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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 from the year 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 not been research on the macroeconomic impacts to the Finnish economy by the previously implemented EU-wide carbon emission reduction policies. My thesis posits itself as

Research done by Känzig is going to be

The concentration on the EU Emission trading system (EU ETS) is relevant as it has been the one policy tool that has been the most widely used (SOURCE???)

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. . .

My thesis can then provide new descriptive information on the response of the Finnish economy, which is fundamental for the economic sciences in the future to offer more ingrained prescriptive policy tools. Additionally, I aim to extend the groundbreaking work of Känzig (2022). With this dual goal in my mind

2 Climate policy in Finland

In this chapter, I will briefly introduce the climate policy in Finland before the implementation of 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 chapter. 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 said institutions.

2.1 Prior to 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, whether household or industrial, of the energy-producing fuels (Ekins and Speck, 1999). The only fuel source exempted from this 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 a more substantial level (Bavbek, 2016). Sweden closely followed the Finnish example and enacted a carbon tax in 1991 (Andersson, 2019). In the next chapter, I will elaborate on the effectiveness of the Finnish and Swedish carbon taxes, where 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 effects of these early carbon taxes are not in the scope of this thesis. Still, they might be the answer to my counterintuitive findings about the reaction of the Finnish economy to the carbon policy shocks of the European Union. The Finnish economy had more time and a solid monetary incentive to use the fossil fuel resources more efficiently and to invest in green infrastructure before the enaction of the European Union ETS. 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.

2.2 EU emission trading system

The second chapter of 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). Also, various allocation schemes have been implemented in the different phases of the EU ETS as the allocation strategy was updated (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 operated 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 was widely considered the experimentation period where the institutions of ETS were tested; also, 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 then scrutinised by the European Commission (Ellerman et al., 2020). Therefore, the verification procedure of the NAPs will be a significant source of the carbon policy surprise, which is discussed in chapter 4.

Phase II continued with a similar framework of NAPs and their Commission approvals (Ellerman et al., 2020). The governments were allowed to auction up to 10 per cent of the allowances, compared to 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 different phases on the prices of the emission trading allowances can be seen clearly in Figure 1.

The oversupply of ETS allowances in late Phase II led to the reforms in Phase III. The most substantial updates to the ETS were the NAP's abolition and the resulting system's resulting centralisation by adopting a single EU-wide cap. This cap was planned to reduce yearly by a linear amount that was 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 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 to the energy sector in 2013, and plans to enact this to 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

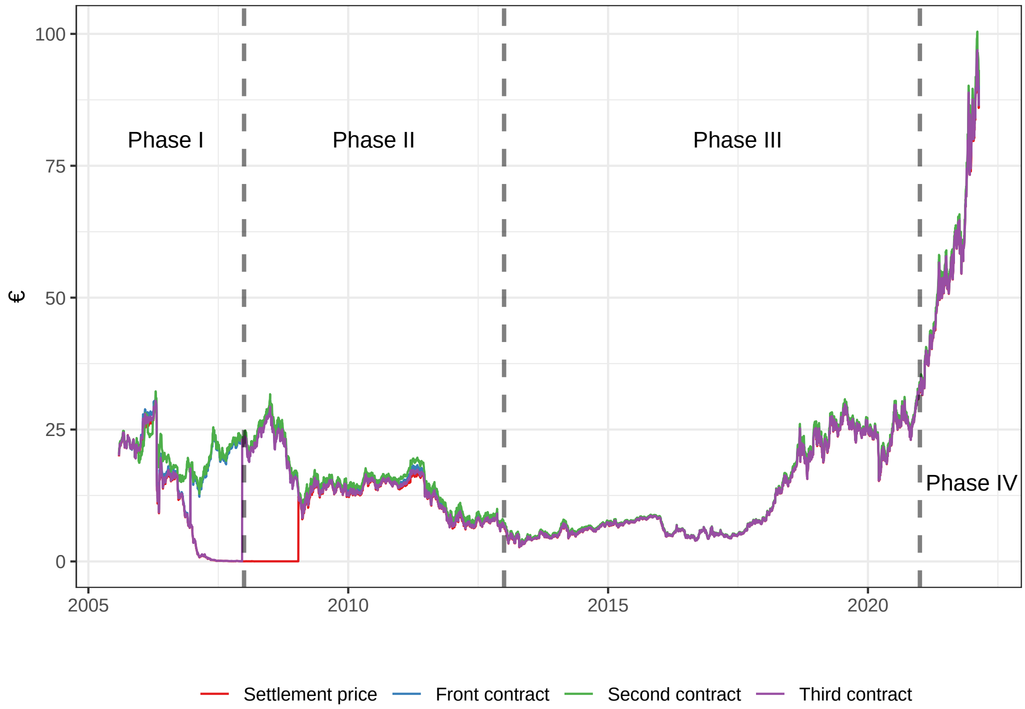


Figure 1: The evolution of the EU Emission trading system spot price and different future lengths prices through the different phases of the system. 2.0

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 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). This ambitious pace was 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 dimension that will test the resolve of the European decision-makers is higher energy costs and the downstream effects of higher prices which I will bring more evidence in the chapter 7.

3 Relevant literature

In this chapter, I will present the previous empirical research on how environmental policy decisions have widely affected consumers and economies. The second subsection will cover a variety of previous research that utilised similar methodologies 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 Effects of environmental policy

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) studied the effects 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, their results were not encouraging; they estimated that between 2013 and 2017, personal transport emissions decreased only about 2.3 per cent (Palanne and Sahari, 2021). Another paper 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' heating choices who 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).

Another research done in the context of Nordic countries that had contrasting 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 quasi-experiment to find significant reductions in carbon emissions after implementing a 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; these findings were achieved using a synthetic control (Andersson, 2019). These findings are in interesting contention with the findings of Palanne and Sahari. Some studies have also concentrated on the Finnish economy in the same period as Anderson was in Sweden. For example, a working paper written by Elbaum (2021) focuses on the response of the Finnish economy to carbon taxes in the 1990s. It uses a similar approach as Andersson to estimate the causal impact of the carbon tax (Elbaum, 2021). He found a similar reaction in the Finnish economy to Andersson's in Sweden (Elbaum, 2021). These results could suggest that at the time of Palanne's and Sahari's research, the effects of carbon taxes were already embedded into the decision-making process of Finnish consumers. Also, it underlines the importance of understanding the historical processes behind the studies as the results seem to be substantially context-dependent.

Another study that takes a much broader view on the macroeconomic impacts of carbon taxes on European economies was written by Metcalf and Stock (2020). They implemented a plethora of time-series analyses on different European countries before and after implementing different carbon taxes (Metcalf and Stock, 2020). Interestingly they found negligible impacts on GDP growth or employment but a substantial reduction in greenhouse gas emissions (Metcalf and Stock, 2020). Metcalf (2021) also published an article where he outlines a theoretical framework on how carbon taxes and other greenhouse gas reduction mechanisms can work and reviews prior theoretical literature on the topic. He adds an essential point to the previous literature; if 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 and 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). The model formalised by Acemoglu et al. predicts 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 lower 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 the greenhouse gas pollution, their findings could also tilt to favour carbon taxes more (Acemoglu et al., 2016). The research by Acemoglu also sidesteps the possibility of the cap-and-trade schemes and the possible effects of these schemes.

This exclusion of a widely used policy is in stark contrast with the main inspiration 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 that is the European Union (Känzig, 2022). He quantified the size of these carbon policy shocks to United Kingdom's economy using the structural vector autoregressive model (Känzig, 2022). This kind of surprise estimation has been previously used in the time series analysis of oil markets. 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). This way, 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

Before developing the instrument, variable-based identification of the structural vector autoregression method will be discussed in chapter 4.

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 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 answered an ingenious way of sidestepping this endogeneity problem in his previous research in the realms of oil and carbon policies (Känzig, 2022, 2021). Moreover, this identification strategy will be further elaborated in the chapter 6, which is fully dedicated to the instrument variable (Känzig, 2022).

Another integral 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 was 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 research of Stock and Watson supports the idea that financial collapse and tight monetary policy had a significant impact on the slow economic recovery (Stock and Watson, 2012).

The SVAR-IV was 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 in this study was the formation of an instrument variable (Keränen et al., 2020). This instrument variable can have use in future research. However, the authors cautioned whether the instrument should be used as an external instrument as used by Stock and Watson (2008, 2012) (Keränen et al., 2020).

Before the research I am replicating in this thesis, 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 the chapter 6. Känzig (2021) identified short- and long-term impulse responses to a negative oil supply news shock. In the short term, the oil price increase was substantial but decreased back to the original price level with time. In contrast, oil and industrial production are not instantaneously affected, but a significant decrease in all 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 research argues that the middle-income countries would be hardest hit by price shocks in the agricultural commodity market, as lower-income countries more reliant on agriculture would incur windfall profits with higher 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 take account of 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). With a similar focus, Faccia et al. (2021) studied the effects of anomalous temperatures in winter and summer on medium-term inflation in a European central bank working paper. 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).

- add Stock and Watson (2018) and Mertens and Ravn (2013)

Mertens and Ravn (2013) followed in the footsteps of Romer and Romer (2010) in further developing a synthesis of SVAR-based estimation methods and the narrative

- also add the Giacomini et al. (2022) as the possible future of the SVAR-IV field

Overall, these studies highlight the value of the SVAR-IV as an instrument in trying to identify the ...

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 an $n \times 1$ vector of the reduced form innovations with a covariance matrix of Σ.

4.2 Identification of the structural shocks

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

$$u_t = S\varepsilon_t$$

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 x, 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 shock of interest, the carbon policy shock. 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:

$$\mathbb{E}(z_t \varepsilon_{1,t}) = \alpha \neq 0 \tag{2}$$

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

The equation (2) is the relevance condition and the equation (3) is 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:

$$s_1 \propto \frac{\mathbb{E}(z_t u_t)}{\mathbb{E}(z_t u_{1,t})} \tag{4}$$

The size of α 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 elaborated in the Stock and Watson (2018), which I 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 Comparing 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 the 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 that the baseline model can be trusted.

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. I also selected the SVAR-IV as my identification approach for reliability and efficiency, which are paramount in estimating the responses to a shock from a short sample.

5 Data

I will follow the Känzig's formulation as having the following endogenous variables. The model consists of two sections: 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 of 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 in 2021. All the endogenous variables are also reported in monthly time series. The Greenhouse gas emissions are an exception and must be disaggregated to a monthly time series.

Following Känzig's (2022) example, all the variables have been stored as log levels, except the 3-month Euribor and Unemployment rate. This is done for the results to be interpretable as percentages.

5.1 Greenhouse gas emission disaggregation

The greenhouse gas emission data is reported annually due to the commitments that were made by the United Nations Framework Convention on Climate Change (Stat Fin, 2022). This produces a problem that has to be addressed as our model will be built on a monthly time series.

Känzig solved the problem by using the Chow-Lin disaggregation method. The accuracy of the disaggregation can be increased by additional relevant indicators reported in the desired frequency and correlated with the target values (Chow and Lin, 1971). Känzig used as his indicators the Consumer price index of energy products and industrial production index. As can be seen from Figure 1, Finnish non-renewable energy production is highly seasonal.

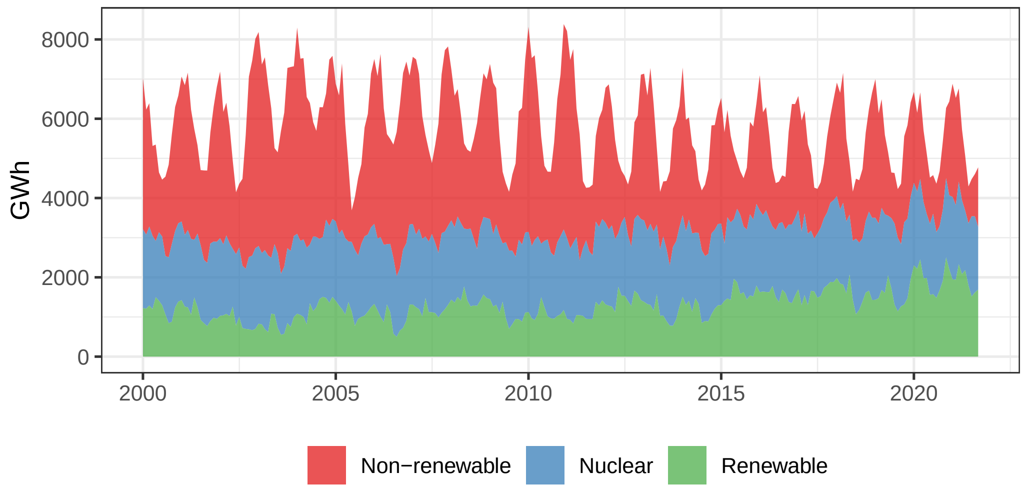


Figure 2: Monthly energy production in Finland by energy source. The increased share of renewable energy production and decreased total energy production have been the prevalent trends after 2010.

As a first impulse, I wanted to capture this seasonal variation in my disaggregated time series. That is why I produced three different disaggregated time series of greenhouse gas emissions: a dummy disaggregation without any indicators, with similar indicators that Känzig (2022) used, and with the additional information of the amounts of non-renewable energy production. The results of these three disaggregations can be seen from Figure 3.

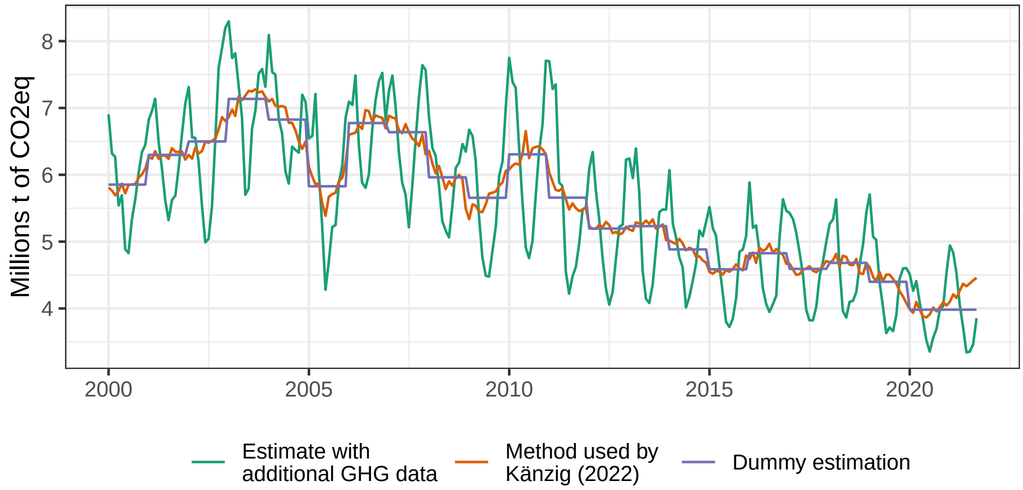


Figure 3: Different disaggregation strategies from yearly values of the GHG emissions in Finland to monthly values. The additional data transforms the disaggregation to aggressively seasonal.

The dummy disaggregation strategy produces a yearly value divided by 12 as it's estimation, this can be considered also as the reported value, when we analyse the other two estimates. The disaggregation produced following in the footsteps of Känzig produces a relatively smooth time series that could be understood as a trend time series. The final disaggregation is the one with additional information. The values are varying wildly between summer months and winter months; this is due to the variation in the usage of non-renewable energy sources, that can be seen in the figure 2.

Even though the my estimate might be more truthful in capturing the actual monthly greenhouse gas emissions. It also produces more noise to the model and in the subchapter 5.2 I will discuss the problems of not using trended values. In appendix D.1 can be seen the impulse response functions that are produced with my estimate, and how it produces seasonal noise.

5.2 Using trend values

Känzig did not utilise trend values in his analysis, this might not been a significant problem, as he used values that were observed from Europe. This means that the seasonal variation was much lower than in the data that was observed from Finland. The seasonal variation of employment can be seen in the figure 3:

Using the original observed unemployment rate bring similar problems as using the disaggregation with additional information. It brings noise to the impulse responses. The in the appendix x can be seen 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 responses of the shocks. These similar problems are also present with the industrial production index.

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

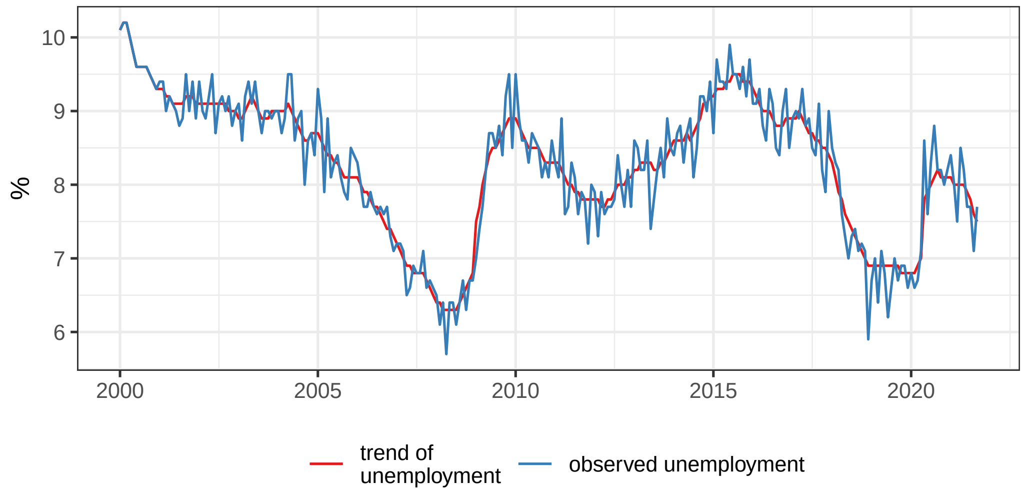


Figure 4: Monthly observed unemployment rate and the seasonally adjusted trend values of unemployment rate in Finland.

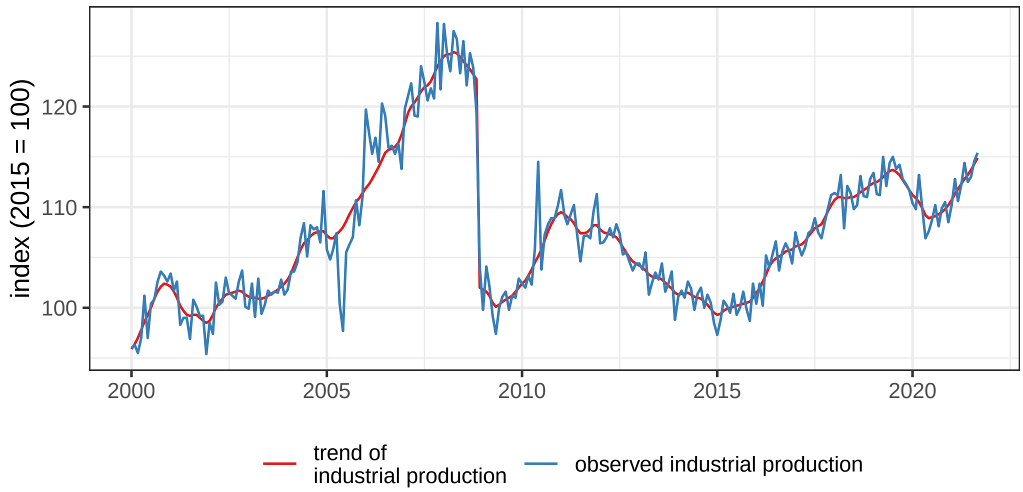


Figure 5: Monthly observed industrial production index and the seasonally adjusted trend values of industrial output in Finland.

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

The intrumental variable has been used since the start of the 20th century

6.1 Futures market

The usage of futures markets relies on the hypothesis that the markets will effectively incorporate all available information to the price discovery mechanism (Hayek, 1945). That would then

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

$$F_d^h = \mathbb{E}_d(P_{d+h}) - RP_d^h \tag{5}$$

The equation (5) 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 to time step h at.

6.2 High-frequency identification

In my thesis I will follow the formulation used by Känzig (2022) with the high-frequency identification of the instrument. It is based on similar approach that was used by Romer and Romer (2010), 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).

$$\begin{aligned} \text{Surprise}_d &= F_d^h - F_{d-1}^h \\ &= \mathbb{E}_d(P_{d+h}) - RP_d^h - \mathbb{E}_{d-1}(P_{d+h}) + RP_{d-1}^h \\ &= \mathbb{E}_d(P_{d+h}) - \mathbb{E}_{d-1}(P_{d+h}) \end{aligned} \tag{6}$$

The daily surprise series elaborated in the equation (6) is then aggregated to a monthly carbon policy surprise series which will be . A indicator function $1_{cp}(d)$ whether a day contains an carbon policy regulatory event is used to mask days with now regulatory events to zero. The regulatory events are listed in Appendix B.

$$\text{CPSurprise}_m = \sum_{d \in m} \text{Surprise}_d 1_{cp}(d)$$

This monthly surprise series is an ideal external instrument due to the exogeneity resulting from the short time frame of the identification. This means that a

6.3 Regulatory Dates

The identification of regulatory events is a vital part of the building of this instrument. In the figure 6 the values of the CPSurprise_m can be clearly seen.

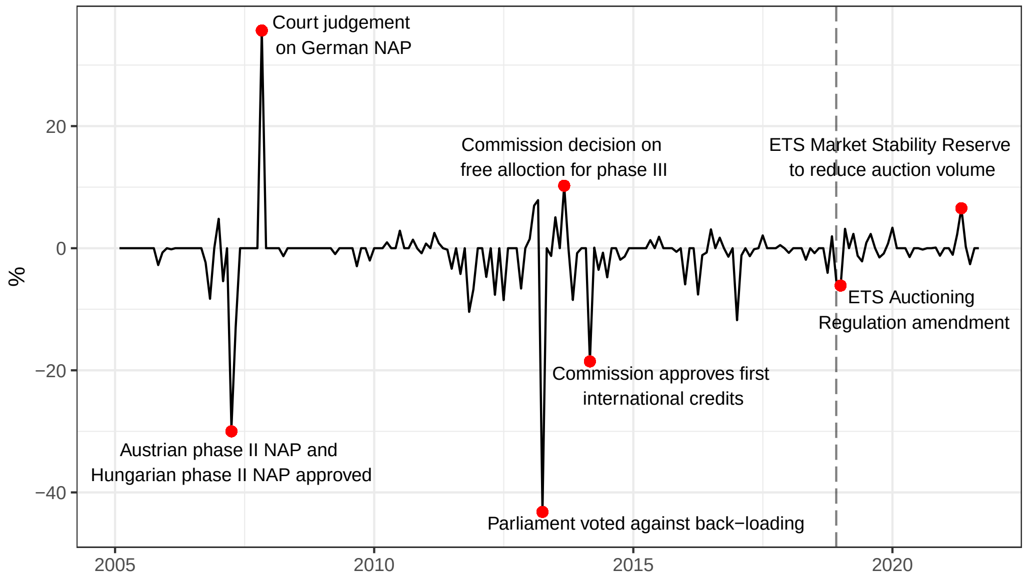


Figure 6: Monthly carbon policy surprise series and some policy events that produced substantial market reactions. The dashed line deliniates between the policy surprise produced by Känzig (2022) and the researcher.

The all the regulatory dates are listed in the appendix B. As in the figure 6, the dates produced in Känzig (2022) and by me are clearly separated.

6.4 Diagnostics of the Surprise as an external instrument

The major problem that the instrument could have is that it would have a is the serial correlation. There is no evidence of persistent autocorrelation. There is a statistically significant autocorrelation as seen in figure 7 after 11 lags and also evidence of partial autocorrelation can be seen in the figure 8. It can be seen from the following figure.

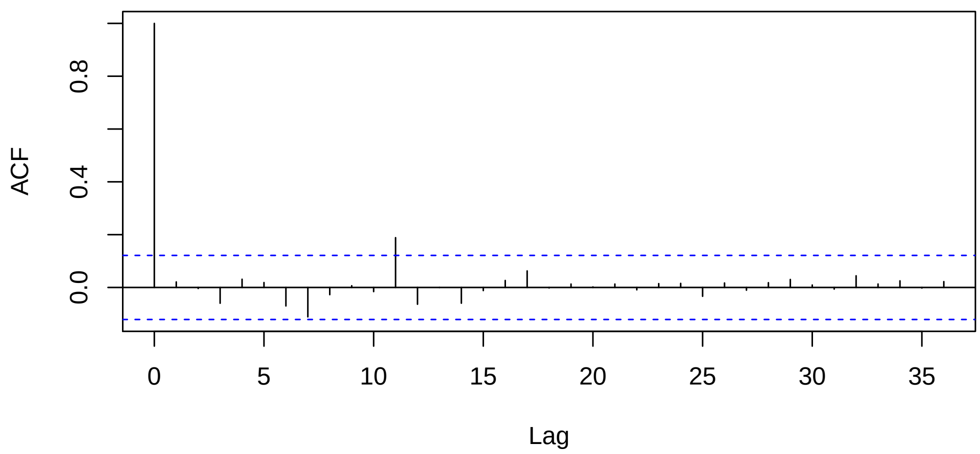


Figure 7: Autocorrelation plot of the instrumental variable.

This autocorrelation of 11 lags would mean that the last year's regulatory announcements have are correlating with the announcements at time step t.

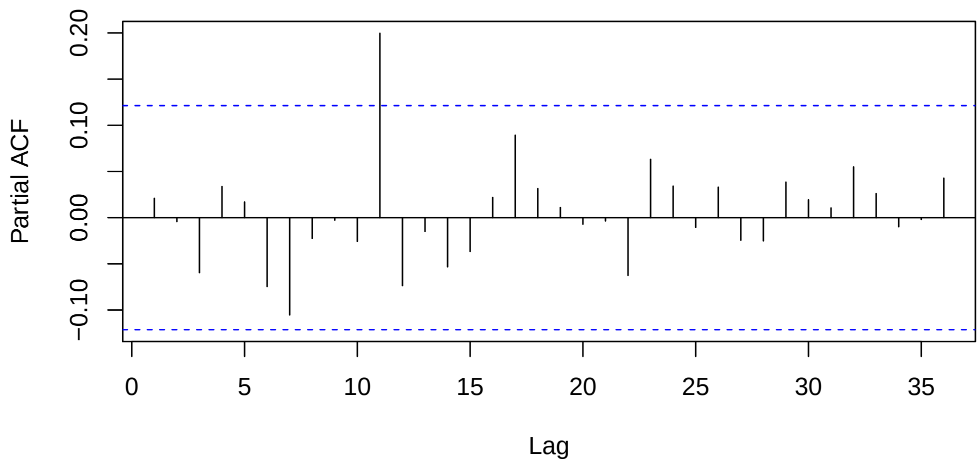
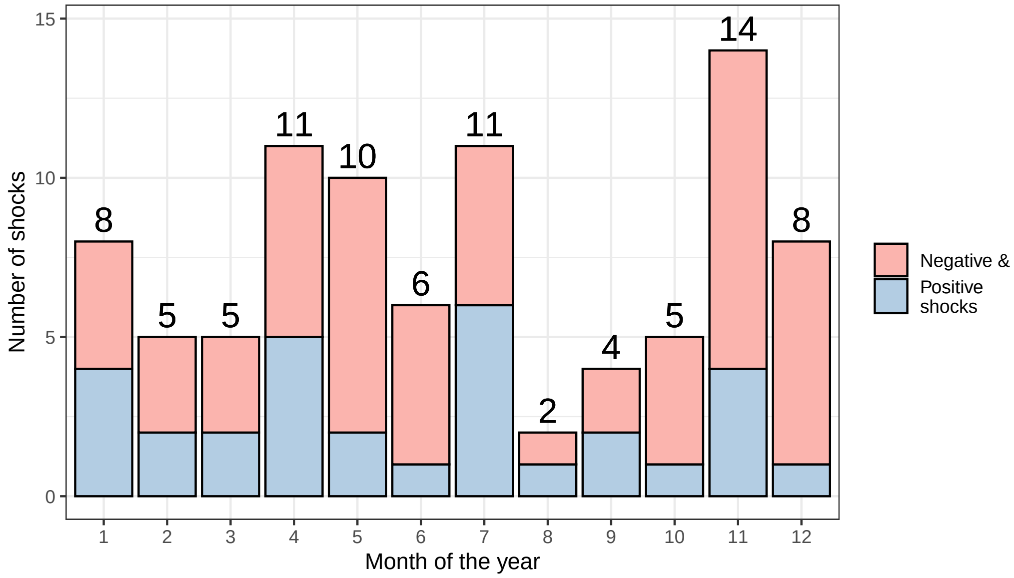


Figure 8: Partial autocorrelation plot of the instrumental variable.

This can be seen from the bar plot below. As the announcements are not equally distributed between months our results may capture some seasonal impacts if the seasonal variation is not adequately handled.



This is an additional reason why there is noticeable seasonal fluctuation in the appendix D.1.

7 Results

In this chapter I will provide the the results of my research. In the first section I will provide the results of the first stage regression results of the power of the instrument. In the second section I will provide a short summary of the results from the research by Känzig (2022). Third section is dedicated to the results of my thesis and fourth section is going to dwell into the reasons how these results may have arisen.

7.1 First stage

Inference with instrumental variables lies on the assumptions of relevancy with the shock of interest and exogeneity with other shocks. An other hidden 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. Due to this Montiel Olea et al. (2021) propose that the first-stage heteroskedasticity-robust F-statistic between the instrument and the VAR-residual should be reported as a measure of the strength of the instrument. They also suggest a rule of thumb of $F > 10$ for to be sure that the instrument is not weak and (Montiel Olea et al., 2021).

For my model the $F = 10.99$, which would imply 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 that were 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)

I will describe in this section the results of Känzig (2022) as they differ in interesting ways to the results I bring forth in chapter 7.3. This way the reader has a better understanding of the context of my results.

Firstly the instantaneous shock from the carbon policy shock to the energy component of the Harmonised Index of Consumer Prices (HICP) is normalised to the tune 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 50 months, that the impulse response was estimated, the energy components of HICP stays statistically significantly above zero (Känzig, 2022).

The price increase in the energy prices effect 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 response curve 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 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 the peak the unemployment rate stays steadily and statistically significantly above zero.

The response of the stock prices 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 rate 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 the figure 9.

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).

For more inquisitive examination of the results from the research done by Känzig (2022) please refer to the Figure 3 of his paper (Känzig, 2022).

7.3 Effects to Finnish macroeconomy

In the following section I will present the resulting impulse response functions to a carbon policy shock. The solid black line is a point estimate and the darker and lighter regions are the 68 and 90 per cent confidence bands respectfully. 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 can be seen in the figure 9 the negative carbon policy shock is normalised to have a effect of 1 per cent increase in the energy components of HICP.

As 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 can the plots be interpreted as percentual changes. In contrast the unemployment rate and the 3 month Euribor interest rate are handled in percentage points and thus the plots represent changes of percentage points.

What can be clearly seen in this figure is the high persistency of the higher prices as a response to the carbon policy shock. This persistency in higher energy prices is feeding into 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 are inline with the findings of Känzig (2022) findings from European wide context. Where my findings differ, and seem to defy the conventional wisdom, is the behaviour of the Finnish economy in the short-run.

There is an rather unexpected, but statistically insignificant, evidence that the Finnish economy benefits 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

[1]The major 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 is relying 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 as in Känzig (2022). If there are any mistakes to be found, they are naturally mine.

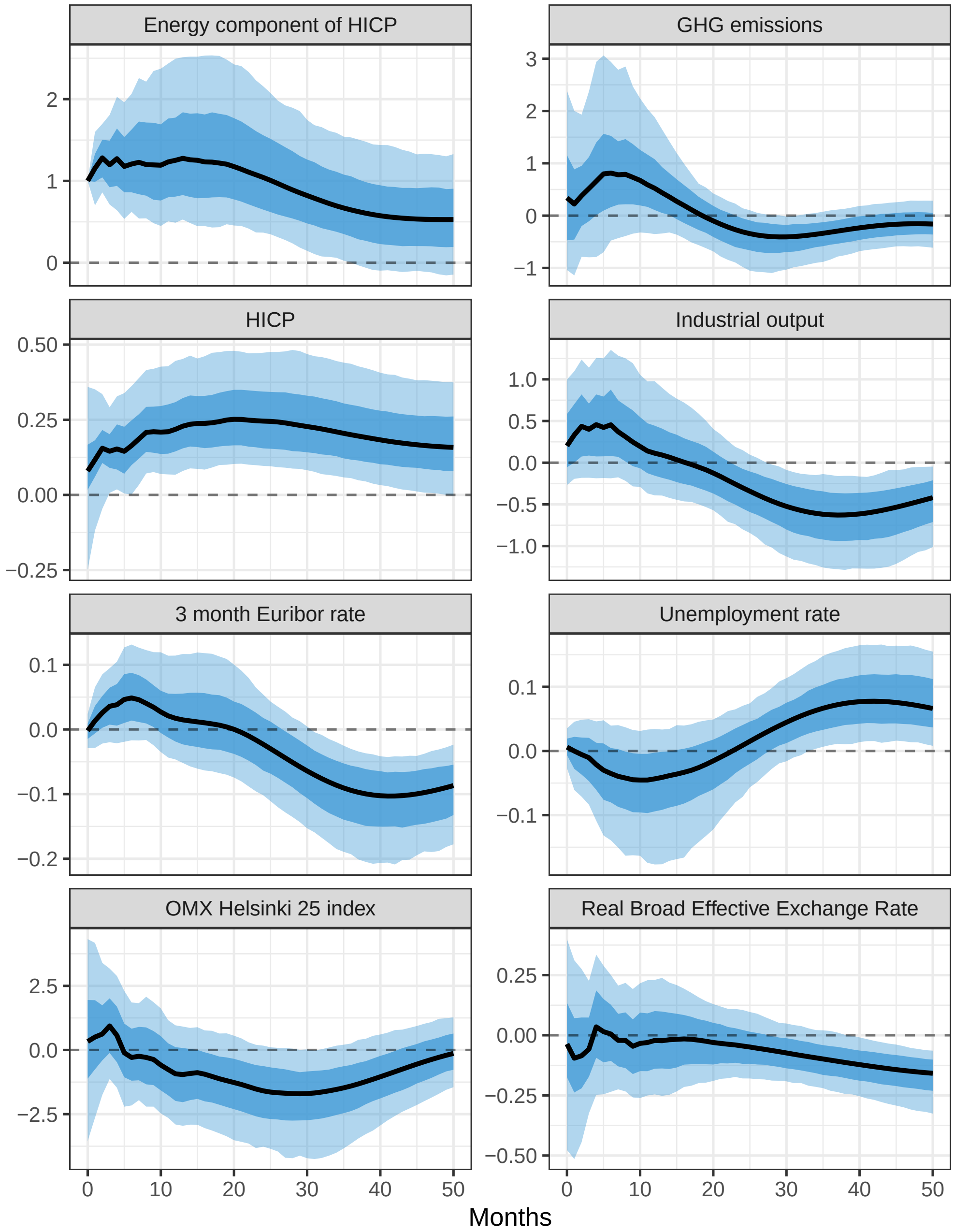


Figure 9: Impulse response functions from carbon policy shocks to macroeconomic indicators of Finland. The policy shock has been normalised to size of instantaneous 1 per cent rise in energy prices. Continuous line represents the point estimate, dark area represents the 68 percent confidence intervals and the light are 90 percent. Variables 3 month euribor and unemployment rate are represented as percentage points, all others are percentage changes.

long term negative impulse. Similar, but opposite signed, impulse is with the unemployment rate. Starting with a statistically insignificant negative simultaneous impact that peaks around 10 months and then 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 time 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 months 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 to the stock market seem to be statistically inconclusive. There is a noticeable evidence of effects to the Finnish real effective exchange rate in the long run.

7.4 Discussion of the findings

The reasons behind these impulses are outside the bounds of this thesis. But for the sake of future research I will provide few hypotheses. I would suggest, that there are two different reactions at play. A short run reaction that stimulates the economy and a long run reaction that is slowing down the economy. One hypothetical reason behind the short run stimulation might arise from the long history of Finnish carbon taxes which as Elbaum (2021) states made the Finnish industry more energy efficient. This energy efficiency would give Finnish industry a competetive advantage to 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

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

stimulus emerge due to the other European countries investing to more sustainable capital which would, in turn make the products of Finnish industrial companies 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 would imply that the lower aggregate demand in Europe, which is demonstrated by Känzig, would after the end of investment surge bring the Finnish economy to a lower long term level. Also as with the short term effects the long term will have to be left to the future research.

8 Conclusion

- conlcusion to my thesis

A Data sources

The data has been collected from various

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 the table 1.

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 2. I extended the carbon policy regulatory update dates from the end of year 2018 to the end of year 2021.

Table 1: 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 1: 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 1: 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 1: 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 2: 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 2: 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

As note in the 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 the chapter 4.3 the external instrument method is based on two foundational assumptions. The relevance assumption stated in equation (2) and exogeneity assumption previously stated in the equation (3):

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

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 $\Sigma = \mathbf{SS}'$:

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

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 $\tilde{s}_{2,1}s_{1,1}$:

$$s_{1,1}^2 + s_{1,2}s_{1,2}^{'} = \sigma_{1,1} \tag{7}$$

$$s_{1,1}^2\tilde{s}_{2,1} + \mathbf{S}_{2,2}s'_{1,2} = \sigma_{2,1} \tag{8}$$

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

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 $\Omega = \text{diag}(\sigma_{\varepsilon_1}^2, \ldots, \sigma_{\varepsilon_n}^2)$ 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

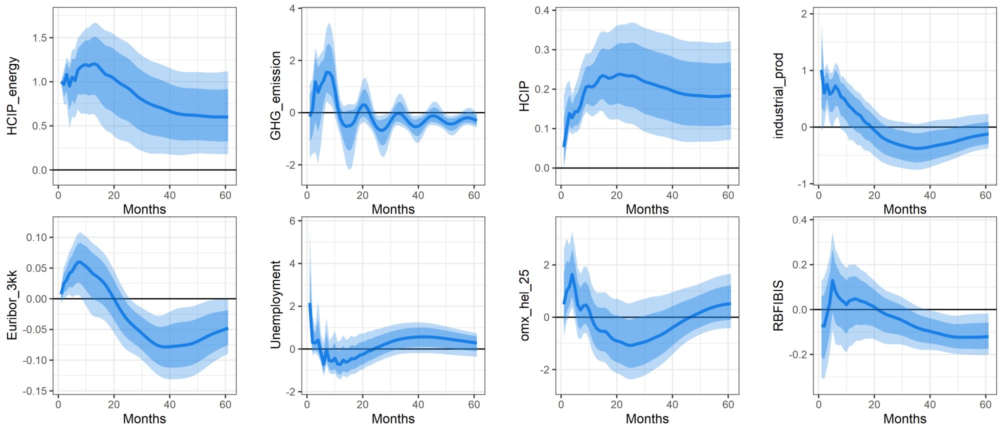


Figure 10: The IRFs with my seasonally agressively varying GHG emissions and with the not seasonally adjusted unemployment rates as endogenous variables.

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

As can be seen from the figure 11 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.

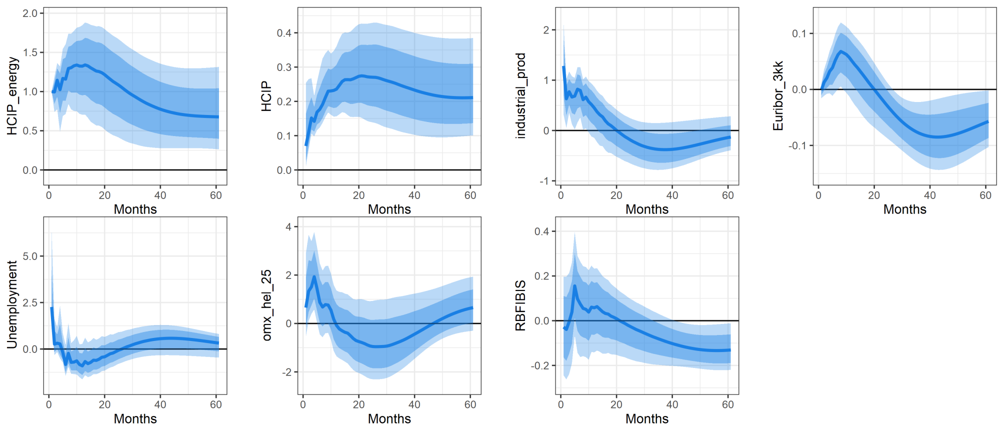


Figure 11: Omitting the Greenhouse gas data from my endogenous variables. It can be seen that the results of the IRF are at least qualitatively similar as the ones reported in my main findings.

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)

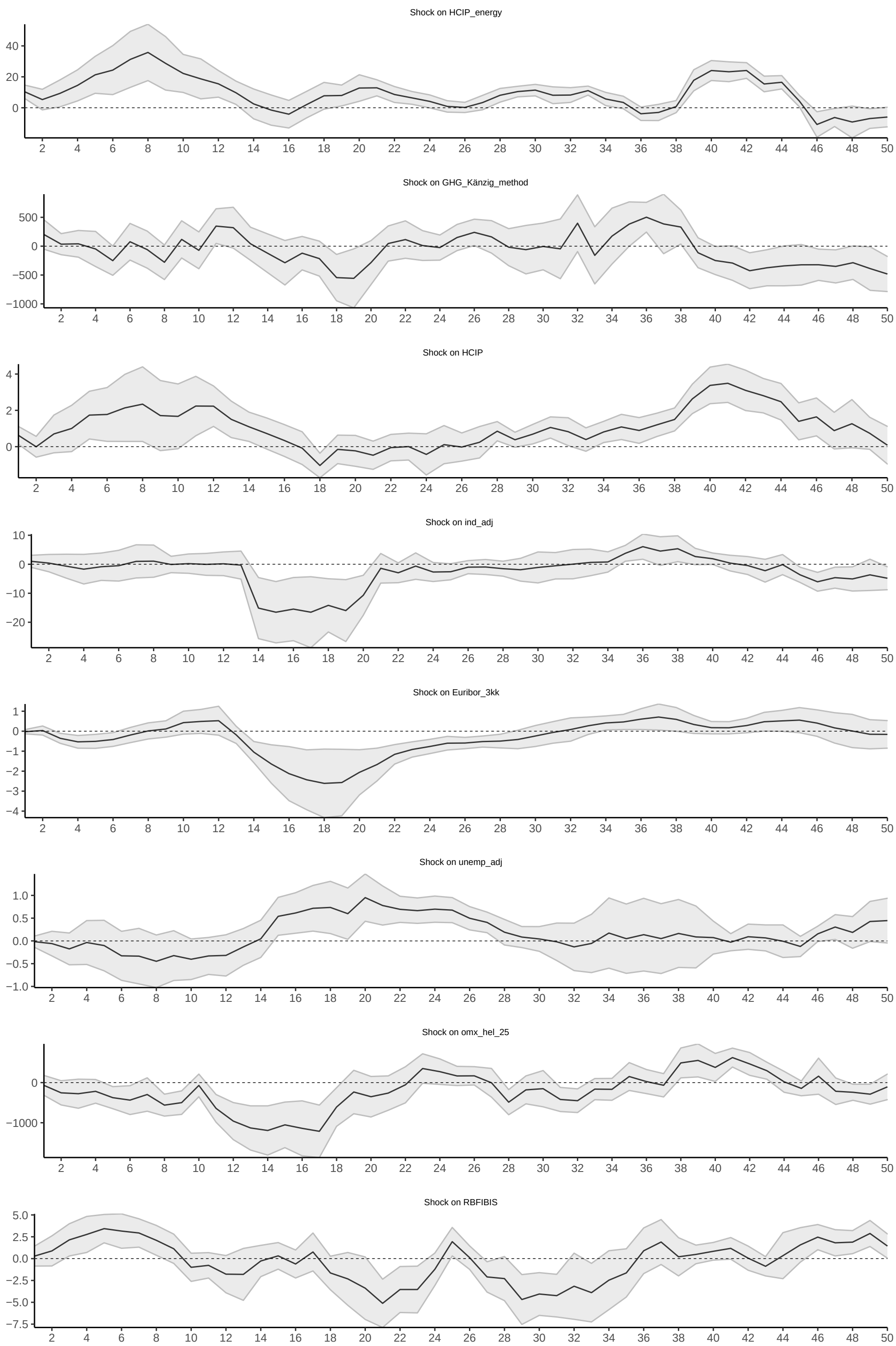


Figure 12: The local projections made

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