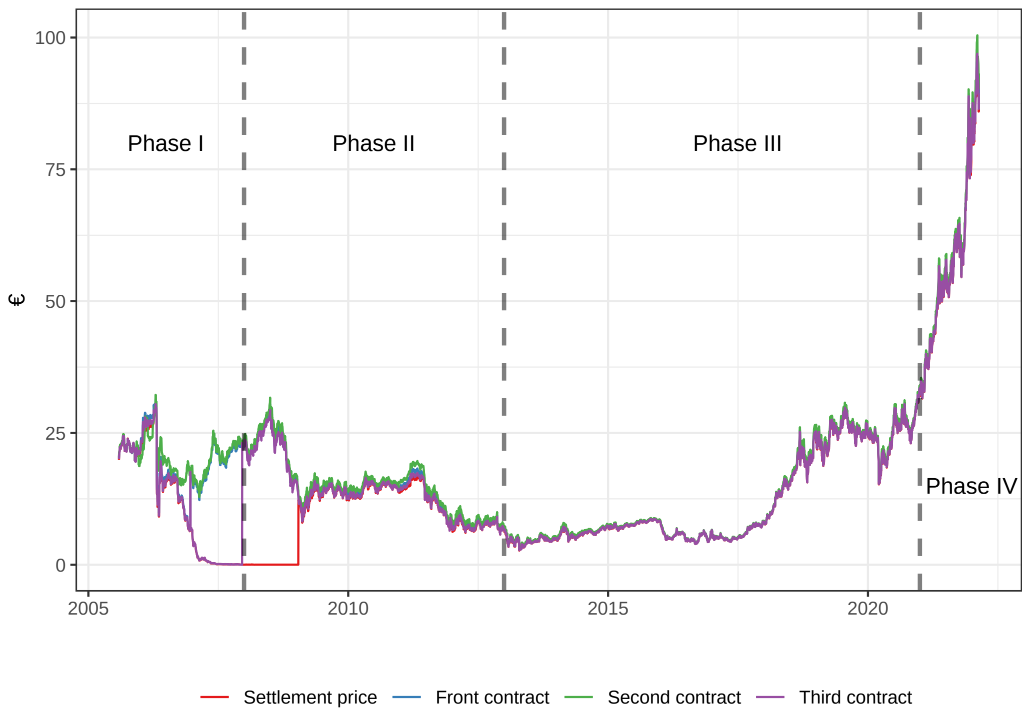

Figure 1: The evolution of the EU Emission trading system spot price and different future lengths prices through the different phases of the system. 2.0. Data was sourced from Datastream.

decided to be 1.74 per cent of the 2010 total allowances. (Ellerman et al., 2020). This linear decrease would lead to a 21 per cent reduction by 2020 in emissions in the sectors of the markets governed by the ETS compared to the levels in 2005 (Verde et al., 2019). Another major reform enacted in Phase III was phasing out the free allocation scheme to the energy sector in 2013, and plans to phase out the free allocation also in the remaining industrial sectors by 2027 (Ellerman et al., 2020). The effects of these strict system overhauls can also be seen in figure 1, where the news of future updates can be seen moving the futures price before it is realised at the spot price of the allowances. This is the essence behind the carbon policy surprise series and its usefulness in identifying the structural shocks in the SVAR model in chapter 5.

The changes that were enacted in Phase IV of the European Union ETS can be characterised by a more ambitious pace of allowance reductions and more stringent rules for the free allocations in the remaining sectors that still had them (Verde et al., 2019). The unintended consequences of this ambitious pace were countervailed by diverting the auction revenues to support energy sector modernisation by the innovation fund and modernisation fund (Verde et al., 2019). As Phase IV has only recently begun, the full implications of the rule changes are yet to be seen. Another challenge that will test the resolve of the European policy-makers is higher energy costs and the downstream effects of higher prices. I will bring more evidence in Chapter 7.

3 Relevant literature

In this chapter, I will present the previous empirical research on how environmental policy decisions have widely affected economies. The second subsection of this chapter will cover a variety of prior research that utilised similar SVAR-IV-based methods as I have used in this thesis. This chapter aims to provide a brief background on the topic and examples of previous similar uses of similar methodological frameworks.

3.1 Research on the effects of environmental policy

«««< HEAD There has been some research on the effects of carbon taxes in different fields. Nevertheless, not one is done as extensively in Finland. Previously Palanne and Sahari (2021) have studied the impact of carbon taxes on Finnish passenger car traffic. They studied how tax schemes affected the carpool and if the break-in higher gasoline taxes would affect the types of cars people would buy (Palanne and Sahari, 2021). Unfortunately, compared to the speed warranted by the decarbonisation goals, their results could have been more encouraging; between 2013 and 2017, personal transport emissions decreased only about 2.3 per cent (Palanne and Sahari, 2021). Another article by Sahari (2019) studied how Finnish consumers reacted to the changing electricity prices. She found out that the electricity prices had a noticeable impact on consumers' choices on their houses' heating sources while they were building or renovating their houses (Sahari, 2019). Furthermore, she used the variability of the electric prices across Finland to estimate the consumers' price elasticity between more environmentally conscious and traditional household heating options (Sahari, 2019). These results suggest that Finnish households respond to the incentives laid out by the energy markets.

Another research done in the context of Nordic countries with exciting results is an article written by Andersson (2019). The author studied the Swedish economy's response to the enaction of carbon tax in the 1990s. Andersson used a synthetic control experiment desing to find significant reductions in carbon emissions after the implementation of the carbon tax in Sweden in 1991 (Andersson, 2019). The carbon tax started as a relatively moderate fiscal policy but was later increased to more substantial heights (Andersson, 2019). He also found that consumers reacted to carbon tax hikes more than just the market-driven price changes (Andersson, 2019). These findings are in interesting contention with the conclusions made in Palanne and Sahari (2021). A working paper by Elbaum (2021) concentrated on the Finnish economy in the same period as Anderson was in Sweden. He focuses on the response of the Finnish economy to carbon taxes in the 1990s. It uses a similar approach as Andersson to estimate the impact of the carbon tax (Elbaum, 2021). He found a similar reaction in the Finnish economy to the carbon taxes ad Andersson did in Sweden (Elbaum, 2021). These results could suggest that at the time of Palanne's and Sahari's research, the effects of carbon taxes could have already changed the decision-making process of Finnish consumers. Also, it highlights the importance of understanding the historical processes behind the studies, as the results are substantially context-dependent.

Another study which has a broader view of the macroeconomic impacts of carbon taxes on European economies was written by Metcalf and Stock (2020). They utilise a plethora of time-series analyses on various European countries before and after implementing various carbon tax schemes with differing severity (Metcalf and Stock, 2020). Interestingly they found negligible impacts on GDP growth rates or employment rates, but a substantial reduction in greenhouse gas emissions (Metcalf and Stock, 2020). Metcalf (2021) also outlines in an article a theoretical framework on how carbon taxes and other similar greenhouse gas reduction mechanisms can work. Additionally, he reviews prior theoretical literature on the topic. Finally, he adds an essential point to the previous literature. When the effects of additional emissions are uncertain, the policymakers should lean more on cap-and-trade models as these have a hard limit on the number of emissions possible to emit, thus lowering the risk of possible tipping point scenarios (Metcalf, 2021).

Similar non-significant effects on employment and total output as Metcalf and Stock (2020) were also reported by Martin et al. (2014) when they studied the United Kingdom's carbon tax implementation on the industrial sector. They differentiated plants using micro-econometric methods that parsed out different tax burdens between them (Martin et al., 2014). They did not find statistically significant evidence that this would have adverse outcomes for the treatment plants compared to their control counterparts (Martin et al., 2014).

In their paper, Acemoglu et al. (2016) reiterated the importance of a quick transition to decarbonise the economy. They based their model on microdata from the United States, contrasting to more macro-centric results of Metcalf and Stock (2020) and Andersson (2019). Acemoglu et al. (2016) predict that only using carbon taxes as the sole policy tool has a high welfare cost, in the long run, significantly lowering the discount rate of future welfare losses. They suggest that subsidies for clean technology and research were a cost-effective intervention to reduce the disutility of future generations (Acemoglu et al., 2016). Their model had a much longer time horizon than other studies, running more than two hundred years. Furthermore, they take a prescriptive approach as most of the studies described above are descriptive (Acemoglu et al., 2016). Their estimated optimal path relied heavily on public investment in less polluting technologies. They also stated that if they would relax the assumption of linear damages from greenhouse gas pollution, their findings could also tilt to favour carbon taxes more (Acemoglu et al., 2016). Acemoglu's research also overlooks the possibility of using cap-and-trade style schemes and the possible effects of these schemes.

This exclusion of a widely used policy is in stark contrast with the primary source of my thesis, which is the research done by Känzig (2022), who studied solely the effects of the European Union emission trading scheme on the European and, particularly, the United Kingdom's economy. He used the futures market to identify the structural shocks of carbon policy surprises in the constantly evolving carbon policy environment of the European Union (Känzig, 2022). He quantified the size of these carbon policy shocks to the European Union's economy using the structural vector autoregressive model (Känzig, 2022). This kind of surprise estimation was previously used in the time series analysis of oil markets and will be discussed in the following chapters. Using the price information from futures markets, Känzig could estimate the surprise felt by the markets using tight time steps around policy announcements of the European emission trading scheme (Känzig, 2022). He found robust evidence of the carbon policy shock's substantial negative impacts on GDP growth and employment (Känzig, 2022).

3.2 Previous SVAR-IV research

The structural vector autoregression models were widely used to analyse macroeconomic phenomena. They are an insightful tool for analysing dynamic interdependent systems. This is why they have been deployed, for example, in macroeconomics to study the responses to changes in monetary policy (Wolf, 2020). Likewise, another widely researched field for macroeconomists is the reactions to the oil price shocks (Kilian, 2009).

An essential study pioneering the usage of macroeconomic news as an instrument was done by Romer and Romer (2010). The authors utilised the record of post-war tax reforms and the context of these reforms (Romer and Romer, 2010). Using narrative methods, the researchers could get substantial and long-lasting effects on production and economic activity (Romer and Romer, 2010). They found that changes in tax rates of 20th century in the United States had substantial impulse responses to the total output (Romer and Romer, 2010).

Both previous research traditions that have utilised SVARs have in common that identifying the shocks is complex due to the endogenous nature of these shocks (Känzig, 2021). However, Känzig (2021) found an ingenious way of sidestepping this endogeneity problem. Moreover, I will elaborate on this identification strategy in Chapter 6, which is fully dedicated to the instrument variable strategy (Känzig, 2022).

Another crucial part of the methodology used by Känzig (2022) is the SVAR-IV-based analysis that was first introduced in a lecture by Stock and Watson (2008). It is an ingenious way to identify the structural shocks using an external instrument (Stock and Watson, 2008). The methodology was developed further in research by Stock and Watson (2012) where they illustrated the propagation channels of the recession of 2007-2009. The evidence presented in the study by Stock and Watson supports the idea that financial collapse and tight monetary policy significantly impacted the slow economic recovery (Stock and Watson, 2012).

The SVAR-IV has also been used in the Finnish context by Keränen et al. (2020), where they examined the size of the fiscal multiplier of government spending. According to the authors, the most important finding of their research was the formation of an instrument variable (Keränen et al., 2020).

Känzig (2021) studied the effects of the news shocks by the Organisation of the Petroleum Exporting Countries (OPEC) by using a similar methodology that he later used in the study of the effects EU Emission Trading system (Känzig, 2021, 2022). To determine the effects of oil supply news shocks, Känzig utilised the external instrument method as they are highly endogenous to the broader macroeconomy (Känzig, 2021). This instrument was constructed by using a tight time frame around the OPEC oil supply news announcements to measure the movement of oil prices (Känzig, 2021). Using this strategy, the researcher could build an exogenous and relevant instrument of the structural oil supply news shock (Känzig, 2021). I will elaborate on how a similar instrument could be used in Chapter 6. Känzig (2021) identified short- and long-term impulse responses to a negative oil supply news shock. The oil price increase was substantial in the short term but decreased back to the original price level with time. In contrast, oil and industrial production are not instantaneously affected, but a significant decrease can be detected in the long run. (Känzig, 2021)

De Winne and Peersman (2021) focused on their research on the effects of extreme weather events on food prices and real GDP in both developed and developing countries. In their research, they used two different instruments to estimate the effects of extreme weather events on the global agricultural commodity market and secondary impacts on economic variables (De Winne and Peersman, 2021). Their analysis presents that price shocks would hit the hardest middle-income countries in the agricultural commodity market. Lower-income countries more reliant on agriculture would incur windfall profits with higher agricultural prices (De Winne and Peersman, 2021). They also suggest that previous research has undervalued the consequences of extreme weather event-related price shocks in the agricultural commodities markets in more affluent countries (De Winne and Peersman, 2021). Even though the evidence is statistically significant, the authors call for additional research to theorise the propagation channels from weather shock to the broader economy (De Winne and Peersman, 2021). The findings should be treated with caution as the authors' analysis does not consider the decrease in agricultural output capacity that might coincide with the changing climate.

Nevertheless, their research is vital in underlining the effects on high-income countries through price shocks (De Winne and Peersman, 2021). For example, in a European central bank working paper, Faccia et al. (2021) studied the impact of abnormal temperatures in winter and summer on medium-term inflation. According to the authors, medium-term inflation is non-trivially affected by extreme weather events. In addition, they also argue that climate change will affect the central banks' primary mandate of price stability (Faccia et al., 2021).

4 Econometric approach

In this section, I will describe the econometric model that I will use to identify the structural shocks using the Structural vector autoregression with instruments variables (SVAR-IV). In the formalisation of my model, I will follow in the footsteps of Känzig (2022) and Montiel Olea et al. (2021).

4.1 VAR

Presume a standard VAR model with a lag length of p.

$$y_t = b + B_1 y_{t-1} + \cdots + B_p y_{t-p} + u_t \tag{1}$$

Where the y_t refers to a $n \times 1$ vector of the observed endogenous variables at time step t. The $B_1, \ldots, B_p$ are $n \times n$ coefficient matrices. u_t is a $n \times 1$ vector of the reduced form innovations with a covariance matrix of Σ.

4.2 Identification of the structural shocks

An integral assumption in using SVAR models is that the one-step-ahead prediction errors, i.e. innovations u_t are a linear combination of a vector of mutually orthogonal structural shocks ε_t:

$$u_t = S\varepsilon_t \tag{2}$$

S is a nonsingular $n \times n$ structural impact matrix. Due to the orthogonality the structural the $n \times n$ covariance matrix of $\text{var}(\varepsilon_t) = \Omega$ is diagonal. Thus due to the linear mapping of the innovations and structural shocks described in Equation (2), we can describe the covariance matrix of the innovations as:

$$\Sigma = S\Omega S'$$

For clarity, the $\varepsilon_{1,t}$ is defined to describe the carbon policy shock i.e. the shock of interest. The latter part of this chapter will present how, using an external instrument approach, we can identify the structural impact vector s_1, which is analogous to the first column of the structural impact matrix S.

4.3 External instrument

For an external instrument z_t to be useful in identifying structural shocks, it has to satisfy the following two conditions:

$$\mathbb{E}(z_t \varepsilon_{1,t}) = \alpha \neq 0 \tag{3}$$

$$\mathbb{E}(z_t \varepsilon_{i \neq 1,t}) = 0 \tag{4}$$

Equation (3) is referred to as the relevance condition and the equation (4) as the exogeneity condition. If these conditions, in tandem with the invertibility requirement, are met, the sign and the scale of the s_1 can be identified by:

$$s_1 \propto \frac{\mathbb{E}(z_t u_t)}{\mathbb{E}(z_t u_{1,t})} \tag{5}$$

The size of α in Equation (3) can be viewed as the power of the external instrument, and it can be tested with the first-stage heteroskedasticity-robust

F-statistic between the instrument and the VAR-residual. This method is further elaborated in the Stock and Watson (2018), and which I also reported in chapter 7.1. After the structural impact vector has been identified, the confidence bands in IRF can be estimated with a moving block bootstrap method, also used by Känzig (2021, 2022).

4.4 Comparison with other identification strategies

Other possible strategies to identify the structural shocks would be to use heteroscedasticity-based identification of structural vector autoregressions or local projections. An interesting article by Plagborg-Møller and Wolf (2021) offers proof that local projections and SVARs estimate the same impulse responses but have different finite-sample properties (Plagborg-Møller and Wolf, 2021).

When comparing the results of SVAR-IV to ones produced with local projection, the variance of the impulse response functions is lower, but with a trade-off of bias in the results if the VAR is noninvertible (Wolf, 2020). In Appendix D.3, I will provide the impulse responses that are produced via the Local projection-instrument variable approach as a robustness check for the results of the baseline SVAR-IV model. The results we see are at least notionally similar and thus provide additional evidence for the reliability of the baseline model.

Even though these would have been a reasonable choice as an identification strategy, as one of the main tasks of this thesis is to quasi-replicate the findings of Känzig, I will continue with the SVAR-Iv so that my findings are as comparable as possible. Additionally, I selected the SVAR-IV as my identification approach for the reliability and efficiency it offers. These strengths are paramount in estimating the responses to shocks from such a short sample.

5 Data

I will follow the Känzig's formulation as having the following endogenous variables. The model consists of the carbon section, which consists of the consumer price index of energy and the disaggregated greenhouse gas emission time series. The macroeconomic section consists of the headline consumer price index, industrial production index, 3-month Euribor rate, unemployment rate, OMX Helsinki stock index, and real exchange rate of Finland.

$$y_t = \begin{bmatrix} \text{Energy consumer price index} \\ \text{GHG emissions} \\ \text{Consumer price index} \\ \text{Industrial production} \\ \text{3 month Euribor} \\ \text{Unemployment rate} \\ \text{OMX Helsinki} \\ \text{Real exchange rate} \end{bmatrix}$$

The sources for these endogenous variables can be found in the appendix A. The sample dates of my variables are from the beginning of the year 2000 to the end of the third quarter of 2021. All the endogenous variables are also reported in monthly time series. The Greenhouse gas emissions are an exception and must be disaggregated into a monthly time series.

Following Känzig's (2022) example, all the variables have been analysed as log levels. However, an exception is made for the 3-month Euribor and Unemployment rates, which are stored in percentage points. This is done for the results to be interpretable as percentages.

5.1 Greenhouse gas emission disaggregation

The greenhouse gas emission data are reported annually due to the commitments made by Finland in the United Nations Framework Convention on Climate Change (Stat Fin, 2022). Therefore, this problem must be addressed as our model will be built on a monthly time series.

Känzig proposes a solution where by using the Chow-Lin disaggregation method. The accuracy of the disaggregation can be increased with the addition of relevant indicators, which are reported in the desired disaggregation frequency and are correlated with the target values (Chow and Lin, 1971). Känzig (2022) used the Consumer price index of energy products and the industrial production index as his indicators. As can be seen from Figure 2, Finnish non-renewable electricity production is highly seasonal.

As my first instinct, I wanted to capture this seasonal variation into my disaggregated time series. This is why I tested my first hypothesis and produced three different disaggregated time series of greenhouse gas emissions. The first was a dummy disaggregation without any indicators, the second was with similar indicators as Känzig (2022), and the third included additional information on the amounts of non-renewable energy production. The results of these three disaggregations can be seen in Figure 3.

The dummy disaggregation strategy produces a yearly value divided by 12 as its estimation, which can also be considered the reported value when we compare it to the other two estimates. The disaggregation produced following the example laid out by Känzig (2022) produces a relatively smooth time series that could be understood as a trend time series.

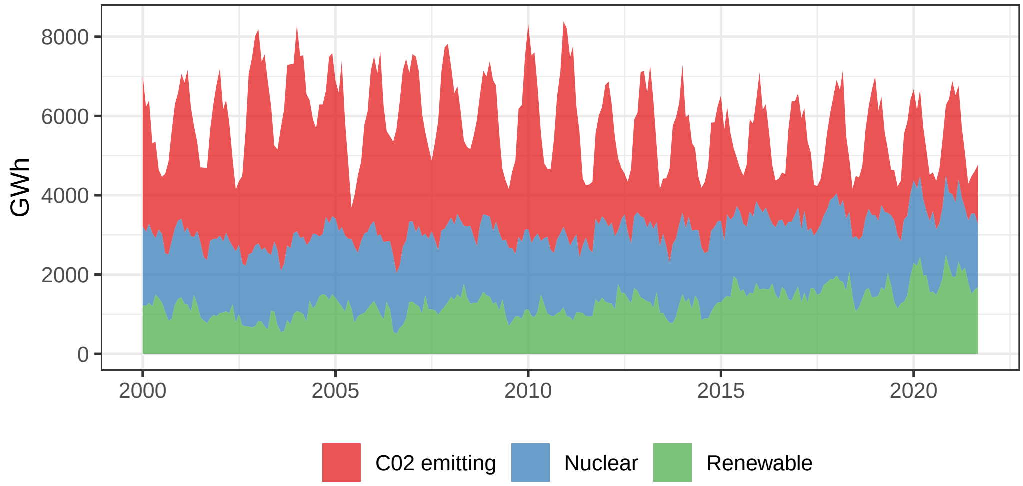

Figure 2: Monthly electricity production in Finland by the sources. The increased share of renewable electricity production and decreased total electricity production have been the prevalent trends after 2010. The carbon emitting electricity sources are in this case considered to be coal, natural gas, oil and peat. Using wood pellets is in this Figure considered to be renewable enrgy production. The Data is collected from the Statistics Finland.

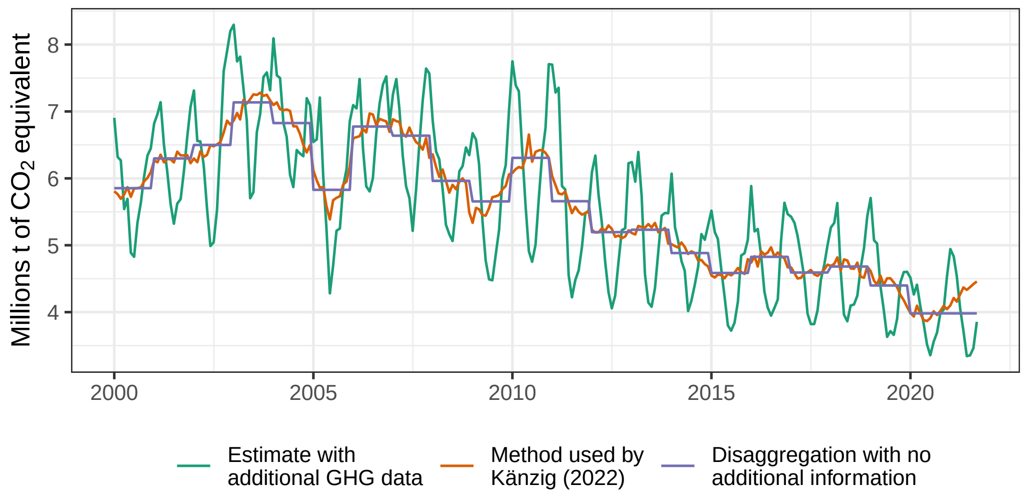

Figure 3: Different disaggregation strategies from yearly values of the GHG emissions in Finland to monthly values. The additional data from the sources of electricity production sources transforms the disaggregation to aggressively seasonal. The method used by Känzig (2022) is likely to be an underestimation on the seasonal variation and the estimation produced my is likey to be an overestimation as it takes into account only the sources of electricity production. The Data for this figure is from the Statistics Finland official statistics, and the disaggregation is done by me.

However, the disaggregation with additional information has values which vary wildly between summer and winter due to the variation in the usage of non-renewable energy sources, as seen in Figure 2.

Even though my estimate might be more truthful in capturing the actual monthly greenhouse gas emissions, it also produces more seasonal noise in the model. In the subchapter 5.2, I will discuss the problems of not using trended values. Finally, Appendix D.1 shows the impulse response functions produced with disaggregation produced with my estimation strategy and how it produces seasonal noise.

5.2 Using trend values

Känzig (2022) not utilise trend values in his analysis, this might not been a significant problem, as he used values that were observed from the whole European Union. This means that the seasonal variation was much lower than in the data that was observed from Finland. For exmaple, the seasonal variation of employment can be seen in Figure **??**.

Using the original observed unemployment rate brings similar problems as using the disaggregation with additional information of electricity production sources. It brings additional noise which is unrelated to the target shocks to the impulse response functions. In Appendix D.1 I have reported the impulse responses when using the observed values. In the impulse response is present a substantial contemporaneous shock to the job market that is highly unlikely, and thus the model might have captured seasonal variation to the impulse response functions.

The problems are similar whether the variable is industrial production index, unemployment rate, or the disaggregated greenhouse gas emissions. The

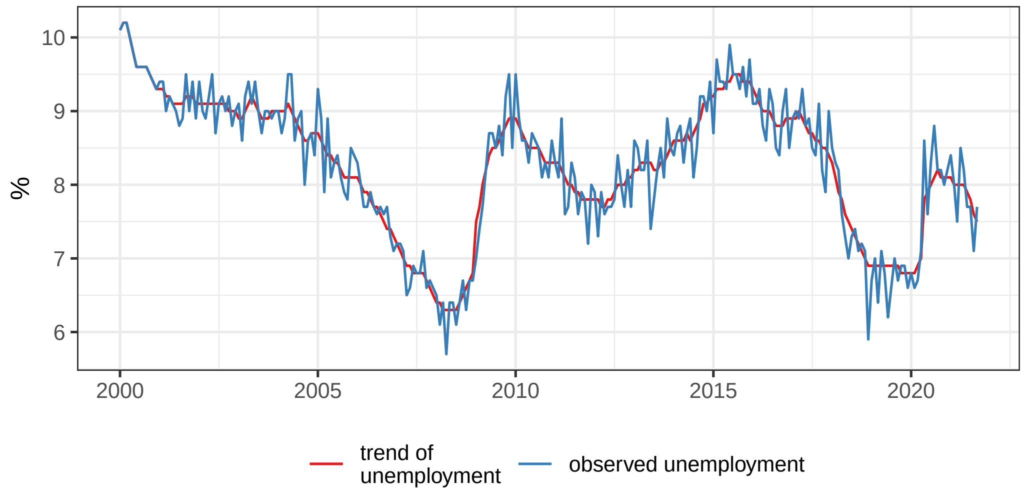

Figure 4: Monthly observed unemployment rate and the seasonally adjusted trend values of unemployment rate in Finland. The Data is from Eurostat.

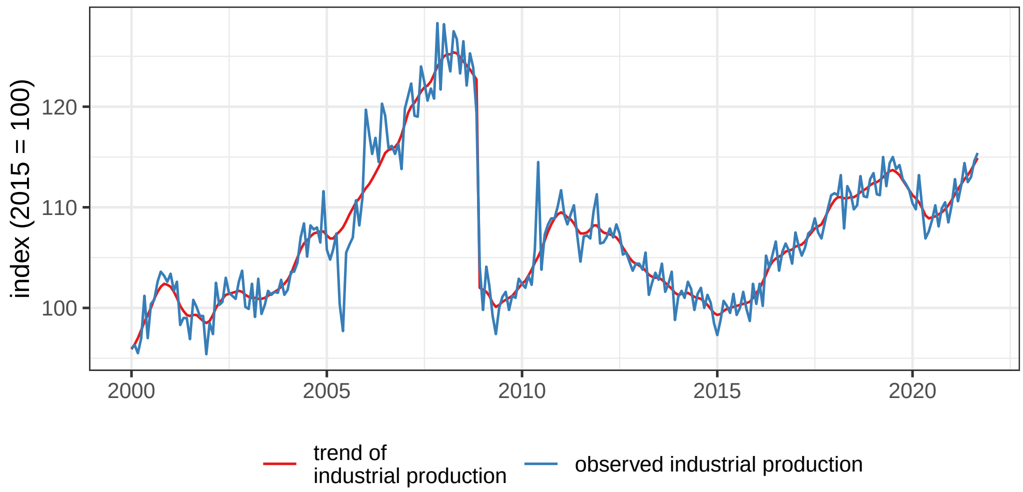

Figure 5: Monthly observed industrial production index and the seasonally adjusted trend values of industrial output in Finland. The Data for this Figure is from the Statistics Finland.

variation that is due to either measurement errors, seasonal variation, or the inherent randomness that is not produced by the processes we want to detect.

Especially when trying to infer long and medium-term effects of the carbon policy shock, the short-term variation of the endogenous variables affect the accuracy greatly. This can be seen when comparing the impulse response functions of the actual model in the chapter 7 and the one produced with the observed data in the appendix D.1.

6 Instrument

In this chapter, I present the identification strategy of the instrument variable that will be used to identify the structural shock of the SVAR model discussed in Chapter 4. The structure of the chapter is as follows. The first subchapter is for introduces a simplistic model of the futures markets. Second, I will explain how based on this model, high-frequency identification can be used to extract information about the changes in the carbon policy regime. Third, I will present the observed values of the carbon policy surprise series. The last part analyses the surprise series and its fitness as an instrumental variable.

6.1 Futures market

The usage of futures markets relies on the hypothesis that the markets will effectively incorporate all available information into the price discovery mechanism (Hayek, 1945). The futures are the markets' best guess for the future price of these carbon permits, given there are no transportation costs, and the risk tolerance of the seller and buyer are equal (Nakamura and Steinsson, 2018)

Standard theory on asset price formation formulated by Pindyck (2001) predicts that futures contracts on a day d with a maturity h are valued as:

$$F_d^h = \mathbb{E}_d(P_{d+h}) - RP_d^h \tag{6}$$

The equation (6) describes that the price of a future is a combination of the expected price of the asset P_{d+h} with the information available on the date

d and the risk premium RP to time step h at time step d.

6.2 High-frequency identification

Following the approach of the high-frequency identification of the instrument used by Känzig (2022). Similar approach that Romer and Romer (2010) used and Känzig (2021) in his previous research on the consequences of the OPEC announcements. The surprise series of the carbon futures market is calculated from the log differences in the daily closing price of the EU emission trading certificate futures.

It can be assumed that because of the tight identification period, the changes in the risk premium are not changing $RP_d \approx RP_{d-1}$ and thus, the surprise series is representing the updates in the expected future price of the emission trading certificates (Känzig, 2021).

$$\begin{aligned}\text{Surprise}_d &= F_d^h - F_{d-1}^h \\ &= \mathbb{E}_d(P_{d+h}) - RP_d^h - \mathbb{E}_{d-1}(P_{d+h}) + RP_{d-1}^h \\ &= \mathbb{E}_d(P_{d+h}) - \mathbb{E}_{d-1}(P_{d+h})\end{aligned} \tag{7}$$

The daily surprise series elaborated in the equation (7) is then aggregated to a monthly carbon policy surprise series. Finally, an indicator function $1_{cp}(d)$ whether a day contains a carbon policy regulatory event is used to mask days with regulatory events to zero. The regulatory events are listed in Appendix B.

$$\text{CPSurprise}_m = \sum_{d \in m} \text{CPSurprise}_d$$

This monthly surprise series is an ideal external instrument due to the exogeneity resulting from the short time frame of the identification. It can be used as the z_t of Equation (5).

6.3 Regulatory Dates

Identifying regulatory events is a vital part of the building of this instrument. In Figure 6, the values of the CPSurprise_m are presented, in addition to some exciting named regulatory events.

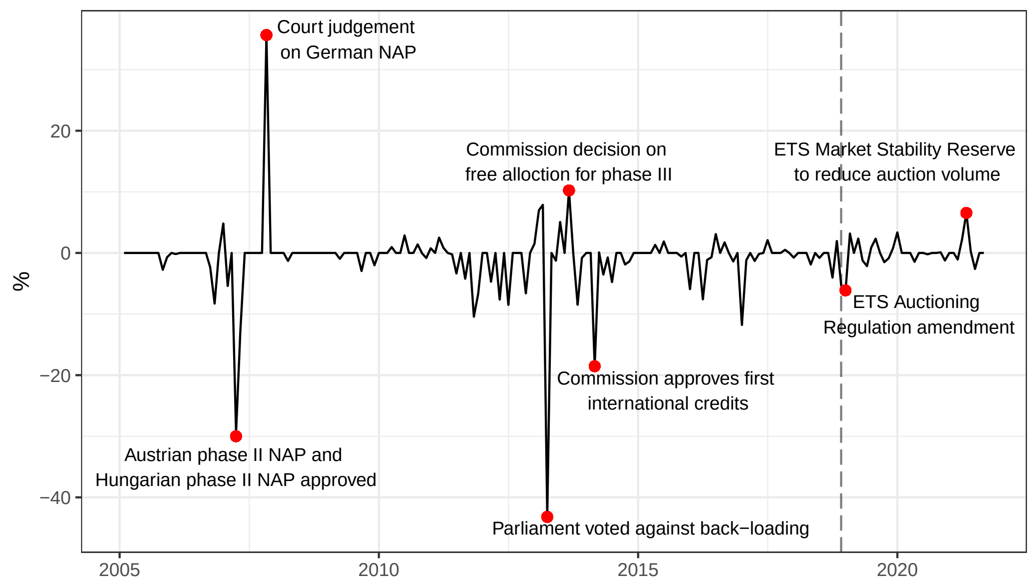

Figure 6: Monthly carbon policy surprise series and some policy events that produced substantial market reactions. The dashed line deliniates between the policy surprise produced by Känzig (2022) and the researcher.

All the regulatory dates are listed in the appendix B. As in Figure 6, the dates produced in Känzig (2022) and by me are separated.

6.4 Diagnostics of the Surprise as an external instrument

One of the significant problems the instrument could have is that it would be serially correlated. There is no evidence of persistent autocorrelation. However, there is a statistically significant autocorrelation, as seen in Figure 7 after 11 lags, and also evidence of partial autocorrelation can be seen in Figure 8.

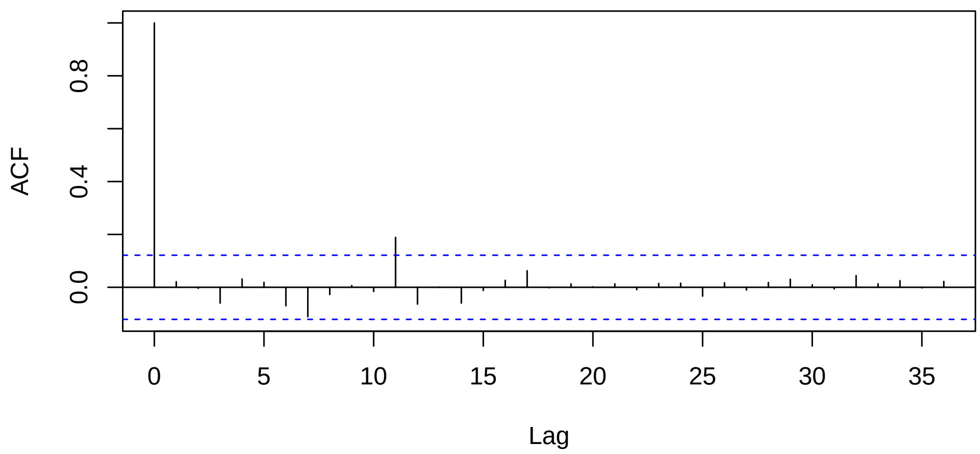

Figure 7: Autocorrelation plot of the monthly carbon policy surprise.

This autocorrelation of 11 lags would mean that the last year's regulatory announcements correlate with the announcements at time step t. This can be seen from Figure 9. As the announcements are not equally distributed throughout the year, our results may capture some seasonal impacts if the seasonal variation is not adequately handled. This is additional reason to use trend values of the variables and why there is noticeable seasonal fluctuation

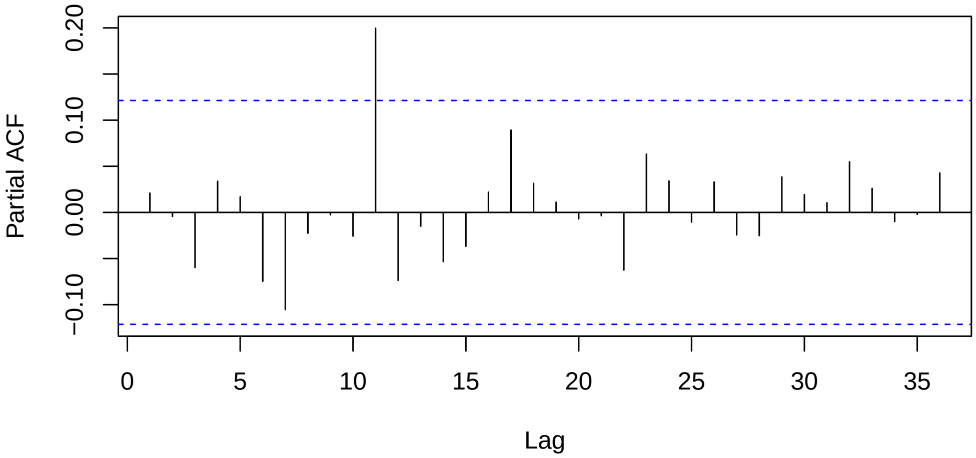

Figure 8: Partial autocorrelation plot of the monthly carbon policy surprise.

in the appendix D.1.

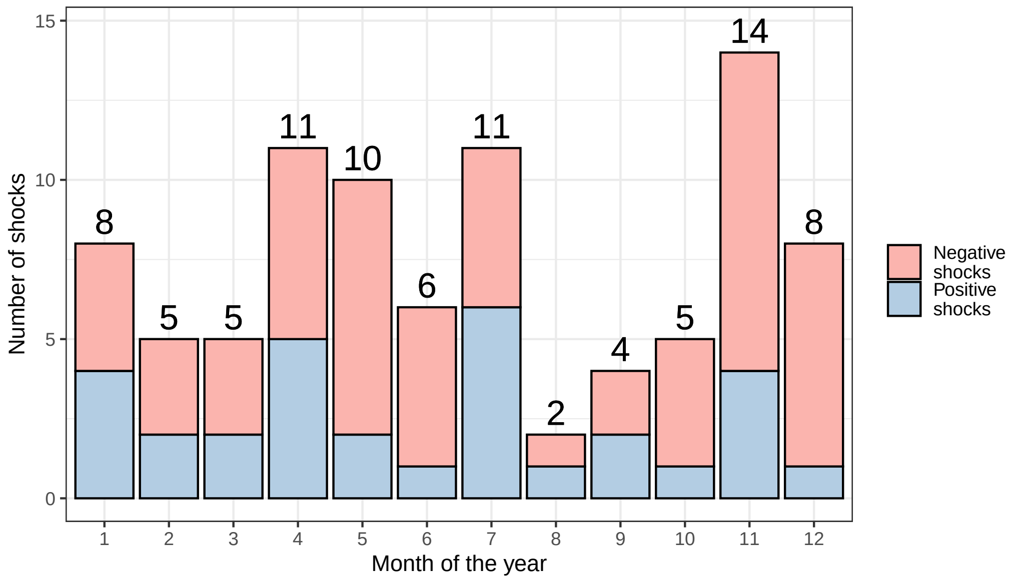

Figure 9: A summary of the amoutns of regulatory days by calender month. The total amounts are displayed as numbers above the bar plots. The bars have been colored to correspond the amounts of positive and negative shocks in every month.

7 Results

In this chapter, I will provide the results of my research. In the first section, I will provide the first-stage regression results of the instrument's power. In the second section, I will summarise the results from the research by Känzig (2022) for the reader to better understand the context of the result of this thesis. The third section is dedicated to the results of my thesis, and the fourth section will dwell on why these results may have arisen.

7.1 First stage

Inference with instrumental variables lies in the assumptions of relevancy with the shock of interest and exogeneity with other shocks. However, another often unstated assumption is that a weak correlation between the instrument and the structural shock of interest compromises the large sample validity of the inference based on the instrument (Montiel Olea et al., 2021). Due to this, Montiel Olea et al. (2021) proposes that the first-stage heteroskedasticity-robust F-statistic between the instrument and the VAR-residual should be reported as a measure of the instrument's strength. They additionally propose a rule of thumb of $F > 10$ to ensure the instrument is not weak and could be used with standard inference (Montiel Olea et al., 2021). If the instrument would be weak their research brings forth a method to use with weaker instrument variables.

For my model, the $F = 10.99$ which implies that the instrument is strong enough to be used with standard inference, and there is no need to use the weak-instrument robust confidence sets elaborated further in Montiel Olea et al. (2021). With the first stage regression, we also find that the instrument explains 2.97% of the energy price index residual, which is not. In conclusion, there is no evidence to consider that a weak instrument problem would affect the following inference based on this instrument.

7.2 Results of Känzig (2022)

The instantaneous shock from the carbon policy shock to the energy component of the Harmonised Index of Consumer Prices (HICP) is normalised to the size of one per cent. 6 months after the carbon policy shock the 90 per cent confidence interval is between 0.5 and 2 per cents. For the whole estimation period of 50 months, the impulse response was estimated, the energy components of HICP stays statistically significantly above zero (Känzig, 2022).

The carbon policy shock would have effect also to the headline HICP. It has a instantaneous response of 0.1 per cent and stays persistently, even though slightly declining, above zero (Känzig, 2022).

To GHG emissions of the EU area the carbon policy shock has a significant and persistent effect. Having a point estimate of −0.5 percent 12 months after the carbon policy shock. Emission levels will slightly rise after the slump but are in a statistically significant manor below zero. Point estimate is roughly −0.25 after 50 months (Känzig, 2022).

The impulse response function of the industrial output has a similar shape as does the GHG emissions. Initial slowdown that has a point estimate of around −0.8 and it also occurs after 12 months. In contrast with the GHG emissions the industrial output recovers to having a point estimate of zero after 40 months.

The unemployment rate responses to the carbon policy shock with a steady increase that peaks after 24 months with a point estimate of 0.2 percentage points. After reaching the peak the unemployment rate stays steadily and statistically significantly above zero.

The impulse response function of the stock price index is negative in the short run, having a point estimate of -2 per cent, but with a wide confidence band that also covers zero. The stock prices rebound and after approximately 25 months the point estimate is above zero (Känzig, 2022).

Policy rate of the three month Euribor has a substantial response to the carbon policy shock that is as its' deepest 0.1 percentage points 20 months after the carbon policy shock. It returns to zero after 40 months (Känzig, 2022). The shape of the impulse response of the policy rate seems to follow closely with the shape of the industrial policy. This is something that can also be seen in Figure 10, where the results of Finnish macroeconomy are reported.

Broad Real Effective exchange rate (REER) doesn't have a short run response to the carbon policy shock but after 15 months there starts a statistically significant decline that persists till the end of the estimation period when the REER is -0.6 per cent (Känzig, 2022).

7.3 Effects to Finnish macroeconomy

In the following section, I will present the resulting impulse response to a carbon policy shock. The solid black line represents a point estimate, and the darker and lighter regions are the 68 and 90 per cent confidence bands, respectively. These confidence bands are calculated with a moving block bootstrap which was first brought forth by Jentsch and Lunsford (2019).[1] With a block size of 20 and with 10000 bootstrap replications.

As shown in Figure 10, the negative carbon policy shock is normalised to have a 1 per cent increase in the energy components of HICP.

The energy components, greenhouse gas emission, headline HICP, industrial output index, OMX Helsinki 25 stock index and the real broad exchange rate index are all handled in log levels. The plots can therefore be interpreted as percentual changes. Only the unemployment and the 3-month Euribor interest rates are in percentage points.

What can be seen in this figure is the high persistence of the higher prices as a response to the carbon policy shock. This persistency in higher energy prices is feeding into the higher headline consumer price index, and it is statistically significant until the end of the estimation period, 50 months ahead. The behaviour of the consumer price indexes is in line with the findings of Känzig (2022) findings from a European-wide context. Where my findings differ from the results of Känzig (2022), is the behaviour of the Finnish economy in the short-run.

There is somewhat unexpected though statistically insignificant, evidence that some parts of the Finnish economy benefit from the carbon policy shocks in the short run. This can be seen as the industrial output index, which is slightly elevated after the shock. But then continues to decrease to a statistically significant long-term negative impulse response. A similar

[1] The significant advantage of the moving block bootstrap method, comparing it to the wild bootstrap method, is that it will produce accurate confidence intervals as the wild bootstrap will produce inaccurate impulse response functions to SVAR-IV (Jentsch and Lunsford, 2016). The code used in my thesis relies on Känzig (2021) reproduction files, which can be found from github. I also inquired through email exchange that the methods used in that reproduction file are similar to Känzig (2022). If any mistakes are found, they are naturally mine.

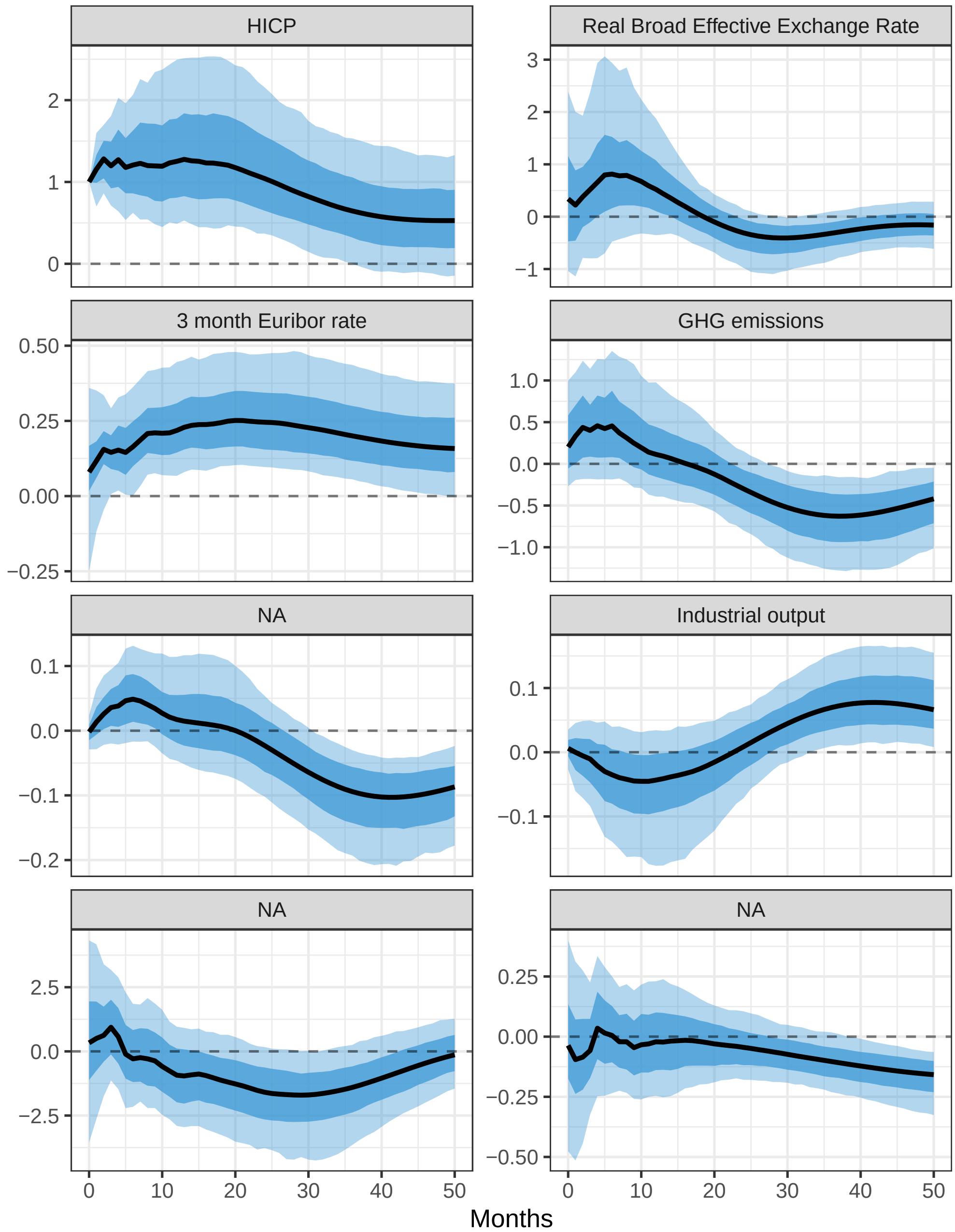

Figure 10: Impulse response functions from carbon policy shocks to macroeconomic indicators of Finland. The policy shock has been normalised to size of instantaneous 1 per cent rise in energy prices. Continuous line represents the point estimate, dark area represents the 68 percent confidence intervals and the light are 90 percent. Variables 3 month euribor and unemployment rate are represented as percentage points, all others are percentage changes.

reaction is to the impulse of the unemployment rate. Starting with a statistically insignificant negative simultaneous impact that peaks around ten months and then a steady rise to a statistically significant positive reaction. The point estimate would imply that a carbon policy shock that would instantaneously raise the energy prices by 1% would, in 40 months lead to a 0.07 percentage point rise in Finnish unemployment.

There is also statistically significant evidence that the carbon policy shock affects the 3 month Euribor interest rate by reducing it with a point estimate of 0.1 percentage point in the long run. The effects of the carbon policy shock on the stock market are statistically inconclusive. There is noticeable evidence of effects on the Finnish real effective exchange rate in the long run.

7.4 Discussion of the findings

The causal reasoning behind these impulses is not the topic of this thesis. Nevertheless, for the sake of future research, I will entertain a few hypotheses that might provide explanatory value. First, I would suggest that two different reactions are at play. A short-run reaction stimulating the economy, and a long-run reaction slowing down the Finnish economy. One hypothetical reason behind the short-run stimulation is the long history of Finnish carbon taxes, which as @ elbaum2021 states, made the Finnish industry more energy efficient. This energy efficiency would give the Finnish industry a competitive advantage over its peers. Another possible explanation is the composition of Finnish industry[2] with the high share of capital goods in the production basket. The short-term stimulus emerged due to the other European countries investing in more sustainable production

[2] According to Statistics Finland 45% of the value produced by Finnish industry is from metal industry products.

capital, which would make Finnish industrial companies' products more attractive. These explanations are hardly exclusive, and thus their relative share of effect or the existence of additional explanations will be left to future research.

The long-term effects of these shocks are more in line with the findings of Känzig (2022). This could be hypothesised to mean that the short-term stimulus of some kind is running out, and Finland will revert to the European norm. This, in turn, would imply that the lower aggregate demand in Europe, demonstrated by Känzig, would bring the Finnish economy to a lower long-term level after the investment surge. Also, as with the short-term effects, the long-term will have to be left to future research.

8 Conclusion

In my thesis, I have examined the effects of the European Union carbon policy shocks on the Finnish economy. I started by examining the institutional development of the European carbon policy regime. Then, I presented a short review of the literature on the impacts of carbon policies and additionally presented the methodological evolvement of the structural autoregressive models. In the following chapters, I elaborated on the model and data on which my inference relies.

The analysis was done using a structural vector autoregressive model, which was identified by using an instrumental variable observed from the day-on-day variation of futures prices. In tandem with my goal of quasireplication of the findings of Känzig (2022), I correspondingly extended the carbon policy surprise time series. As a result, the time series was extended to the end of the year 2021.

The results I have produced show that the Finnish economy has a significantly different impulse to Carbon Policy shock than the broader European economy. The impulse reaction of the Finnish economy has a fascinating dual nature. Short-run and long-run reactions have opposite signs in multiple variables. This would mean the carbon policy shock would benefit the Finnish economy in the short run. However, in the longer run, the economy reverts to the European norm.

My thesis underlines the need for further research on the macroeconomic impacts of the changes in carbon policy regimes. Also, the impacts of rising energy prices are today as topical as ever.

A Data sources

The data has been collected from various sources and these are individualised in Table 1. Additionally, a short description of the variables, the sample dares and the reporting frequency of the variables is reported in the table.

Table 1: Data sources for the baseline model presented in Chapter 7.3

Variable name	Description	Source	Sample dates	Data Frequency
ICE EUA Future c1	Settlement price of the ICE EUA futures front contract.	Datastream	04.08.2005 - 18.02.2022	Daily
HCIP - energy	Harmonised consumer price index of electricity, gas and other fuels.	Statistics Finland	01.01.2000 - 01.01.2022	Monthly
GHG Emissions	Greenhouse gas emissions without LULUCF sector	Statistics Finland	2000 - 2021	Yearly
HCIP	Harmonised consumer price index of all items	Statistics Finland	01.01.2000 - 01.01.2022	Monthly
Industrial production	Industrial production index	Statistics Finland	01.01.2000 - 01.01.2022	Monthly
3 month Euribor	Monthly averages of 3 month Euribor rate	ECB	01.01.2000 - 01.01.2022	Monthly
Unemployment rate	Monthly trend cycle data of the unemployment rate	Eurostat	01.01.2000 - 01.01.2022	Monthly
OMX Helsinki	OMX Helsinki 25 (OMXH25) - Price index	Datastream	01.01.2000 - 01.01.2022	Monthly
REER - Finland	Broad Effective Exchange Rate for Finland	FRED	01.01.2000 - 01.01.2022	Monthly

B Regulatory dates

In this appendix I will detail the dates from previous research and the dates that I have identified using the same sources and methodology as Känzig (2022).

The first stage of regulatory news which happened prior to year 2010 were retrieved by Känzig the from the official journal of the European Union (Känzig, 2022). Känzig also added the information of the dates of the NAP decisions which was collected from the research of Mansanet-Bataller and Pardo (2009) which covers the phase I and phase II (Känzig, 2022, Mansanet-Bataller and Pardo (2009)). After the year 2010 dates of interest are archived to the European Commission Climate Action news archive (Känzig, 2022). All of these dates are collected to Table 2.

I followed the example of Känzig (2022) and collected the regulatory dates also from the European Commission Climate Action news archive and these dates are detailed in the table 3. I extended the carbon policy regulatory update dates from the end of year 2018 to the end of year 2021.

Table 2: Regulatory dates from the research of Känzig (2022)

Dates	Even description	Type
25.05.2005	Italian phase I NAP approved	Free alloc.
20.06.2005	Greek phase I NAP approved	Free alloc.
23.11.2005	Court judgement on proposed amendment to NAP, UK vs Commission	Free alloc.
22.12.2005	Further guidance on allocation plans for the 2008–2012 trading period	Cap
22.02.2006	Final UK Phase I NAP approved	Free alloc.
23.10.2006	Stavros Dimas delivered the signal to tighten the cap of phase II	Cap
13.11.2006	Decision avoiding double counting of emission reductions for projects under the Kyoto Protocol	Intl. credits
29.11.2006	Commission decision on the NAP of several member states	Free alloc.
14.12.2006	Decision determining the respective emission levels of the community and each member state	Cap
16.01.2007	Phase II NAPs of Belgium and the Netherlands approved	Free alloc.
05.02.2007	Slovenia phase II NAP approved	Free alloc.
26.02.2007	Spain phase II NAP approved	Free alloc.
26.03.2007	Phase II NAPs of Poland, France and Czech Republic approved	Free alloc.
02.04.2007	Austrian phase II NAP approved	Free alloc.
16.04.2007	Hungarian phase II NAP approved	Free alloc.
30.04.2007	Court order on German NAP, EnBW AG vs Commission	Free alloc.
04.05.2007	Estonian phase II NAP approved	Free alloc.
15.05.2007	Italian phase II NAP approved	Free alloc.
07.11.2007	Court judgement on German NAP, Germany vs Commission	Free alloc.
08.04.2008	Court order on German NAP, Saint-Gobain Glass GmbH vs Commission	Free alloc.
23.04.2009	Directive 2009/29/EC amending Directive 2003/87/EC to improve and extend the EU ETS	Cap
23.09.2009	Court judgement on NAP, Poland vs Commission	Free alloc.
24.12.2009	Decision determining sectors and subsectors which have a significant risk of carbon leakage	Free alloc.
19.04.2010	Commission accepts Polish NAP for 2008-2012	Free alloc.
09.07.2010	Commission takes first step toward determining cap on emission allowances for 2013	Cap
14.07.2010	Member states back Commission proposed rules for auctioning of allowances	Auction
22.10.2010	Cap on emission allowances for 2013 adopted	Cap
12.11.2010	Commission formally adopted the regulation on auctioning	Auction
25.11.2010	Commission presents a proposal to restrict the use of credits from industrial gas projects	Intl. credits
15.12.2010	Climate Change Committee supported the proposal on how to allocate emissions rights	Free alloc.
21.01.2011	Member states voted to support the ban on the use of certain industrial gas credits	Intl. credits
15.03.2011	Commission proposed that 120 million allowances to be auctioned in 2012	Auction
22.03.2011	Court judgement on NAP, Latvia vs Commission	Free alloc.
29.03.2011	Decision on transitional free allocation of allowances to the power sector	Free alloc.

Table 2: Regulatory dates from the research of Känzig (2022) *(continued)*

Dates	Even description	Type
27.04.2011	Decision 2011/278/EU on transitional Union-wide rules for harmonized free allocation of allowances	Free alloc.
29.04.2011	Commission rejects Estonia's revised NAP for 2008-2012	Free alloc.
07.06.2011	Commission adopts ban on the use of industrial gas credits	Intl. credits
13.07.2011	Member states agree to auction 120 million phase III allowances in 2012	Auction
26.09.2011	Commission sets the rules for allocation of free emissions allowances to airlines	Free alloc.
14.11.2011	Clarification on the use of international credits in the third trading phase	Intl. credits
23.11.2011	Regulation 1210/2011 determining the volume of allowances to be auctioned prior to 2013	Auction
25.11.2011	Update on preparatory steps for auctioning of phase 3 allowances	Auction
05.12.2011	Commission decision on revised Estonian NAP for 2008-2012	Free alloc.
29.03.2012	Court judgments on NAPs for Estonia and Poland	Free alloc.
02.05.2012	Commission publishes guidelines for review of GHG inventories in view of setting national limits for 2013-2020	Cap
23.05.2012	Commission clears temporary free allowances for power plants in Cyprus, Estonia and Lithuania	Free alloc.
05.06.2012	Commission publishes guidelines on State aid measures in the context of the post-2012 trading scheme	Free alloc.
06.07.2012	Commission clears temporary free allowances for power plants in Bulgaria, Czech Republic and Romania	Free alloc.
13.07.2012	Commission rules on temporary free allowances for power plants in Poland	Free alloc.
25.07.2012	Commission proposed to backload certain allowances from 2013-2015 to the end of phase III	Auction
12.11.2012	Commission submits amendment to back-load 900 million allowances to the years 2019-2020	Auction
14.11.2012	Commission presents options to reform the ETS to address growing supply-demand imbalance	Cap
16.11.2012	Auctions for 2012 aviation allowances put on hold	Auction
30.11.2012	Commission rules on temporary free allowances for power plants in Hungary	Free alloc.
25.01.2013	Update on free allocation of allowances in 2013	Free alloc.
28.02.2013	Free allocation of 2013 aviation allowances postponed	Free alloc.
25.03.2013	Auctions of aviation allowances not to resume before June	Auction
16.04.2013	The European Parliament voted against the Commission's back-loading proposal	Auction
05.06.2013	Commission submits proposal for international credit entitlements for 2013 to 2020	Intl. credits
03.07.2013	The European Parliament voted for the carbon market back-loading proposal	Auction
10.07.2013	Member states approve addition of sectors to the carbon leakage list for 2014	Free alloc.
30.07.2013	Update on industrial free allocation for phase III	Free alloc.
05.09.2013	Commission finalized decision on industrial free allocation for phase three	Free alloc.
26.09.2013	Update on number of aviation allowances to be auctioned in 2012	Auction

Table 2: Regulatory dates from the research of Känzig (2022) *(continued)*

Dates	Even description	Type
08.11.2013	Member states endorsed negotiations on the back-loading proposal	Auction
21.11.2013	Commission submitted non-paper on back-loading to the EU Climate Change Committee	Auction
10.12.2013	European Parliament voted for the back-loading proposal	Auction
11.12.2013	Climate Change Committee makes progress on implementation of the back-loading propsal	Auction
18.12.2013	Commission gives green light for a first set of member states to allocate allowances for calendar year 2013	Free alloc.
08.01.2014	Climate Change Committee agrees back-loading	Auction
22.01.2014	Commission proposed to establish a market stability reserve for phase V	Cap
26.02.2014	Commission gives green light for free allocation by all member states	Free alloc.
27.02.2014	Back-loading: 2014 auction volume reduced by 400 million allowances	Auction
13.03.2014	Commission approves first batch of international credit entitlement tables	Intl. credits
28.03.2014	Commission approves second batch of international credit entitlement tables	Intl. credits
04.04.2014	Update on approval of international credit entitlement tables	Intl. credits
11.04.2014	Commission approves four more international credit entitlement tables	Intl. credits
23.04.2014	Commission approves final international credit entitlement tables	Intl. credits
02.05.2014	Commission published the number of international credits exchanged	Intl. credits
05.05.2014	Commission submits proposed carbon leakage list for 2015-2019	Free alloc.
04.06.2014	Auctioning of aviation allowances to restart in September	Auction
04.07.2014	Commission published the first update on the allocation of allowances from the New Entrants' Reserve	Free alloc.
09.07.2014	Climate Change Committee agrees proposed carbon leakage list for the period 2015-2019	Free alloc.
27.10.2014	Commission adopts the carbon leakage list for the period 2015-2019	Free alloc.
04.11.2014	Updated information on exchange and international credit use	Intl. credits
04.05.2015	Updated information on exchange and international credit use	Intl. credits
15.07.2015	Proposal to revise the EU emissions trading system for the period after 2020	Cap
23.07.2015	Commission publishes status update for New Entrants' Reserve and allocation reductions	Free alloc.
04.11.2015	Updated information on exchange and international credit use	Intl. credits
15.01.2016	Commission publishes status update for New Entrants' Reserve	Free alloc.
28.04.2016	Court judgment on free allocation in the EU ETS for the period 2013-2020	Free alloc.
02.05.2016	Updated information on exchange and international credit use	Intl. credits
23.06.2016	Following court judgement, commission to modify cross-sectoral correction factor for 2018-2020	Free alloc.
15.07.2016	Commission published a status update on the allocation of allowances from the New Entrants' Reserve 2013-2020	Free alloc.
08.09.2016	Court judgment on free allocation in the EU ETS for the period 2013-2020	Free alloc.
04.11.2016	Updated information on exchange and international credit use	Intl. credits
16.01.2017	Commission publishes status update for New Entrants' Reserve	Free alloc.

Table 2: Regulatory dates from the research of Känzig (2022) *(continued)*

Dates	Even description	Type
24.01.2017	Commission adopts Decision to implement Court ruling on the cross-sectoral correction factor	Free alloc.
15.02.2017	European Parliament voted in support of the revision of the ETS Directive for the period after 2021	Cap
27.04.2017	Climate Change Committee approves technical changes to auction rules	Auction
02.05.2017	Updated information on exchange and international credit use	Intl. credits
12.05.2017	Commission publishes first surplus indicator for ETS Market Stability Reserve	Auction
17.07.2017	Commission publishes status update for New Entrants' Reserve	Free alloc.
26.07.2017	Court judgment again confirms benchmarks for free allocation of ETS allowances for 2013-2020	Free alloc.
06.11.2017	Updated information on exchange and international credit use	Intl. credits
15.01.2018	Commission publishes status update for New Entrants' Reserve	Free alloc.
04.05.2018	Updated information on exchange and international credit use	Intl. credits
08.05.2018	Commission Notice on the preliminary carbon leakage list for phase IV (2021-2030)	Free alloc.
15.05.2018	ETS Market Stability Reserve will start by reducing auction volume by almost 265 million allowances	Auction
16.07.2018	Commission publishes status update for New Entrants' Reserve	Free alloc.
30.10.2018	Commission adopts amendment to ETS auctioning regulation	Auction
06.11.2018	Updated information on exchange and international credit use	Intl. credits
05.12.2018	Poland's 2019 auctions to include some allowances not used for power sector modernization	Auction

Table 3: Regulatory dates I have found using similar methodology as Känzig (2022).

Dates	Event description	Type
07.01.2019	ETS Auctioning Regulation amendment: auctions on renewed opt-out platform for Germany to resume soon	Auction
15.01.2019	Commission publishes status update for New Entrants' Reserve	Free alloc.
15.02.2019	Adoption of the Delegated Decision on the carbon leakage list for 2021-2030	Free alloc.
23.04.2019	EU Emissions Trading System: Iceland, Liechtenstein and Norway to start auctions on the common auction platform soon	Auction
15.05.2019	ETS Market Stability Reserve to reduce auction volume by almost 400 million allowances between September 2019 and August 2020	Auction
16.05.2019	Revised 2019 auction calendars including EEA EFTA volumes published	Auction
11.06.2019	Draft implementing regulation on the free allocation adjustments due to activity level changes	Free alloc.
12.06.2019	Poland's 2020 auction volume to include allowances not used for power sector modernisation	Auction
19.06.2019	Updated information on exchange and international credit use in the EU ETS	Intl. credits
15.07.2019	Commission publishes status update for New Entrants' Reserve	Free alloc.
28.08.2019	Commission amends ETS Auctioning Regulation for phase 4	Auction
31.10.2019	Adoption of the Regulation on adjustments to free allocation of emission allowances due to activity level changes	Free alloc.
05.11.2019	2020 auction calendars for aviation allowances published	Auction
08.11.2019	Auctioning Regulation amendment for phase 4 of the EU ETS published and to enter into force	Auction
09.12.2019	Agreement on linking the emissions trading systems of the EU and Switzerland	Intl. credits
15.01.2020	Commission publishes status update for New Entrants' Reserve	Free alloc.
31.01.2020	Lifting the suspension of UK-related processes in the Union Registry of the EU ETS	Intl. credits
06.05.2020	Provisional solution for transfer of allowances between EU and Swiss emissions trading registries postponed	Intl. credits
08.05.2020	ETS Market Stability Reserve to reduce auction volume by over 330 million allowances between September 2020 and August 2021	Auction
05.08.2020	2020 calendar for transfers of allowances between the EU and Swiss emission trading registries	Intl. credits
27.11.2020	2021 calendar for transfers of allowances between the EU and Swiss emission trading registries	Intl. credits
11.12.2020	Further information on the start of phase 4 of the EU ETS in 2021: emission allowances to be issued for aircraft operators and the Market Stability Reserve	Auction
15.03.2021	Adoption of the Regulation determining benchmark values for free allocation for the period 2021-2025	Free alloc.
21.04.2021	Commission welcomes provisional agreement on the European Climate Law	Cap
12.05.2021	ETS Market Stability Reserve to reduce auction volume by over 378 million allowances between September 2021 and August 2022	Auction
25.05.2021	Updated information on exchange and international credits' use in the EU ETS	Intl. credits

Table 3: Regulatory dates I have found using similar methodology as Känzig (2022). *(continued)*

Dates	Event description	Type
31.05.2021	Commission adopts the uniform cross-sectoral correction factor to be applied to free allocation for 2021 to 2025 in EU ETS	Free alloc.
29.06.2021	Commission publishes the national allocation tables of Member States for EU ETS stationary installations eligible to receive free allocation in the period 2021-2025	Free alloc.
22.07.2021	Revised 2021 and 2022 auction calendars published	Auction
15.11.2021	Calendar 2022 for the execution of transfers between the emission trading registries of the EU and Switzerland	Intl. credits

C Identification of the structural shock vector from the instrumental variable

In this appendix I will provide a detailed solution to the identification of the structural shock using the instrumental variable method.The following method is used to identify structural impact vector that is scaled with a value x. In the results presented in Chapter 7.3 $x = 1$.

As noted in Chapter 6 the structural shock s_1 can be identified to the tune of size sing using the external instrument. In this chapter I will mainly follow the example of Känzig (2021) and occasionally Stock and Watson (2018) and with some additions also additions from Montiel Olea et al. (2021). As stated in Chapter 4.3 the external instrument method is based on two foundational assumptions. The relevance assumption stated in Equation (3) and the exogeneity assumption previously stated in equation (4):

$$\begin{aligned} \mathbb{E}(z_t \varepsilon_{1,t}) &= \alpha \neq 0 \\ \mathbb{E}(z_t \varepsilon_{i \neq 1,t}) &= 0 \end{aligned}$$

If these assumptions are met the proportions of s_1 can be identified.

$$s_1 \alpha = \mathbb{E}(z_t u_t) = \mathbf{S}\mathbb{E}(z_t \varepsilon_t) = \begin{pmatrix} s_1 & \mathbf{S}_2 \end{pmatrix} \begin{pmatrix} \mathbb{E}(z_t \varepsilon_{1,t}) \\ \mathbb{E}(z_t \varepsilon_{2,t}) \end{pmatrix}$$

In the equation above the s_1 represents the first column of the structural impact matrix and the $\mathbf{S}_2$ are the rest of the columns of the structural impact matrix. To shorten the notations used in this appendix all parameters that represent the variables $\{2 \ldots n\}$ are indexed by 2 rather than $2 : n$. The equation above can be divided to the following:

$$\mathbb{E}(z_t u_t) = \begin{pmatrix} \mathbb{E}(z_t u_{1,t}) \\ \mathbb{E}(z_t u_{2,t}) \end{pmatrix} \begin{pmatrix} s_{1,1}\alpha \\ s_{2,1}\alpha \end{pmatrix}$$

If we combine these two equations above we it will produce:

$$\tilde{s}_{2,1} \equiv s_{2,1}/s_{1,1} = \frac{\mathbb{E}(z_t u_{2,t})}{\mathbb{E}(z_t u_{1,t})}$$

This will hold both the $\alpha \neq 0$ and $s_{1,1} \neq 0$.The scale of s_1 is from the following normalisation:

$$\Sigma = \mathbf{S}\Omega\mathbf{S}'$$

There is two different normalisation strategies when it comes to the choice Ω. It can be declared as $\Omega = \mathbb{I}_n$ this would yield a structural impact matrix that would affect and unit positive value of $\varepsilon_{1,t}$ would have an impact of magnitude of one standard deviation on $y_{1,t}$. Alternative strategy is to set the $\Omega = \text{diag}(\sigma^2_{\varepsilon_1} \ldots \sigma^2_{\varepsilon_n})$. This in contrast would mean that a unit positive value $\varepsilon_{1,t}$ has a positive effect of magnitude x that can be assigned by the author.

In my thesis I assigned the $x = 1$ which would imply in the context of my thesis that the EU carbon policy shock of unit magnitude would be normalised to the size of having an one percentage point increase in Finnish energy prices. In the rest of this appendix I will utilise the former strategy of assigning the $\Omega = \mathbb{I}_n$ as it is more computationally more interesting and the results are so similar that the normalised values can also be derived through this strategy.

Firstly by partitioning the:

$$\Sigma = \begin{pmatrix} \sigma_{1,1} & \sigma_{1,2} \\ \sigma_{2,1} & \Sigma_{2,2} \end{pmatrix}, \text{ and } \qquad \mathbf{S} = \begin{pmatrix} s_{1,1} & s_{1,2} \\ s_{2,1} & \mathbf{S}_{2,2} \end{pmatrix}$$

And as the $\Omega = \mathbb{I}_n$ it means that the $\Sigma = \mathbf{S}\mathbf{S}'$:

$$\begin{pmatrix} s_{1,1} & s_{1,2} \\ s_{2,1} & \mathbf{S}_{2,2} \end{pmatrix} \begin{pmatrix} s_{1,1} & s'_{2,1} \\ s'_{1,2} & \mathbf{S}'_{2,2} \end{pmatrix} = \begin{pmatrix} \sigma_{1,1} & \sigma_{1,2} \\ \sigma_{2,1} & \Sigma_{2,2} \end{pmatrix}$$

Because the Σ is a symmetric matrix the $\sigma'_{1,2} = \sigma_{2,1}$ it will give us three equations that will have to be solved:

$$\begin{aligned} s_{1,1}^2 + s_{1,2}s_{1,2}^{'} &= \sigma_{1,1} \\ s_{1,1}s_{2,1} + \mathbf{S}_{2,2}s'_{1,2} &= \sigma_{2,1} \\ s_{2,1}s'_{2,1} + \mathbf{S}_{2,2}\mathbf{S}'_{2,2} &= \Sigma_{2,2} \end{aligned}$$

Now we can substitute the $s_{2,1}$ by $\tilde{s}_{2,1}s_{1,1}$:

$$s_{1,1}^2 + s_{1,2}s_{1,2}^{'} = \sigma_{1,1} \tag{8}$$

$$s_{1,1}^2\tilde{s}_{2,1} + \mathbf{S}_{2,2}s'_{1,2} = \sigma_{2,1} \tag{9}$$

$$s_{1,1}^2\tilde{s}_{2,1}\tilde{s}'_{2,1} + \mathbf{S}_{2,2}\mathbf{S}'_{2,2} = \Sigma_{2,2} \tag{10}$$

It can be clearly seen, from the equation that the $s_{1,1} = \pm\sqrt{\sigma_{1,1} - s_{1,2}s_{1,2}^{'}}$. For the full identification of s_1 we now only need to solve for the $s_{1,2}s_{1,2}^{'}$.

By subtracting equation multiplied by $\tilde{s}_{2,1}$ from equation :

$$
\begin{aligned}
\mathbf{S}_{2,2}s'_{1,2} - \tilde{s}_{2,1}s_{1,2}s'_{1,2} &= \sigma_{2,1} - \tilde{s}_{2,1}\sigma_{1,1} \\
(\mathbf{S}_{2,2} - \tilde{s}_{2,1}s_{1,2})s'_{1,2} &= \sigma_{2,1} - \tilde{s}_{2,1}\sigma_{1,1} \\
\Rightarrow s'_{1,2} &= (\mathbf{S}_{2,2} - \tilde{s}_{2,1}s_{1,2})^{-1}(\sigma_{2,1} - \tilde{s}_{2,1}\sigma_{1,1})
\end{aligned}
$$

Now we get that the

$$s_{1,2}s'_{1,2} = (\sigma_{2,1} - \tilde{s}_{2,1}\sigma_{1,1})'\Gamma^{-1}(\sigma_{2,1} - \tilde{s}_{2,1}\sigma_{1,1})$$

Where the

$$\Gamma = \mathbf{S}_{2,2}\mathbf{S}'_{2,2} - \mathbf{S}_{2,2}s'_{1,2}\tilde{s}'_{2,1} - \tilde{s}_{2,1}s_{1,2}\mathbf{S}'_{2,2} + \tilde{s}_{2,1}s_{1,2}s'_{1,2}\tilde{s}'_{2,1}$$

Next step is to subtract the equation which is multipled by $\tilde{s}'_{2,1}$ from the equation :

$$
\begin{aligned}
\mathbf{S}_{2,2}\mathbf{S}'_{2,2} - \mathbf{S}_{2,2}s'_{1,2}\tilde{s}'_{2,1} &= \Sigma_{2,2} - \sigma_{2,1}\tilde{s}'_{2,1} \\
\Rightarrow \mathbf{S}_{2,2}s'_{1,2}\tilde{s}'_{2,1} &= \mathbf{S}_{2,2}\mathbf{S}'_{2,2} - (\Sigma_{2,2} - \sigma_{2,1}\tilde{s}'_{2,1}).
\end{aligned}
$$

Substituting this and transpose of it to the helper equation Γ will give us

$$\Gamma = -(\mathbf{S}_{2,2}\mathbf{S}'_{2,2} - \tilde{s}_{2,1}s_{1,2}s'_{1,2}\tilde{s}'_{2,1}) + 2\Sigma_{2,2} - \tilde{s}_{2,1}\sigma_{1,2} - \sigma_{2,1}\tilde{s}'_{2,1}.$$

Last step in the manipulation of the helper function is to premultiplicate equation by $\tilde{s}_{2,1}$ and and subtract it with equation which has been postmultiplied by $\tilde{s}'_{2,1}$. Which will give us the following

$$\mathbf{S}_{2,2}\mathbf{S}'_{2,2} - \tilde{s}_{2,1}s_{1,2}s'_{1,2}\tilde{s}'_{2,1} = \Sigma_{2,2} - \sigma_{1,1}\tilde{s}_{2,1}\tilde{s}'_{2,1}.$$

This will then give us the final form of the helper function:

$$\Gamma = \Sigma_{2,2} - (\tilde{s}_{2,1}\sigma_{1,2} - \sigma_{2,1}\tilde{s}'_{2,1}) + \sigma_{1,1}\tilde{s}_{2,1}\tilde{s}'_{2,1}.$$

This will then give us the solution for the:

$$s_{1,2}s'_{1,2} = (\sigma_{2,1}-\tilde{s}_{2,1}\sigma_{1,1})'[\Sigma_{2,2}-(\tilde{s}_{2,1}\sigma_{1,2}-\sigma_{2,1}\tilde{s}'_{2,1})+\sigma_{1,1}\tilde{s}_{2,1}\tilde{s}'_{2,1}]^{-1}(\sigma_{2,1}-\tilde{s}_{2,1}\sigma_{1,1})$$

Now the whole stuctural impact vector is identified as a function of known quantities. By choosing the $s_{1,1} = \sqrt{\sigma_{1,1} - s_{1,2}s'_{1,2}}$ it can be interpreted as the standard deviation of $\varepsilon_{1,t}$. The structural impact vector is

$$s_1 = \begin{pmatrix} s_{1,1} \\ \tilde{s}_{2,1}s_{1,1} \end{pmatrix}$$

As mentioned above I am suing this as he algorithm and thus I provided the mathematical proof of it providing the s_1 structural impact vector. The justification of using the notations in equation x in the econometric approach chapter can be clearly seen that if the $\Omega = \text{diag}(\sigma^2_{\varepsilon_1}, \ldots, \sigma^2_{\varepsilon_n})$ is chosen. The $s_{1,1}$ can be chosen to be a scalar x as the standard deviation is normalised with using the diagonal matrix. This mean that the final impact vector is then

$$s_1 = \begin{pmatrix} x \\ \tilde{s}_{2,1}x \end{pmatrix}.$$

It can be then seen that after the $s_{1,1}$ is know it is trivial to transform between the two strategies of normalisation. This is how I used the code that was inspired from the Känzig (2021) replication files that used an similar strategy that Känzig (2022).

D Sensitivity checks

Here can be seen few different IRF plots with different choices with endogenous variables. This will bring some insight how sensitive the results of my thesis are on the choices made with the selection of endogenous variables and the choices made on the

D.1 Seasonally varying endogenous variables

In the figure below it can be seen that the model captures a significant seasonal variation to the greenhouse gas emissions. It is also unplausible to consider that a modest price shock would raise the Finnish unemployment rate by two percentage points. This is an excellent argument against using the seasonally varying data. As I demonstrated in the chapter 6.4 that the regulatory dates are accumulated on same times of the year, this could then combined with the seasonally varying Greenhouse gas data and seasonally varying unemployment data explain the impulse responses seen below. Also in this model is used the seasonally varying industrial production index, the

My aim is not to explain this unusual impulse response functions but to use it as an argument on behalf of using data from where the seasonal variation is cleaned out. Reassuringly the main findings of my thesis are still, at least qualitatively present even though this is a model with endogenous variables that have seasonal variation.

D.2 Omitting GHG emissions

To test whether the large contemporaneous effects in industrial production and unemployment rate are solely due to the substantially varying greenhouse

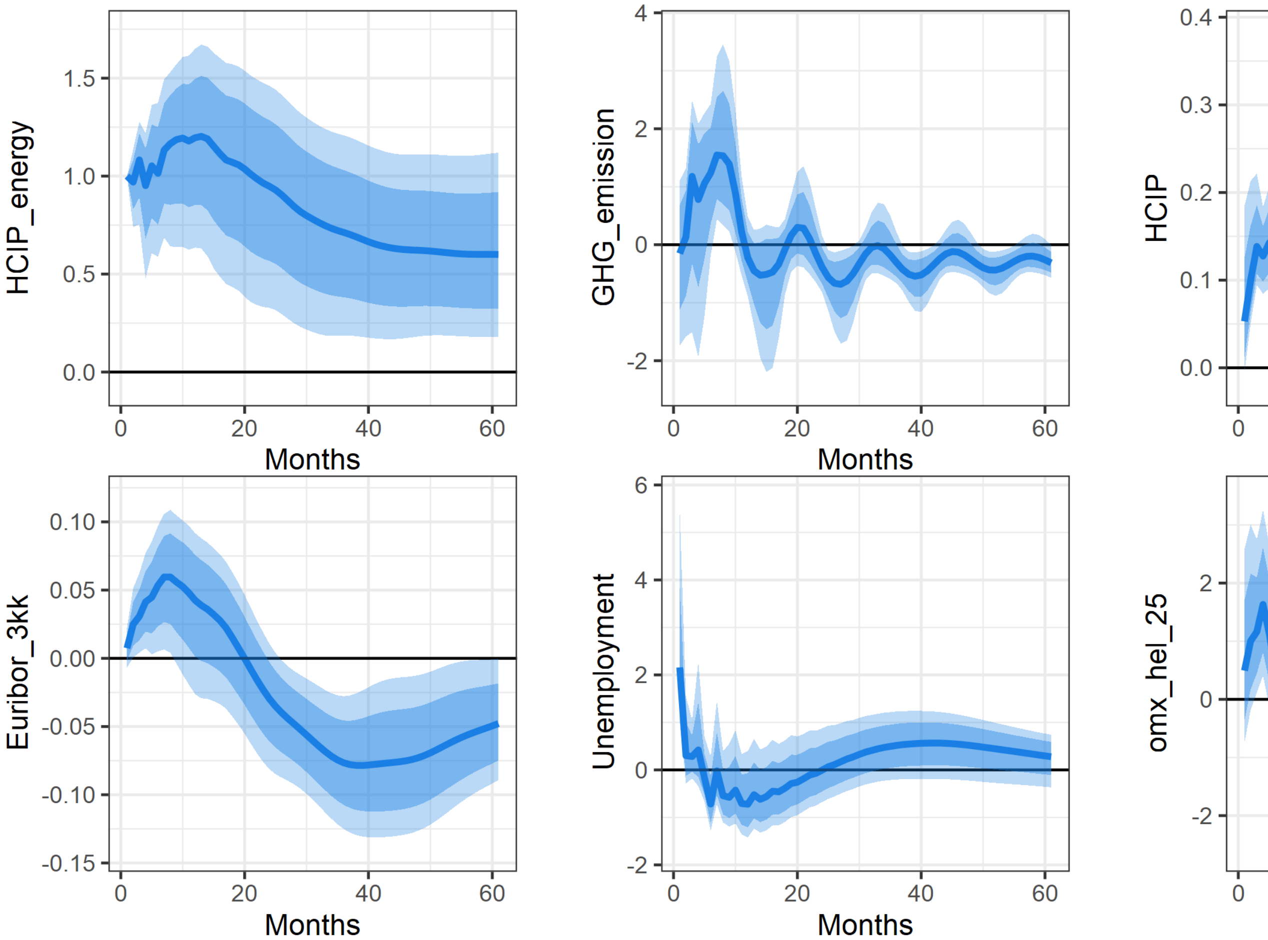

Figure 11: The IRFs with my seasonally agressively varying GHG emissions and with the not seasonally adjusted unemployment rates as endogenous variables.

gas data. I will in this model I have omitted the Greenhouse gas emissions from the model.

As can be seen from the figure 12 the large contemporaneous effects are still present and thus it could be interpreted as evidence for using the trend values, I have utilised in the core model I have presented. It is reassuring that if the contemporaneous effects are ignored the effects are similar to the core model. This could be interpreted to indicate that the drastic contemporaneous effects are due to seasonal variation. Yet again my aim here is not to prove this. But on contrary, I will the counter I will provide these as an argument for the selection of the endogenous variables in my core model. Additionally, these two figures suggest that the core findings of my thesis are robust to a wide variety of choices in handling the endogenous variables.

D.3 Local projection

In this subchapter I will produce local projection impulse responses as used in the supplementary material of Plagborg-Møller and Wolf (2021).

There is notional resemblance with the signs of the IRF's, but as the sample size is as small as it is the local projections is not a viable strategy.

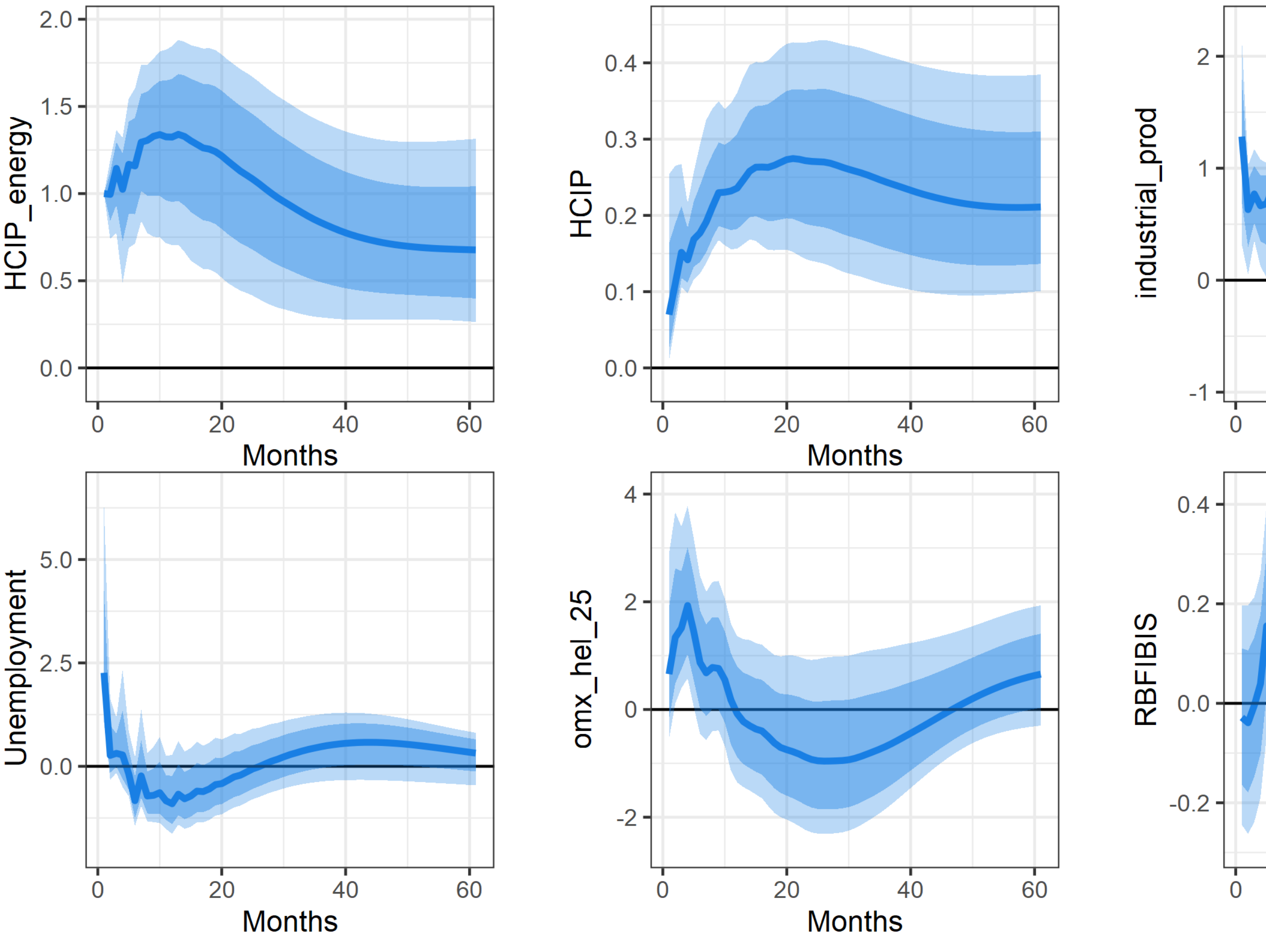

Figure 12: Omitting the Greenhouse gas data from my endogenous variables. It can be seen that the results of the IRF are at least qualitatively similar as the ones reported in my main findings.

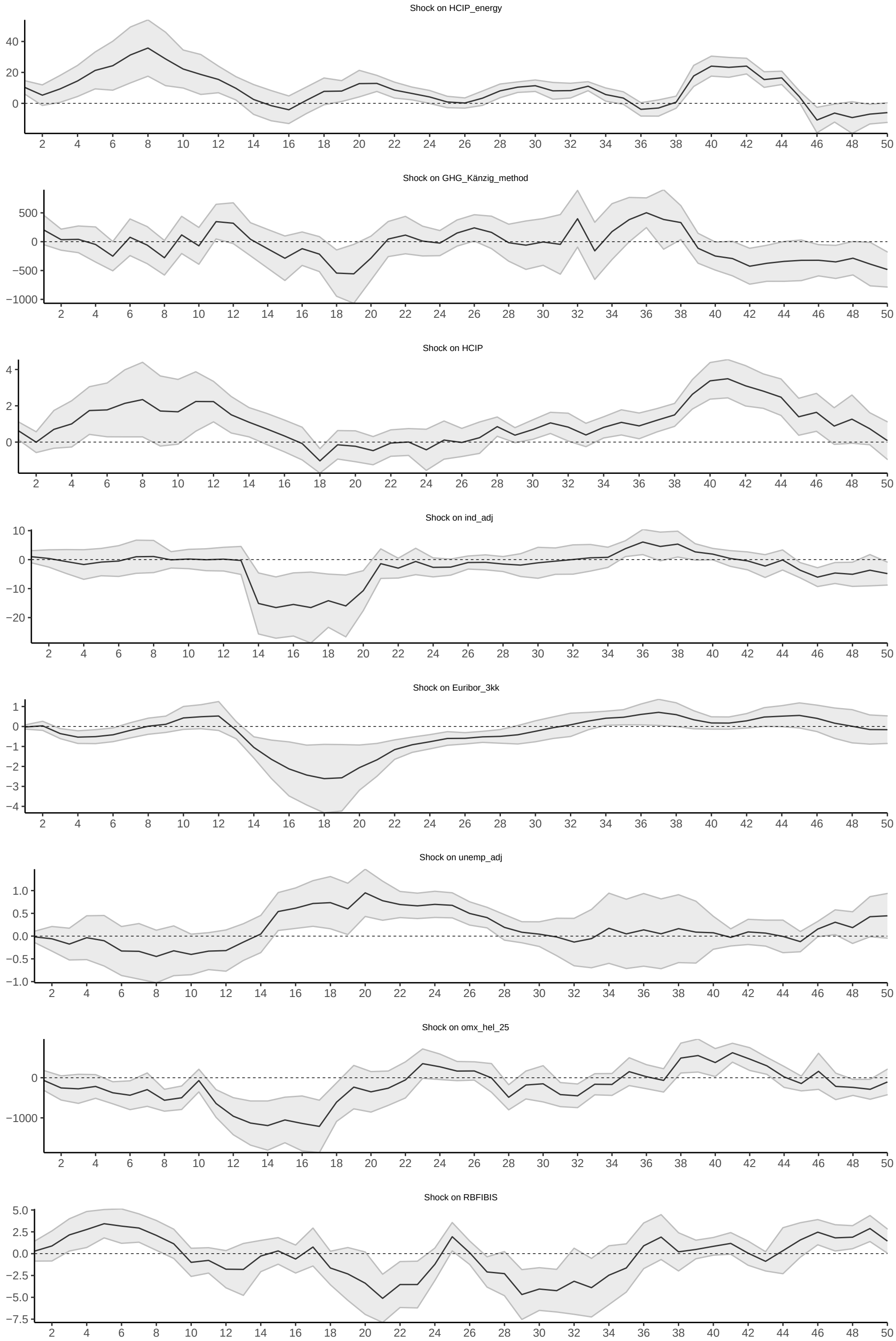

Figure 13: The local projections made

E References

Acemoglu, D., Akcigit, U., Hanley, D., and Kerr, W. (2016). Transition to clean technology. *Journal of political economy*, 124(1):52–104.

Andersson, J. J. (2019). Carbon taxes and co 2 emissions: Sweden as a case study. *American Economic Journal: Economic Policy*, 11(4):1–30.

Bavbek, G. (2016). Carbon taxation policy case studies. *EDAM Energy and Climate Change. Climate Action Paper Series 2016*, 4:15.

Chow, G. C. and Lin, A.-l. (1971). Best linear unbiased interpolation, distribution, and extrapolation of time series by related series. *The review of Economics and Statistics*, pages 372–375.

De Winne, J. and Peersman, G. (2021). The adverse consequences of global harvest and weather disruptions on economic activity. *Nature Climate Change*, 11(8):665–672.

Ekins, P. and Speck, S. (1999). Competitiveness and exemptions from environmental taxes in europe. *Environmental and resource economics*, 13(4):369–396.

Elbaum, J.-D. (2021). The effect of a carbon tax on per capita carbon dioxide emissions: evidence from finland. Technical report, IRENE Working Paper.

Ellerman, A. D., Marcantonini, C., and Zaklan, A. (2020). The european union emissions trading system: ten years and counting. *Review of Environmental Economics and Policy*.

Faccia, D., Parker, M., and Stracca, L. (2021). Feeling the heat: extreme temperatures and price stability. *ECB Working Paper*.

García, A., García-Álvarez, M. T., and Moreno, B. (2021). The impact of eu allowance prices on the stock market indices of the european power industries: evidence from the ongoing eu ets phase iii. *Organization & Environment*, 34(3):459–478.

Hallituksen esitys, . (1989). Hallituksen esitys n:o 122 eduskunnalle laiksi polttoaineverosta annetun lain väliaikaisesta muuttamisesta.

Hayek, F. A. (1945). The use of knowledge in society. *American Economic Review*, 35(4):519–560.

Jentsch, C. and Lunsford, K. (2016). Proxy svars: Asymptotic theory, bootstrap inference, and the effects of income tax changes in the united states (working paper no. 16-19). *Cleveland, OH: Federal Reserve Bank of Cleveland*.

Jentsch, C. and Lunsford, K. G. (2019). The dynamic effects of personal and corporate income tax changes in the united states: Comment. *American Economic Review*, 109(7):2655–78.

Joltreau, E. and Sommerfeld, K. (2019). Why does emissions trading under the eu emissions trading system (ets) not affect firms' competitiveness? empirical findings from the literature. *Climate policy*, 19(4):453–471.

Känzig, D. (2022). The unequal economic consequences of carbon pricing. Accessed: 2022-08-20.

Känzig, D. R. (2021). The macroeconomic effects of oil supply news: Evidence from opec announcements. *The American economic review*, 111(4):1092–1125.

Keränen, H., Lähdemäki, S., et al. (2020). Identification of fiscal svars in small open economies using trading partner forecast errors as instruments.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3):1053–69.

Lin, B. and Li, X. (2011). The effect of carbon tax on per capita co2 emissions. *Energy policy*, 39(9):5137–5146.

Mansanet-Bataller, M. and Pardo, A. (2009). Impacts of regulatory announcements on co2 prices. *The Journal of Energy Markets*, 2(2):1–33.

Martin, R., De Preux, L. B., and Wagner, U. J. (2014). The impact of a carbon tax on manufacturing: Evidence from microdata. *Journal of Public Economics*, 117:1–14.

Metcalf, G. E. (2021). Carbon taxes in theory and practice. *Annual Review of Resource Economics*, 13:245–265.

Metcalf, G. E. and Stock, J. H. (2020). The macroeconomic impact of europe's carbon taxes. Technical report, National Bureau of Economic Research.

Montiel Olea, J. L., Stock, J. H., Watson, M. W., et al. (2021). Inference in structural vector autoregressions identified with an external instrument. *Journal of Econometrics*, 225(1):74–87.

Nakamura, E. and Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: the information effect. *The Quarterly Journal of Economics*, 133(3):1283–1330.

Palanne, K. and Sahari, A. (2021). Henkilöautoliikenteen co2-päästöt ja päästöjen vero-ohjaus.

Pindyck, R. S. (2001). The dynamics of commodity spot and futures markets: a primer. *The energy journal*, 22(3).

Plagborg-Møller, M. and Wolf, C. K. (2021). Local projections and vars estimate the same impulse responses. *Econometrica*, 89(2):955–980.

Romer, C. D. and Romer, D. H. (2010). The macroeconomic effects of tax changes: estimates based on a new measure of fiscal shocks. *American Economic Review*, 100(3):763–801.

Sahari, A. (2019). Electricity prices and consumers' long-term technology choices: Evidence from heating investments. *European Economic Review*, 114:19–53.

Statistics Finland (2022). Official statistics of finland (osf): greenhouse gases [e-publication]. http://www.stat.fi/til/khki/2020/khki_2020_2022-03-17_tie_001_en.html. Accessed: 2022-08-20.

Stock, J. H. and Watson, M. W. (2008). What's new in econometrics-time series. *NBER Summer Institute, Lecture*, 7(2012):2007–09.

Stock, J. H. and Watson, M. W. (2012). Disentangling the channels of the 2007-2009 recession.

Stock, J. H. and Watson, M. W. (2018). Identification and estimation of dynamic causal effects in macroeconomics using external instruments. *The Economic Journal*, 128(610):917–948.

Valtioneuvosto (2019). Inclusive and competent finland – a socially, economically and ecologically sustainable society: Programme of prime minister sanna marin's government 2019. https://valtioneuvosto.fi/en/marin/government-programme. Accessed: 2022-08-20.

Verde, S. F., Teixidó, J., Marcantonini, C., and Labandeira, X. (2019). Free allocation rules in the eu emissions trading system: what does the empirical literature show? *Climate policy*, 19(4):439–452.

Wolf, C. K. (2020). Svar (mis) identification and the real effects of monetary policy shocks. *American Economic Journal: Macroeconomics*, 12(4):1–32.