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The impact of carbon policy news on the national energy industry*

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May 6, 2024

Abstract

This paper explores the impact of unexpected changes in European carbon policy on Portugal's energy sector, focusing on effects on sales, output prices, and labor market dynamics. Using a structural vector autoregression (SVAR) model, the study finds that news of tighter carbon regulations leads to a significant short-term increase in domestic sales. Output prices rise in both home and foreign markets, with a larger increase observed in the latter. The labor market responds positively, as evidenced by higher wages and hours worked. The study also reveals that these carbon policy changes have played a significant role in historical fluctuations within the energy sector, especially during the Great Financial Crisis and key policy changes. The findings highlight the importance of judicious policymaking concerning carbon regulations, as the escalation in energy prices wields significant economic effects, though not all of these effects are bad from the energy industry standpoint.

JEL Codes: E32; E62; H23; Q48; Q58; L94

Keywords: climate policy, carbon credits, emissions trading, cap and trade, Euro Area, SVAR

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1 Introduction

The energy industry is a critical player in the battle against climate change. In the European Union (EU), efforts to curb carbon emissions led to the creation of the EU Emissions Trading System (EU ETS). This cap-and-trade system has undergone numerous revisions and faced various technical challenges. How, then, does the energy sector respond to unexpected changes in carbon policies? Does it affect how the industry performs both inside and outside the country? And what about the people working in the industry? These pressing questions require examination, especially for policymakers who must comprehend the full impact of their decisions, especially during periods of high energy prices that predominantly affect low-income families.

In this paper, I zoom in on these questions by examining the energy sector in Portugal. To achieve this, I combine Portuguese sectoral-level survey data with a Bayesian Structural Vector Autoregression (SVAR) model and identify carbon policy surprise shocks through correlation restrictions using the carbon policy surprise series from Känzig (2023) as a proxy, which comprises 126 regulatory events.

Preview of results. Carbon policy surprise shocks propagate significantly across the energy sector affecting turnover, labor and price dynamics. When stricter carbon regulations are announced, the energy sector does not necessarily crumble. In fact, the domestic business measured by the turnover actually gets a small boost. However, this is not accompanied by the non-domestic counterpart. The shock leads to an immediate rise in the output prices practiced within the home market. In contrast, in foreign markets, there is no significant change on impact, but subsequently, prices exhibit a persistent rise at a rate twice as pronounced as that in home market. This evidence suggests that although Portugal has a competitive edge compared to other European partners, it has not been very successful in expanding its green industry to export markets, which indicates a lack of production capacity to materialize the gains from stricter standards. In the labor market, another positive development is that companies in the energy industry start looking for employees and offering higher wages. This increase in labor demand aligns with firms' need to adapt to environmentally friendly technologies and install new equipment mandated by updated regulations.

A major finding in an extended analysis utilizing variance and historical decomposition is that news of unexpected carbon policy changes contributes to a substantial portion of the historical variations in energy industry variables during major episodes such as the Great Financial Crisis, the introduction of regulations obligating power plants in the EU to purchase carbon permits, and landmark court rulings. I also carry out an extensive series of sensitivity checks to ensure the robustness of my results, considering various aspects, such as adding or excluding exogenous variables, the estimation approach, and the model specification. The model proves to be resilient to including the significant exogenous changes caused by the pandemic and the war, and it effectively deals with the changes in the specification.

Related literature and contribution The effectiveness of carbon pricing in reducing emissions is well corroborated by empirical evidence in the EU (Martin et al. (2014); Andersson (2019); Bayer and Aklin (2020), among many others)[1]. However, its economic consequences remain a topic of contention with mixed conclusions[2]. For instance, Gilbert E. Metcalf (2019) and Bernard and Kichian (2021) work into the ramifications of the carbon tax implemented in British Columbia, revealing no significant influence on GDP. Similarly, through their analyses, Metcalf and Stock (2020) and Metcalf and Stock (2021) papers find no negative consequences on employment and output growth due to carbon

[1]This is not necessarily the case for the United States, where, according to Tapia Granados and Spash (2019) carbon taxes or emission trading schemes have not been particularly successful in reducing emissions. Emissions continue to be strongly correlated with economic growth conditions.

[2]In a series of studies, Rickels et al. (2007), Knopf et al. (2014), Boersen and Scholtens (2014), and Hintermann et al. (2016) ascertain that the price of carbon allowances in the EU ETS is influenced by a myriad of elements, including but not limited to fuel prices, energy prices, political factors, and regulatory uncertainty.

taxes in European nations. Konradt and di Mauro (2023) explore the possible inflationary impacts of carbon taxes within Europe and Canada, concluding them to be insubstantial. On the other hand, several studies, including those by McKibbin et al. (2017), Goulder and Hafstead (2017) and Benmir and Roman (2022), employ general equilibrium models and show that carbon pricing can exert contractionary effects on output. Other recent research, such as Krämer and Solveen (2021), Santabárbara and Suárez-Varela (2022) and Moessner (2022) suggest that it increases short-term inflation[3] and its volatility[4].

Furthermore, Morão (2023) provides evidence from the Euro Area suggesting that carbon pricing can negatively affect the real economy and financial markets.

This paper goes beyond the macroeconomic effects of carbon policies. Researchers have been digging deeper into the effects of carbon policy in recent years. Känzig and Konradt (2023) finds that the impact on the power sector heavily relies on how emission permits are allocated and how concentrated the market is. Using the same carbon policy shocks, Mangiante (2023) demonstrates that real economic activity in poorer Euro Area countries is more sensitive to carbon price fluctuations than that in their richer counterparts. In a complementary paper, Hensel et al. (2023) uses a French firm-level dataset and finds that high energy-intensive firms tend to have an exaggerated response in their price expectations relative to the actual price changes brought about by these shocks.

This paper contributes to this literature by concentrating on the sectoral level effects in an EU country with below-average income. Using sectoral data from Portugal, this study evaluates how the energy industry responds to changes in carbon prices.

Additionally, motivated by the criticisms and inconsistencies of recursive identification highlighted by Kilian et al. (2022), this paper makes a short methodological contribution to the macroeconomic literature that employs commodity price proxies for shock identification. Notable examples include Piffer and Podstawski (2018), which deploys gold prices, Känzig (2021), which utilizes oil prices, and the aforementioned Känzig (2023),

[3] Ferrari and Nispi Landi (2023a,b) analyze green policy in using central banking perspective.

[4] Pardo (2021) argues that carbon allowances can hedge against unanticipated inflation.

which employs carbon prices. In particular, we depart from the conventional recursive identification by using the latter series as an external variable within an SVAR framework, identified through a correlation restriction approach à la Ludvigson et al. (2021).

Roadmap. In what follows, I explain the model, data, and identification techniques that I use to estimate the effects of carbon policy changes, in Section 2, I examine the effects on energy industry of carbon policy surprise shocks and their quantitative importance in Section 3. In Section 4, I conduct a series of sensitivity checks and present some model extensions. Finally, Section 5 provides concluding remarks.

2 Methodology and Data

In this section, I outline the empirical framework, discuss the identification strategy, and describe the dataset used in this study.

2.1 Framework

Consider a VAR model with n endogenous variables and m exogenous variables which can be written as:

$$y_t = \mathcal{A}_1 y_{t-1} + \ldots + \mathcal{A}_p y_{t-p} + \mathcal{C} x_t + \varepsilon_t \qquad \varepsilon_t \sim \mathcal{N}(0, \Sigma) \tag{2.1}$$

where p is the lag order, y_t is an $n \times 1$ vector of endogenous variables, $\mathcal{A}_1, \ldots, \mathcal{A}_p$ are p coefficient matrices of dimension $n \times n$, Additionally, $\mathcal{C}$ is an $n \times m$ matrix, x_t is an $m \times 1$ vector of exogenous variables, and ε_t is an $n \times 1$ vector of reduced-form innovations which are assumed to be Gaussian with zero mean and positive definite covariance matrix, Σ. By gathering the regressors into a single matrix, we obtain:

$$y = \bar{X}\beta + \varepsilon \tag{2.2}$$

with $\bar{X} = I_n \otimes X$, where $X_t = [y'_{t-1}, y'_{t-2}, \ldots, y'_{t-p}, x'_t]$ is a $T \times (np + m)$ dimensional matrix of lagged endogenous variables and exogenous variable. Then we have $\beta = \text{vec}\left([A_1, A_2, \ldots, A_p, C]'\right)$, $y = \text{vec}\left([y_1, y_2, \ldots, y_T]'\right)$, and $\varepsilon = \text{vec}\left([\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_T]'\right)$. The Bayesian aspect of this analysis is introduced by assigning prior distributions to the unknown parameters, utilizing an independent Normal-Wishart prior. This particular prior diverges from the traditional normal inverse-Wishart configuration by not employing the Kronecker structure and omitting the conditioning on Σ in the prior for β. The formulation of the independent normal inverse-Wishart prior for the VAR slope coefficients is $\beta \sim \mathcal{N}(\beta_0, \Omega_0)$ with β_0 being a zero mean and Ω_0 is approximated by the residual variance derived from an AR(1) regression simarly to what is shown in Litterman (1986). Concurrently, the prior for the covariance matrix follow an inverse-Wishart distribution $\Sigma \sim \mathcal{IW}(S_0, \alpha_0)$ with S_0 being the scale matrix and α_0 the degrees of freedom as described in Karlsson (2013). The joint posterior distribution $\mathbb{P}(\beta, \Sigma|y)$ does not have an analytical form unless the identical Kronecker structure present in the likelihood function is identical. However, the conditional posterior distributions $\mathbb{P}(\beta|\Sigma, y)$ and $\mathbb{P}(\Sigma|\beta, y)$ are both analytically accessible, which allows for the utilization of Gibbs sampling for posterior inference. Although implementing the Gibbs sampling procedure is not particularly complex, it is computationally intensive. Dieppe et al. (2016) detail the Gibbs sampling approach for Bayesian VARs with independent normal inverse-Wishart priors. The algorithm is set to run for a total of 5000 iterations, with a burn-in period of 2000. The hyperparameters are set around values typically found in the literature. These values are provided in Table 3[5]. The VAR is estimated in log levels. All variables undergo seasonal adjustment using X13. I employ six lags for all endogenous variables, and regarding deterministic components, both a constant term and the Economic Policy Uncertainty (EPU) Index for Portugal (as introduced by Morão (2024)) are included. Additional source details can be seen in Table 4. However, the results have been found to be robust across all

[5] In one of the robustness checks, grid search is employed to optimize the hyperparameters.

these choices, as evidenced in Appendix B.

2.2 The identification of the carbon policy shocks

In a SVAR model, the innovations, denoted by ε_t, are expressed as linear combinations of the structural shocks, denoted by η_t:

$$\varepsilon_t = A_0 \eta_t \tag{2.3}$$

where A_0 is an $n \times n$ matrix that contains the contemporaneous effects of the variables on each other, and η_t is an $n \times 1$ vector of structural shocks, which are assumed to be normally distributed with zero mean and a diagonal covariance matrix(i.e., $\eta_t \sim \mathcal{N}(0, I)$). To ensure economic validity of the shocks estimated in equation 2.5, certain identifying restrictions must be applied. In this study, it is used the identification approach proposed by Ludvigson et al. (2021), which involves applying correlation restrictions to the shocks by setting that the correlation between η_t and S_t consistently remains above a predetermined threshold ($\bar{c}$). The specific formulation of this approach is expressed as follows:

$$\rho_1 = \text{corr}\left(S_t, \eta_{1,t}\right) \geq \bar{c} \tag{2.4}$$

In this setup, we are taking into consideration the correlations between the unexpected changes in carbon policy, which is my focus here, and the unexpected carbon policy events documented by Känzig (2023) shown in Figure 1. The series carbon policy surprises is constructed by measuring the percentage change in futures carbon prices around regulatory events[6]. Specifically, the surprise for each event is calculated as the difference between the EUA futures price in the day of the events and the last before the event cor-

[6] Juvenal and Petrella (2024) employ a similar approach for commodity shocks.

rect by the wholesale electricity price.

$$\text{CPSurprise}_{t,d} = \frac{F_{t,d}^{carbon} - F_{t,d-1}^{carbon}}{P_{t,d-1}^{electricity}} \tag{2.5}$$

Here, d and t indicate the day and month of the policy event. $F_{t,d}^{carbon}$ is the settlement price of the EUA futures contract in the day of the event, and $P_{t,d-1}^{elec}$ is the wholesale electricity price on the day before the policy event. The procedure is designed to isolate variations in carbon prices solely influenced by regulatory news, relying on the uncontroversial assumption that risk premia remain constant throughout the narrow event window. Subsequently, by summing the daily surprises within each month, these surprises are aggregated into a monthly time series, which is used in this paper as external variable to the SVAR.

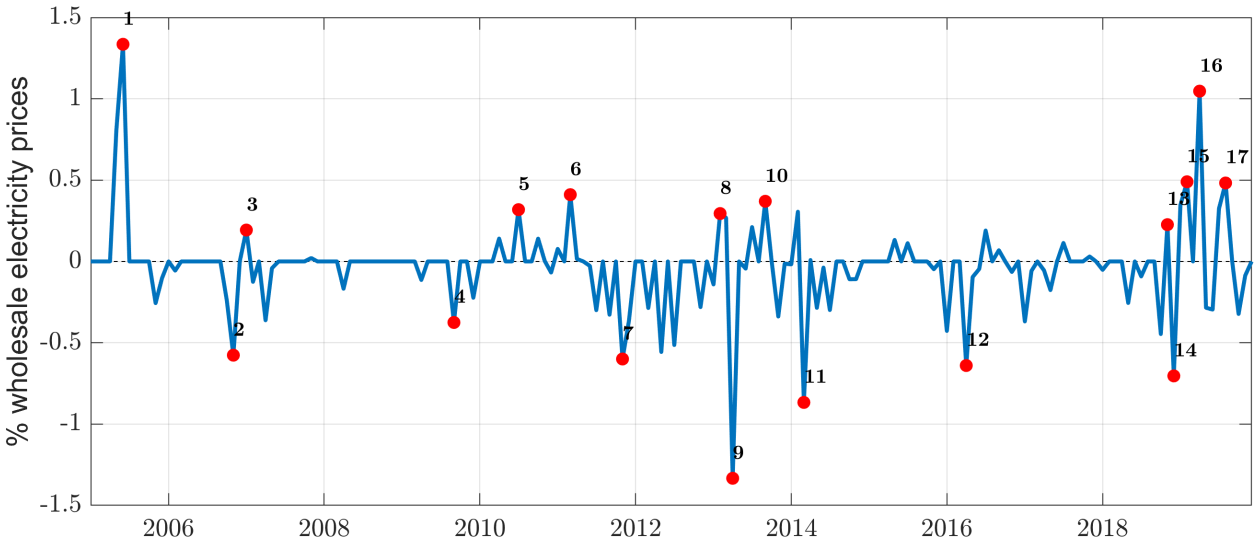


Figure 1: The Carbon Policy Surprise Series by Känzig (2023)

The European Union Emission Trading System (EU ETS) is a central instrument in the EU's strategy for combating climate change using market-based mechanisms. The EU ETS evolved over four phases, each with its distinct characteristics and regulatory events which have played pivotal roles in shaping the system. The following paragraphs link the chronological evolution of the EU ETS to the regulatory events listed in Table 2, providing narrative background on how these regulatory decisions have influenced carbon market dynamics.

In 2005, the EU ETS commenced its inaugural Phase. The first regulatory event highlighted this in 2005, wherein Italy and Greece's Phase I National Allocation Plans (NAPs) were approved. In this period, individual-level emissions caps were set by following historical emissions data. Ellerman and Buchner (2007) describe the allowance allocation process within the EU ETS, specifically focusing on the challenges and issues encountered. Regulatory decisions on NAPs were crucial in establishing the foundation for emissions trading in the EU. Event 2 in 2006 played an crucial role in ensuring compliance with the Kyoto Protocol by preventing the double-counting of emission reductions. In January 2007, the Phase II NAPs of Belgium and the Netherlands were approved. Subsequently, Phase II (2008-2012) shifted towards sectoral-level emissions caps. Although this Phase added more flexibility, it resulted in a misalignment with the EU's broader climate goals. A significant event occurred in 2009 in Poland vs. Commission court case (Event 4) concerning the Polish National Allocation Plan (NAP). This case exemplifies the multifaceted nature of the EU ETS, where legal proceedings can also exert influence on its evolution. Johnston (2006) conducts a legal examination of critical issues related to the allocation of emissions allowances under the EU's Emissions Trading Scheme Directive. In 2010, the Commission initiated establishing a cap on emissions allowances for 2013 (Event 5), which marked the transition to Phase III (2013-2020) that aimed at a more transparent and predictable reduction in emission caps through a simple linear reduction factor[7]. Many regulatory events transpired during the third Phase, with the EU Commission fine-tuning the cap-and-trade system. Event 6 in 2011 affected the transitional free allocation of allowances concerning the power sector. In addition, Events 8, 9, and 10 in 2013 focused on auctions and free allocations. Particularly Event 9, where the European Parliament rejected the Commission's back-loading proposal showing the

[7]See Okinczyc (2011) for prospective analysis of challenges and prospects for this Phase III.

Table 1: Regulatory events

#	Date	Sign	Event description	
1	2005m6	+	Italy and Greece's Phase I National Allocation Plans (NAP) approved	Free alloc.
2	2006m11	-	Resolution to prevent double counting of emission reductions for Kyoto Protocol projects. Commission's decision on the NAPs of various member states.	Intl. Credit and Free alloc.
3	2007m1	+	Approval of Phase II NAPs for Belgium and the Netherlands	Free alloc.
4	2009m9	-	Court ruling in the Poland vs. Commission case regarding NAP	Cap
5	2010m7	+	Commission initiates setting an emissions cap for 2013, with member states supporting the Commission's auction rules	Cap and Auction
6	2011m3	+	Proposal from the Commission to auction 120 million allowances in 2012. Court ruling in the Latvia vs. Commission case. Decision on transitional free allocation to the power sector	Auction and Free alloc.
7	2011m11	-	Details provided on the use of international credits in the third trading phase. Regulation 1210/2011 sets pre-2013 auction volume. Update on Phase 3 allowance auctioning preparations	Intl. Credits
8	2013m2	+	Postponement of 2013 aviation allowance free allocation	Free alloc. and Auction
9	2013m4	-	European Parliament rejection of the Commission's back-loading proposal	Auction
10	2013m9	+	Commission concludes decision on free allocation for industrial phase three and updates aviation allowance auction numbers for 2012	Free alloc. and Auction
11	2014m3	-	Approval of the first and second batches of international credit entitlement tables by the Commission	Intl. Credits
12	2016m4	-	Court ruling on free allocation within the EU ETS for 2013-2020	Free alloc.
13	2018m11	+	Latest details on exchange and use of international credits	Intl. credits
14	2018m12	-	Inclusion of unused allowances in Poland's 2019 auctions for power sector modernization	Auction
15	2019m2	+	Adoption of the Delegated Decision on the carbon leakage list for 2021-2030	Free alloc.
16	2019m4	+	Upcoming auctions on the common platform by Iceland, Liechtenstein, and Norway	Auction
17	2019m8	+	Commission revises ETS auctioning regulation for Phase 4	Auction

contentious nature of regulatory decisions and their potential can meaningfully impact the market dynamics and sentiment within the EU ETS. Regulatory events 11 and 13 are about the approval and update of international credits use. Event 12 was a court judgment on free allocation in the EU ETS for 2013-2020. A literature review of the empirical papers relating to the 2013-2020 period can be checked in Verde et al. (2019). The Fourth Phase (2021-2030), currently ongoing, aims to further refine the EU ETS by incorporating insights from previous phases. For instance, Event 15 in 2019, involving the adoption of the Delegated Decision on the carbon leakage list for 2021-2030, exemplifies the regulatory attempts to curb carbon leakage[8] and ensure that the EU ETS aligns with the overarching objective of decarbonization.

2.3 Energy sector data

A comprehensive understanding of the Portuguese energy sector requires analytical examination that takes into account domestic, labor, and foreign factors[9]. To do this, I will describe the dataset that contains the evolving dynamics of the Portuguese energy industry compiled from the Portuguese National Institute of Statistics, spanning from January 2005 to December 2019. The baseline specification consists of six variables. The index of domestic turnover (t_t) provides a measure of the revenues generated within Portugal by the energy industry, while its counterpart, the index of non-domestic turnover (t^t), captures the revenues from exports and international transactions. The index of gross wages and salaries (w_t) offers insights into labor costs, and the index of hours worked (h_t) provides insight into the labor inputs in the energy industry. Regarding output prices, π_t represents the home market output prices, reflecting the selling prices for goods sold within Portugal. Conversely, π_t^* quantifies the prices received for goods sold abroad (foreign markets).

[8]Yu et al. (2021) emphasizes that addressing carbon leakage is crucial for the effective development, implementation, and assessment of climate policies.

[9]Morão (2024b) and Morão (2024a) use similar datasets to analyze water uncertainty and climate policy uncertainty.

Figure 2 displays the series included in the baseline VAR throughout the sample period.

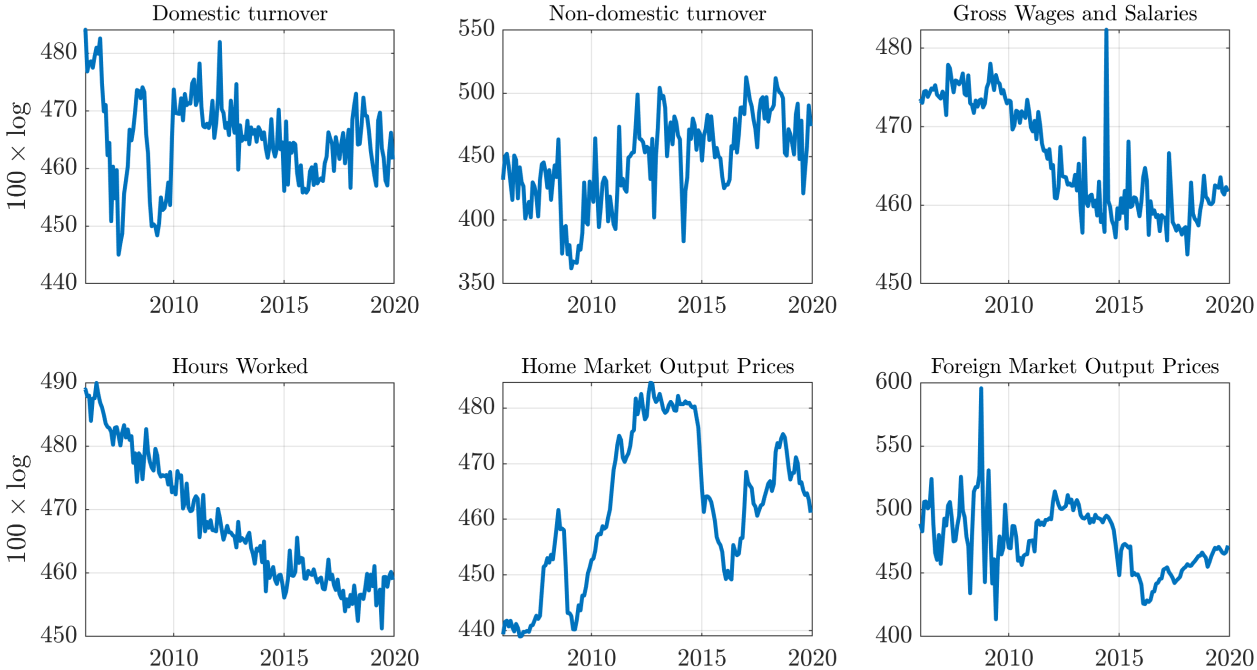


Figure 2: The energy industry data series in the baseline model

Now, let's examine the dynamics of each variable more closely. t_t exhibits a high degree of volatility in the first half of the sample, followed by a general trend of stabilization in the subsequent years. This can be explained by the maturation of the domestic energy market and an increased emphasis on renewable energy sources. t_t^* demonstrates a rising trend, particularly after 2010, which can be attributed to the increasing globalization of the energy market and the Portuguese energy sector's growing competitiveness in renewable energy technologies. w_t undergoes several fluctuations. Initially, there is a slight upward trend that matches with the economic performance pre-crisis. This is followed by a decline, reflecting a cooling down of the market and the impact of austerity measures on wage growth. In the later years, there is a mild rise, indicative of a modest recovery in the economy and a corresponding upward pressure on wages. A noticeable decline is observed in h_t until about 2014, after which it stabilizes. This pattern suggests that the adoption of technological advancements led to improved efficiency in the industry and a transition towards more capital-intensive production methods, reducing the need for labor hours. The home market output prices (π_t) steadily increase over the years, reflecting the rising costs of energy production and higher demand for cleaner energy sources, partly due to initiatives like the EU ETS. In contrast, the foreign market output prices (π_t^*) exhibit a downward trend but with considerable volatility, influenced by fluctuations in global energy prices, exchange rates, and international regulations.

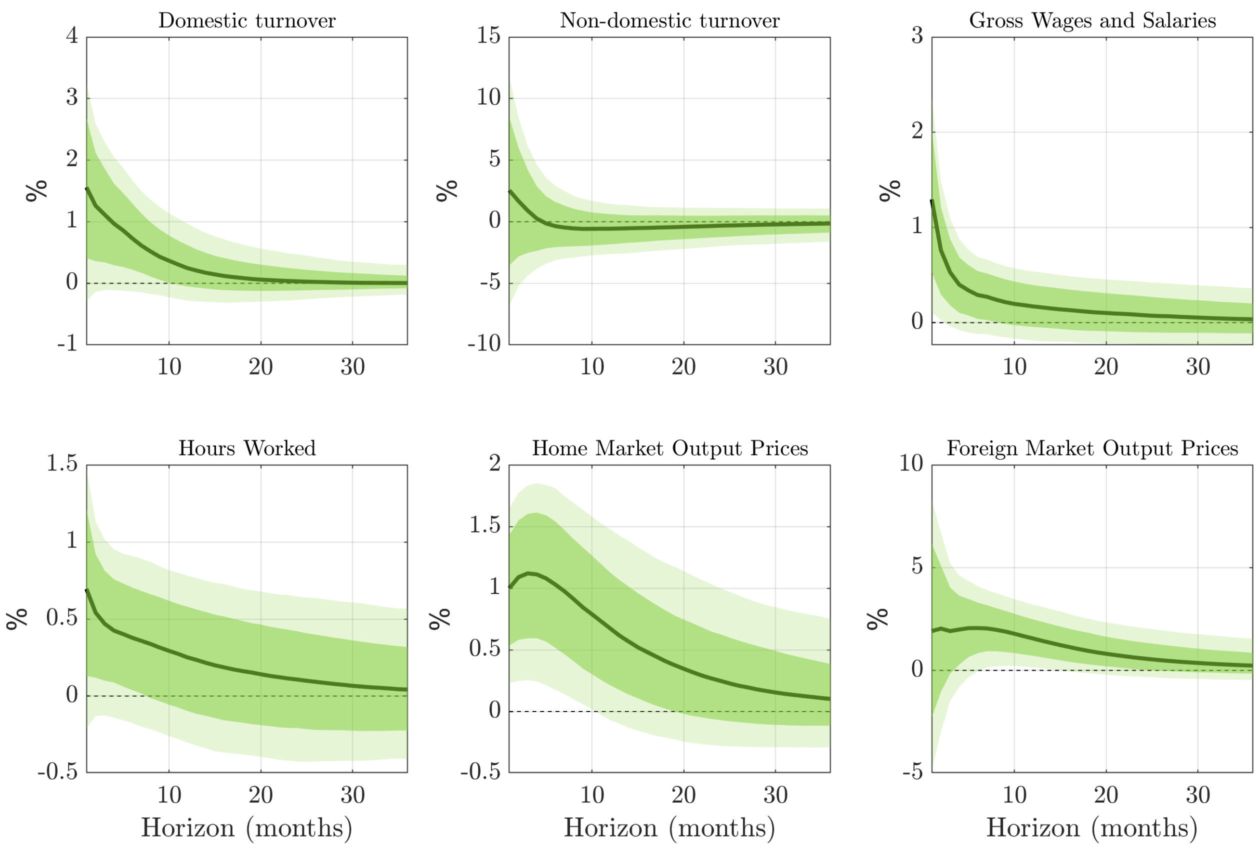
3 The impact on the energy industry

To evaluate the economic repercussions of the European carbon pricing policy within the Portuguese energy industry, an in-depth investigation is conducted on the six key variables. The Structural Dynamic Analysis toolset is applied to create and interpret results in this section. The Impulse Response Functions (IRF) will show how the energy market variables in the model change over time due to carbon policy shocks. Next, the Forecast Error Variance Decomposition (FEVD) will help us understand if carbon policy surprise shocks are sources of fluctuations. The Historical Decomposition will examine how carbon policy shocks have affected the dynamics in the past. Finally, the Historical Decomposition (HD) will examine how carbon policy shocks have affected the dynamics in the past.

3.1 IRF analysis

Now, let's take a closer look at the IRFs. We want to understand how carbon policy shocks affect aspects like domestic sales, foreign sales, and jobs in the energy sector. By doing this, we will get a better picture of the true implications of these policies and contribute significantly to a wider economic analysis of the economic consequences of these measures.

Figure 3 illustrates the impact of carbon policy surprise shocks on all variables within



Note: Impulse responses to a carbon policy surprise shock normalized to increase the home market prices by 1% on impact. The solid black line represents the (point) posterior median estimate and the shaded areas 68% and 90% credible bands.

Figure 3: Impulse responses to a carbon policy surprise shock

the energy sector markets. The shock immediately boosted the domestic turnover, an effect catalyzed by an upswing in domestic business activity among low-carbon firms as higher carbon prices are expected to disproportionately affect high-carbon firms, potentially their competitiveness and profitability. Dechezleprêtre et al. (2023) also found that EU ETS augmented firms' revenues, as evidenced by data from France, the Netherlands, Norway and the United Kingdom. In response to the new policies, this upturn was facilitated by other domestic firms' investment in low-carbon technologies. Hoffmann (2007) argues that the EU ETS serves as a main driver for small-scale investments with short amortization periods, a case that aligns well with the Portuguese economic environment, which is dominated by micro and small companies. However, the positive effect wanes by the end of the second year, implying that the Portuguese economy reacts swiftly to these policy changes. This new equilibrium is beneficial from a welfare perspective, as it results in enhanced efficiency owing to the latest innovative technologies and practices. This result can be explained by Portugal's pioneering efforts in several renewable technologies, such as wind energy, enhancing the potential for accruing extra benefits from European carbon policy changes. For non-domestic turnover, the policy surprise initially triggered a positive effect that persisted for three months. This development can be interpreted as a small competitive edge of the Portuguese energy exports under the newly instituted policy. However, this positive effect is short-lived, as non-domestic market players adapt to the revised carbon regulations. The wider confidence bands suggest a high level of uncertainty in these estimates.

The strong positive effect on gross wages and salaries signals a surge in labor demand, particularly in the realm of green technologies. Supporting this observation, Ren et al. (2020) also documented a significant rise in labor demand within China's industries following the introduction of the emissions trading program. This is evident in the wage differentials between general labor and specialists in the renewable energy sector. For instance, a general worker with a 12th-grade education typically earns around €10,000 annually, while a technician in the solar and wind energy field, with the same level of education, earns about €27,000. However, this increase may also be partly due to the rise in policy compliance consultancy, which does not invariably yield productive outcomes. Higher consultancy costs can put a strain on firms' budgets, especially small and medium enterprises. The observed immediate 1.2% increase in hours worked indicates that firms are either recruiting new personnel with relevant expertise, upskilling existing employees, or investing in new technology and equipment to accommodate environmentally friendly practices. This aligns with findings from Marin et al. (2018) that EU ETS improves labor productivity. It's worth noting the different speeds of decline after the impact. However, the pace of adjustment post-impact varies, with hours worked demonstrating a slower decline than gross wages. This suggests that firms are incentivizing their workforce to undertake the additional tasks necessary to transition to low-carbon operations. As many of these investments are one-offs in nature, the higher costs normalize by the third year following the policy announcement, as the industry transitions towards more efficient and environmentally sustainable operations, and labor demand returns to its pre-policy level.

Both home and foreign market output prices showed a positive humped-shaped response to the policy shock. Home prices peaked at 1.2% at the three-month mark and declined persistently to zero. This suggests a temporary surge in domestic energy prices due to the increased costs associated with reducing carbon emissions followed by a return to pre-policy levels by the fourth year as industry adjusted. The effects on π_t^* seem to be more powerful and persistent over a 1-year horizon compared to π_t, as these foreign prices are quite vulnerable to trade dynamics like exchange rates and global energy prices. This observation is consistent with Nagel et al. (2023), who found that the EU ETS contributes to price volatility in the Nordic power market. Since home and foreign markets are affected differently, this necessitates national regulators to integrate domestic systems into multinational markets, Green et al. (2014). Hintermann and Ludwig (2023) also points out that home market bias is a concerning problem as marginal abatement costs are not uniform across market participants of the EU ETS. When juxtaposed with existing literature on carbon policy, these findings resonate with a recurrent theme: such policies are effective in reducing emissions but can cause temporary economic disruptions, such as higher prices. Conversely, we observed that there are also positive effects that should not be overlooked, especially in the labor markets, which experienced an increase in hours worked and a rise in gross wages.

In the context of the Portuguese economy, the energy sector's expansion due to the implementation and investment in green technologies may offer a realm of potential growth trajectories. Yet, given the sector's proportion in relation to the overall economy, the extrapolation of these effects to the national level warrants caution. Beyond the effects already examined, another important factor to consider is that as labor market conditions in the energy sector improve alongside increasing output prices, this escalation can have adverse repercussions throughout the economy. These increased costs can propagate through the economy in two major channels as explained in deeper detail by Känzig (2023). For industries that are energy-intensive, such as chemicals, steel, paper, plastics, or mining, higher energy prices mean higher operational costs, leading to a reduction in competitiveness, especially if they are competing on a global scale where energy costs are a major factor in overall pricing or the competitors are subject to slacker carbon regulations. Consequently, these businesses are likely to cut labor costs, which will eventually lead to job losses in these sectors. The second channel is the demand sensitivity channel, arising from the fact that sectors such as retail trade, hospitality, and services are particularly sensitive to aggregate demand fluctuations. These sectors, being quite sensitive to changes in aggregate demand, are more likely to experience immediate and stronger effects from policies that alter consumer spending patterns. For instance, if the carbon policy raise the prices of goods and services, thereby reducing disposable income, the sectors most sensitive to demand will experience a sharp decline in sales. This, in turn, leads in job losses and reduced income for employees within these sectors. In contrast, sectors such as utilities or healthcare exhibit less sensitivity to aggregate demand, due to the relatively inelastic nature of their services, hence, they are less affected by changes in the business cycle or policy changes. Känzig (2023) notes that households in demand-sensitive sectors face the most pronounced income drops, while those in less sensitive sectors see more stable income responses. This disparity hurts low-income households, which are overrepresented in these sectors, making them more vulnerable to these economic shifts. This illustrates how the unemployment rate may increase while, at the same time, the labor market conditions in energy industry could even improve.

Profits What insights can be drawn regarding profits? Given the analysis on prices and turnover, it is essential here to acknowledge that the main purpose of a carbon policy is to increase the cost of carbon-intensive activities. Since the demand for energy is relatively inelastic, this cost increase leads to higher prices without a significant reduction in quantity demanded, thus increasing turnover, as shown in the IRF. Anticipation of future price increases can also lead consumers and businesses to increase current consumption and production, resulting in a temporary boost in turnover. Regarding profitability, although a rise in both prices and turnover alone is not enough to derive the sign of profits. If we consider labor variables such as hours and wages, we can infer whether the shock is expansionary or recessive. Since both wages and hours tend to react positively or at least not negatively, it is reasonable to conclude that the shock likely boosts profits. It would be counterintuitive for firms to increase their real capacity if the 'net' effect of higher turnover and prices resulted in reduced profit margins, this underscores the need for further empirical research to substantiate these economic claims.

3.2 Historical importance

Variance decomposition analysis. To further analyze the impact of climate policy shocks on energy sector variables, I conduct a forecast error variance decomposition (FEVD). Table 2 shows the percentage contribution of the carbon policy shock to the variance of each variable at four different forecast horizons: 1 month,12 months, 24 months, and 36 months.

Table 2: Forecast error variance decomposition

h	t_t	t_t^*	w_t	h_t	π_t	π_t^*
1	27.00	6.93	35.54	29.54	43.27	6.68
	[2.69, 67.80]	[0.88, 35.58]	[5.80, 79.72]	[2.23, 61.37]	[12.05, 85.63]	[0.82, 34.46]
12	30.96	9.45	30.87	25.22	39.65	19.07
	[4.53, 69.32]	[2.92, 30.28]	[6.66, 61.76]	[3.70, 56.23]	[10.64, 84.72]	[6.22, 45.29]
24	30.96	10.47	28.75	21.51	34.53	22.46
	[5.55, 66.69]	[3.48, 28.90]	[7.13, 51.65]	[4.49, 48.97]	[10.26, 79.35]	[7.17, 46.03]
36	30.72	10.62	27.52	20.30	32.06	22.91
	[4.53, 69.32]	[2.92, 30.28]	[6.66, 61.76]	[3.70, 56.23]	[10.64, 84.72]	[6.22, 45.29]

Notes: The table displays the median values of the forecast error variance decomposition for the carbon policy surprise shock results at the 1-month, 12-month, 24-month, and 36-month horizons. The 90 percent confidence intervals are displayed in brackets.

In the immediate aftermath ($h = 1$), the policy shock exhibits a strong effect on domestic turnover (t_t), gross wages (w_t), hours worked (h_t), and home market output prices π_t. This can be attributed to the rise in direct costs associated with carbon-intensive energy production, necessitating changes in the workforce, home price structures, and domestic output.

In striking contrast, the impact on non-domestic turnover (t_t^*) and foreign market output prices π_t^* is comparatively muted. This limited effect can be understood in light of Portugal's position within the EU's integrated energy market, which provides a degree of insulation against sudden shocks.

The subsequent section will go deeper into this point. Factors beyond Portugal's isolated position on the Iberian Peninsula can play a significant role in explaining this effect.

In particular, price adjustments might be delayed due to existing long-term contracts and hedging strategies. Furthermore, the EU ETS can help soften the immediate impact of the shock through carbon permit trading among member states.

A pattern emerges as we shift to the longer-term horizons of 12-, 24-, and 36 month, and the policy shock's contribution to t_t^* and π_t^* increases. The contribution to t_t^* is small but not negligible. This ascending trend can be interpreted as Portugal's international energy trading relationships adjusting in response to the new European carbon pricing regime. Initially, foreign customers and partners maintain the existing trading relationships and pricing expectations. However, as time passes, the policy-driven changes in the energy sector become more pronounced, and the external entities reassess their positions.

Simultaneously, we observe a diminishing effect of the policy shock on wages and hours worked over time. These declines hint at labor market tensions. As businesses reduce labor inputs in response to higher costs due to the policy, but over time, they likely find ways to offset these costs. This underscores climate policy's critical role in energy prices and eventually shaping the macroeconomic environment.

Historical decomposition analysis. I undertake a historical decomposition, to consider the role of carbon policy in the context of energy industry markets, and to analyze the influence of carbon policy in historical episodes within energy markets. While carbon policy surprise shocks have considerable impacts on emissions, an intriguing question is the extent to which these shocks can account for historical variations in the energy industry variables.

Figure 4 shows the historical contribution of carbon policy surprise shocks to energy variables from 2005 to 2019. Policy shocks have made substantial contributions to energy variables during three main episodes. However, it is crucial to note that, similar to the findings in the IRF analysis, carbon policy surprise shocks did not contribute significantly to the non-domestic turnover. It is insightful to examine specific episodes. First,

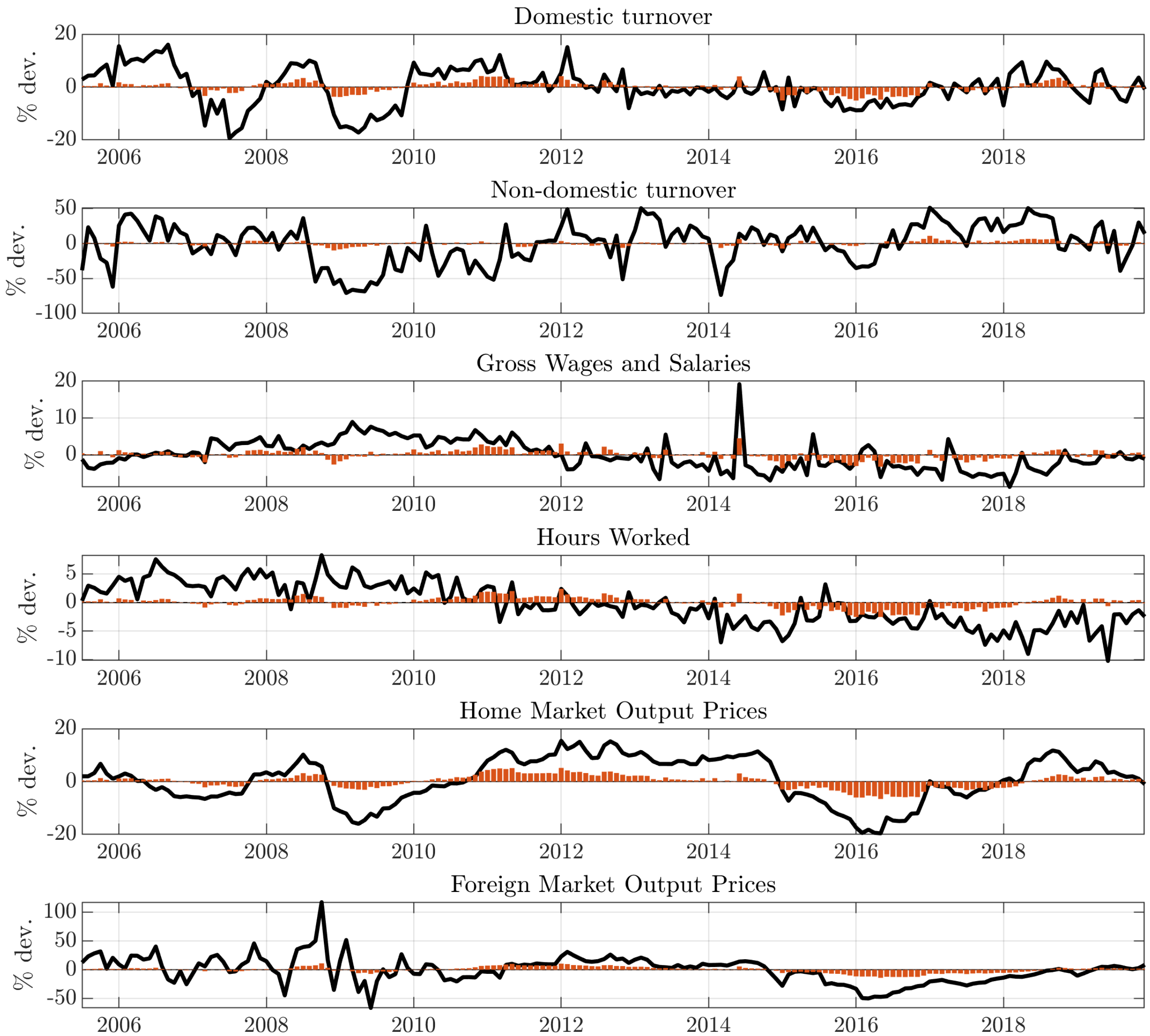


Figure 4: Historical decomposition of the energy industry variables

Note: The solid bar represents the median estimate, and the black line depicts the time series of the variables in % deviations.

let us consider the period around the Great Financial Crisis and the energy crisis of 2008-2009. In early 2008, the shock positively impacted domestic turnover and foreign market output prices, accounting for approximately 25% to 30% of the variation. The shock also significantly explains the fluctuations in wages and hours during this period, with its contribution exceeding 50% in some months. However, by the end of 2008 and the beginning of 2009, the contribution reversed in sign and ceased to be significant, likely due to the onset of recessionary effects.

Secondly, there was a decision that required power plants in the EU to purchase carbon permits, rather than receiving them for free. This shift led to an increase in power prices. See Müller and Teixidó (2021) for a case study examining the effects of this policy on Poland's power sector. This is primarily due to the investment in new infrastructure, research, and development and the decommissioning of old, high-emitting facilities. These costs were passed on to consumers through higher electricity prices, reflected in higher output prices and domestic turnover. At the same time, gross wages increased, with the policy shock accounting for about half of the total change in the gross wages around the time of the decision. However, while the policy's impact on hours worked made a noticeable positive contribution, it did not result in a significant change. This muted effect is attributed to Portugal's deep recession, which kept the time series closer to zero.

The third and final period of interest occurs around early 2016, when the contribution peaks. The driving force behind this peak was the court judgment on free allocation in the EU ETS for 2013-2020. This decision led to a significant drop in wholesale electricity prices, which spilled over into the Portuguese energy market. This spillover effect resulted in a decline in output prices and domestic turnover, which subsequently reduced hours worked and wages. The contribution to foreign market output prices was significant; however, in relative terms, it was minor due to the considerably high volatility of the series.

4 Additional results and robustness analysis

In this section, I test the main results under alternative setups. This section examines alternative setups and provide some robustness check of the primary findings.

Instrument approach The initial alternative methodology involves applying a Bayesian proxy SVAR, as delineated in Caldara and Herbst (2019) utilizing the shock estimated in Känzig (2023) as an *external* instrument approach. A potential limitation is that the shock from Känzig (2023) is estimated from a model for encompassing the entire Euro Area, whereas Portuguese energy network is somewhat isolated of the rest of the Europe. Employing this approach offers valuable insights into the effects of including Europe-wide impacts on the Portuguese energy industry model. To assess the impact of the information within the VAR affects the results, I incorporate the surprise series as the initial variable in a recursive VAR, see Ramey (2011); Plagborg-Møller and Wolf (2021). Some authors highlight the susceptibility of SVAR models to Cholesky decomposition identification issues. Kilian et al. (2022) argue that recursively identified VAR models are dubious if their identifying restrictions are not supported by extraneous evidence, which is not the case here. Nevertheless, examining alternative recursive orderings of variables in SVAR models remains a common practice in empirical macroeconomics.

Figure 5 illustrates the responses from the both internal together with external instrument approach. It is evident that the responses are qualitatively very similar, with all signs being consistent and the shapes of the responses resembling each other The main distinction is in the reaction of output prices; the external instrument model suggests a strong response in foreign markets and a longer-lasting effect in home markets, compared to the internal instrument model. Interestingly, the magnitudes of domestic turnover also turn out to be half on the impact. These results indicate that the outcomes are robust when the assumption of invertibility is relaxed. Additionally, we can observe that the external instrument responses are much less precisely estimated as the credibility bands

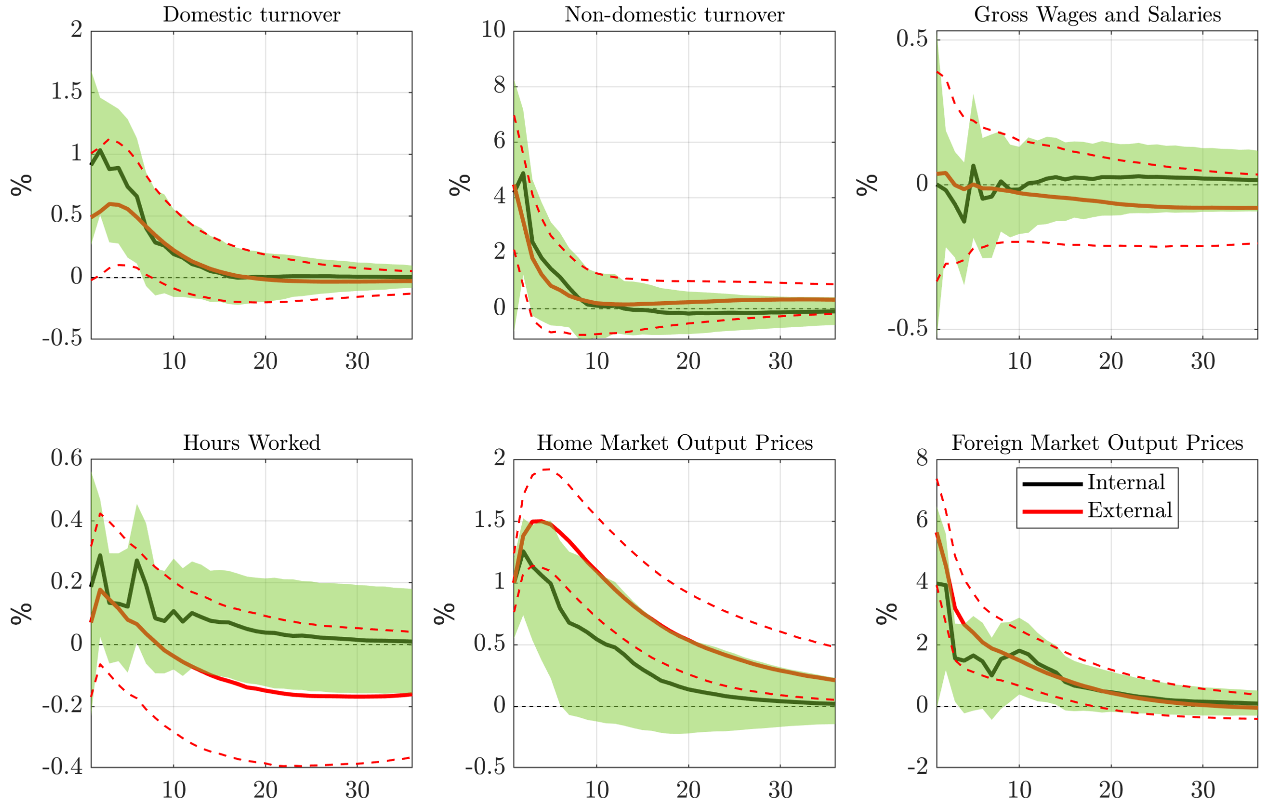


Figure 5: Internal and external instruments approach

look significantly more dispersed.

The final point, as previously mentioned, is to examine the influence of pan-European effects on our primary conclusions. It is evident that foreign market prices now have a significantly immediate impact, rather than merely a delayed one, and this impact is substantially stronger compared to that of the domestic market, though slightly less persistent.

Pandemic. It is important to incorporate to include unprecedented exogenous shocks, such as the COVID-19 pandemic or the 2022 Russian invasion of Ukraine, into the model. In the context of the energy industry, the pandemic introduced a notable non-linearity by causing structural breaks in various sectors, but not in energy. This phenomenon is evident as energy prices declined during the pandemic while hours worked remained stable The Russia-Ukraine war escalated geopolitical tensions, affecting energy prices and causing disruptions in many supply chains, including those in the food and electronics sectors. Figure 6 contrasts the IRFs from the benchmark with those scenarios that include the COVID-19 pandemic (green line) and the Russian invasion of Ukraine (red line). These events are incorporated into the model by enlarging the sample size and em-

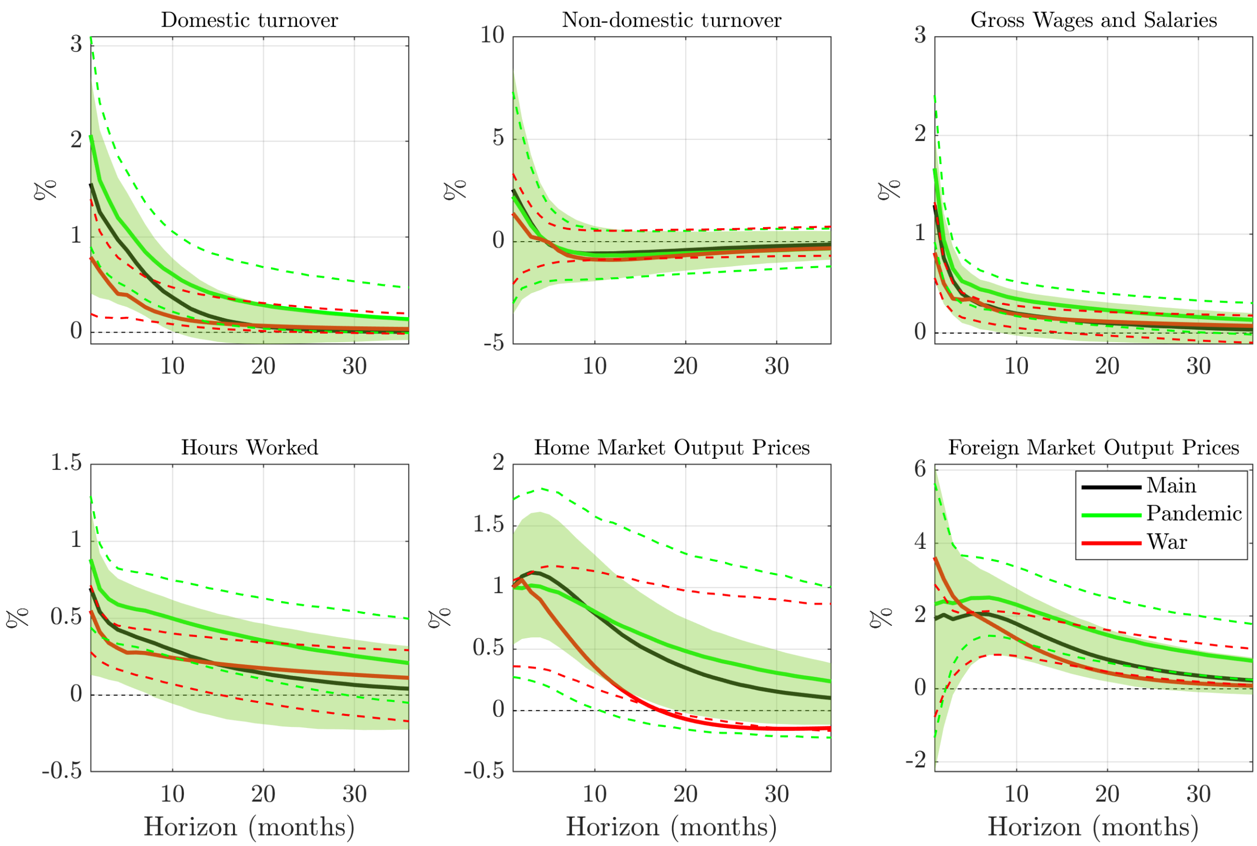


Figure 6: Including pandemic and war

ploying dummy variables. Through this approach, we can effectively isolate the effects of European carbon pricing policy on the energy sector and facilitate a close examination of the interplay between climate policy changes and energy dynamics, considering two real-world uncertainties. Upon visual inspection, we can draw the following conclusions: Both events cause the domestic turnover IRF to be slightly more persistent after the sixth month, and the lower bands remain different from zero for more than two years, in contrast to the benchmark, which is about one year. The Russian invasion of Ukraine seems to affect the non-domestic turnover primarily, but ultimately, the response is not as significant as in the benchmark. The pandemic exerts a downward pressure on output prices in the foreign market, but not in foreign markets. Notably, when the war period is included in the analysis, this effect fades away. Lastly, wages and salaries remain unchanged, while the hours worked becomes more persistent in the version that includes the pandemic, particularly in the second year following the shock.

Model specification. Robustness checks are essential to validate the results derived from the SVAR analysis in this paper. To examine the robustness of the results, I subject the model to various modifications including the introduction of a different exogenous variable, namely the Real Effective Exchange Rate (REER) to account for potential currency devaluations, to capture (Figure 8) and by conducting the analysis again, this time without the EPU index (Figure 9). Additionally, I experiment with different lag lengths (Figures 9 and 10), and different priors (Figures 11 and 12). Furthermore, I investigate the sensitivity of the outcomes to different choices in hyperparameters (Figures 13, 14 and 15), different assumptions regarding S_0 matrix (Figure 16), as well as the inclusion of the constant and trend terms (Figures 17 and 18). Collectively, these modifications suggest that the results are robust to a substantial degree of change in specification and further extensions of the model, it should be feasible to implement. This suggests that adding more features to the model should be practically achievable. For further details and figures, refer to Appendix B.

5 Conclusion

Combating climate change poses significant challenges for the energy industry within the European Union. This paper quantifies the impact of news regarding changes in carbon policy on the domestic, foreign, and labor market dynamics within the energy industry. To achieve this, I combine Portuguese sectoral-level survey data with an SVAR model and identify carbon policy surprise shocks through correlation restrictions using the carbon policy surprise series from the Känzig (2023) as a proxy. The implementation of more stringent carbon standards has intriguing short-term economic consequences for the energy sector. There is a notable positive impact on domestic turnover; however, this effect is less pronounced in international markets. Output prices in both home and foreign markets increase, with the effect being significantly larger in foreign markets, indicating asymmetries in the assimilation of the new regulations. The Portuguese labor market responds positively to announcements about carbon regulations, as firms increase labor demand, offer higher gross wages, and seek more hours worked. Through historical decomposition analysis, I demonstrate that unanticipated changes in carbon policy have significantly contributed to the historical fluctuations observed in the energy sector. This is particularly evident during the Great Financial Crisis, and in events such as the rule that obliged power plants in the EU to purchase carbon permits, as well as the court ruling on free allocation in the EU ETS for the period spanning 2013-2020.

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APPENDIX NOT FOR PUBLICATION

A Appendix: Data and Model

Table 3: Hyperparameters

	Value	Description	Observation
ρ	1	autoregressive coefficients	Used in all models
λ_1	0.1	overall tightness	$\lambda_1 = 1000$ in model 14 & $\lambda_1 = 1$ in model 15
λ_3	1	lag decay	Used in all models
λ_4	10^5	exogenous variable tightness	Used in all models

Table 4: Data Description and Sources

Label	**Description**	**Source**
ζ_t	Carbon policy surprises in the Euro Area	Känzig (2023)
t_t	Index of domestic turnover in industry	INE/Own
t_t^*	Index of non-domestic turnover in industry	INE/Own
w_t	Index of gross wages and salaries in industry	INE/Own
h_t	Index of hours worked in industry	INE/Own
π_t	Indexes of output prices (internal)	INE/Own
π_t^*	Indexes of output prices (external)	INE/Own
Z_t	Global price of Brent Crude deflated by portuguese headline CPI	FRED/Own
epu_t	Economic Policy Uncertainty Index for Portugal	Morão (2024)

Notes: Data series are monthly and covering 2005m1-2019m12 period in the main specification.

B Appendix: Sensitivity analysis

B.1 Robustness: REER

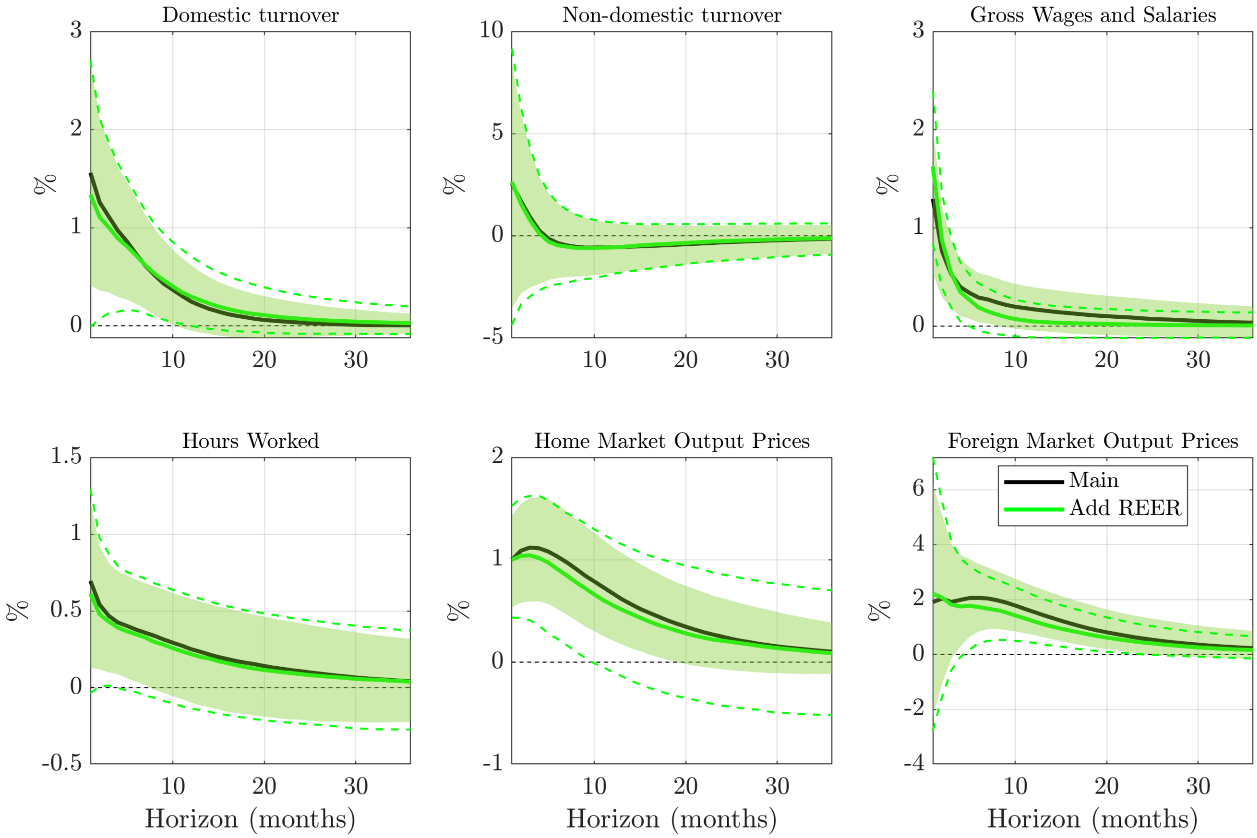

Figure 7: Model including REER as exogenous variable

B.2 Robustness: No exogenous variables

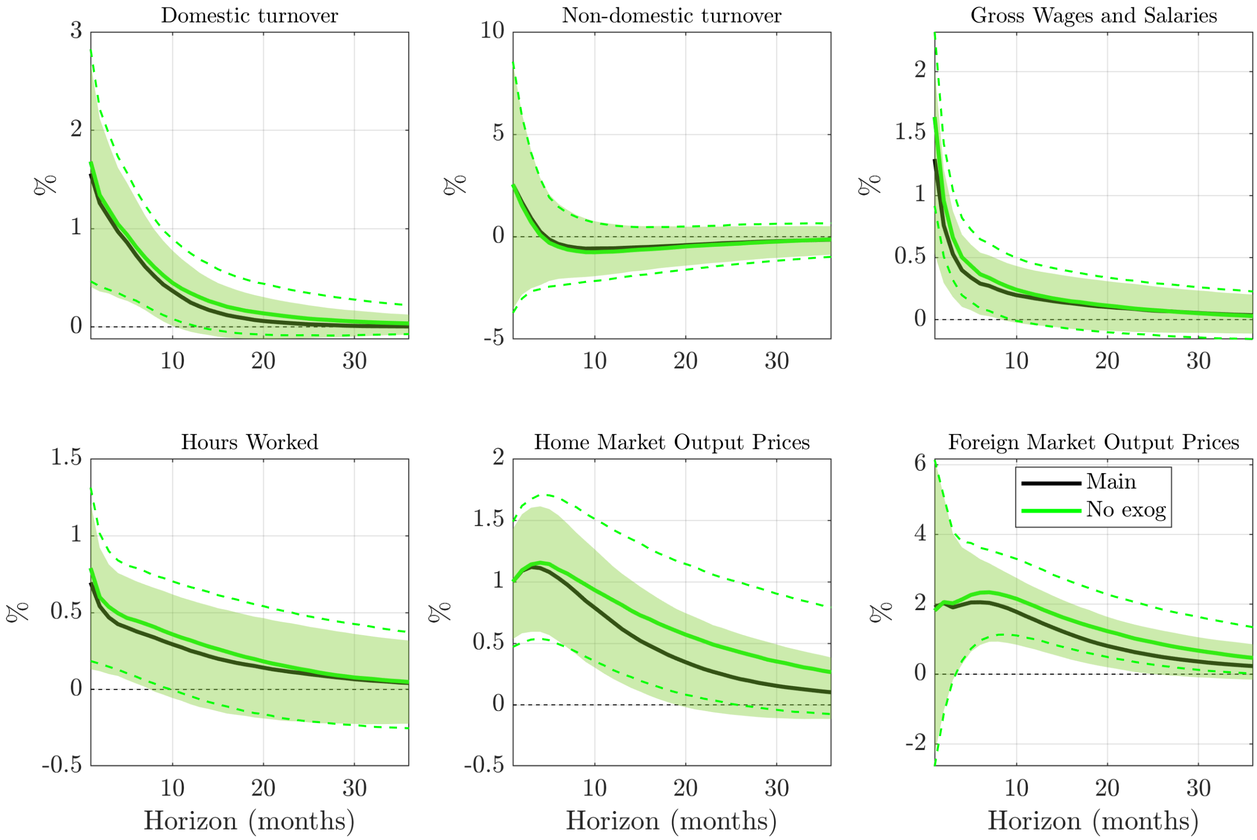

Figure 8: Model excluding the exogenous variable

B.3 Robustness: 3 lag

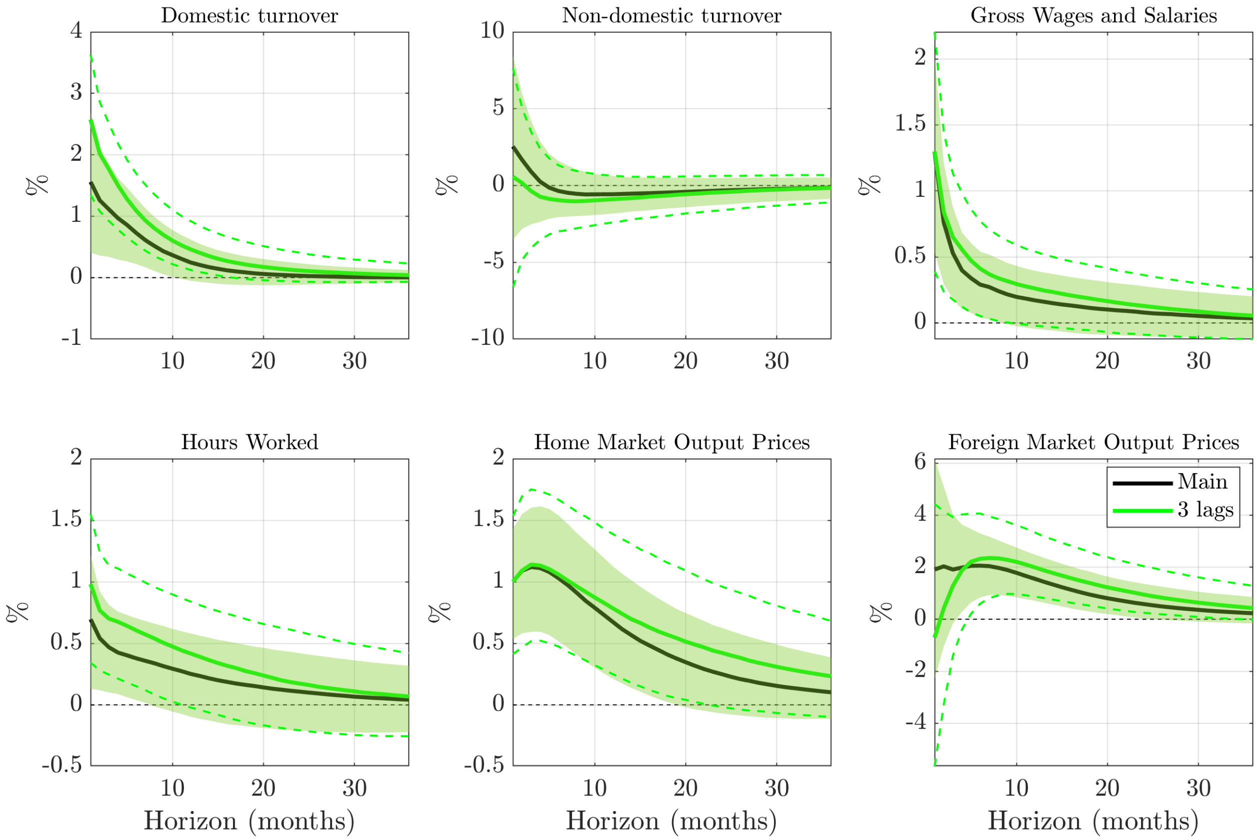

Figure 9: Results from a BVAR(3)

B.4 Robustness: 12 lags

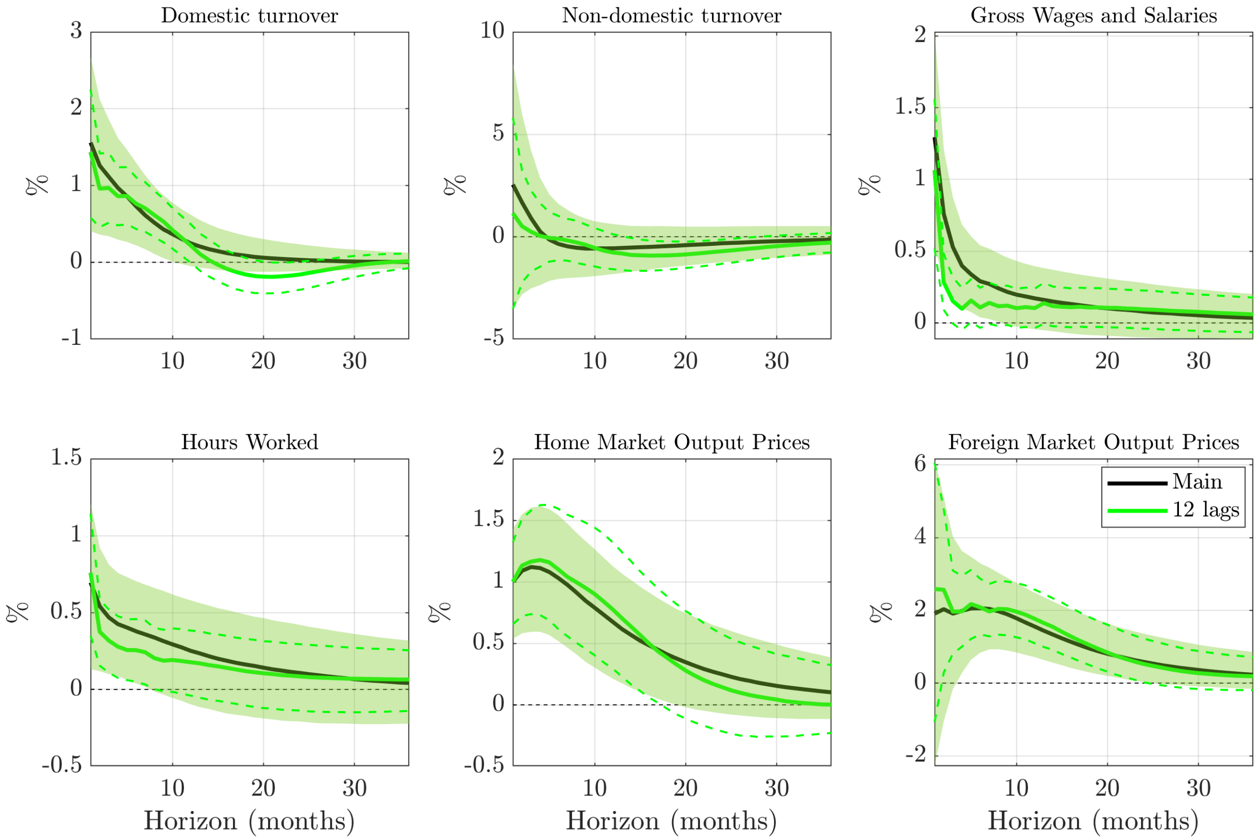

Figure 10: Results from a BVAR(12)

B.5 Robustness: $\mathcal{NW}$ prior

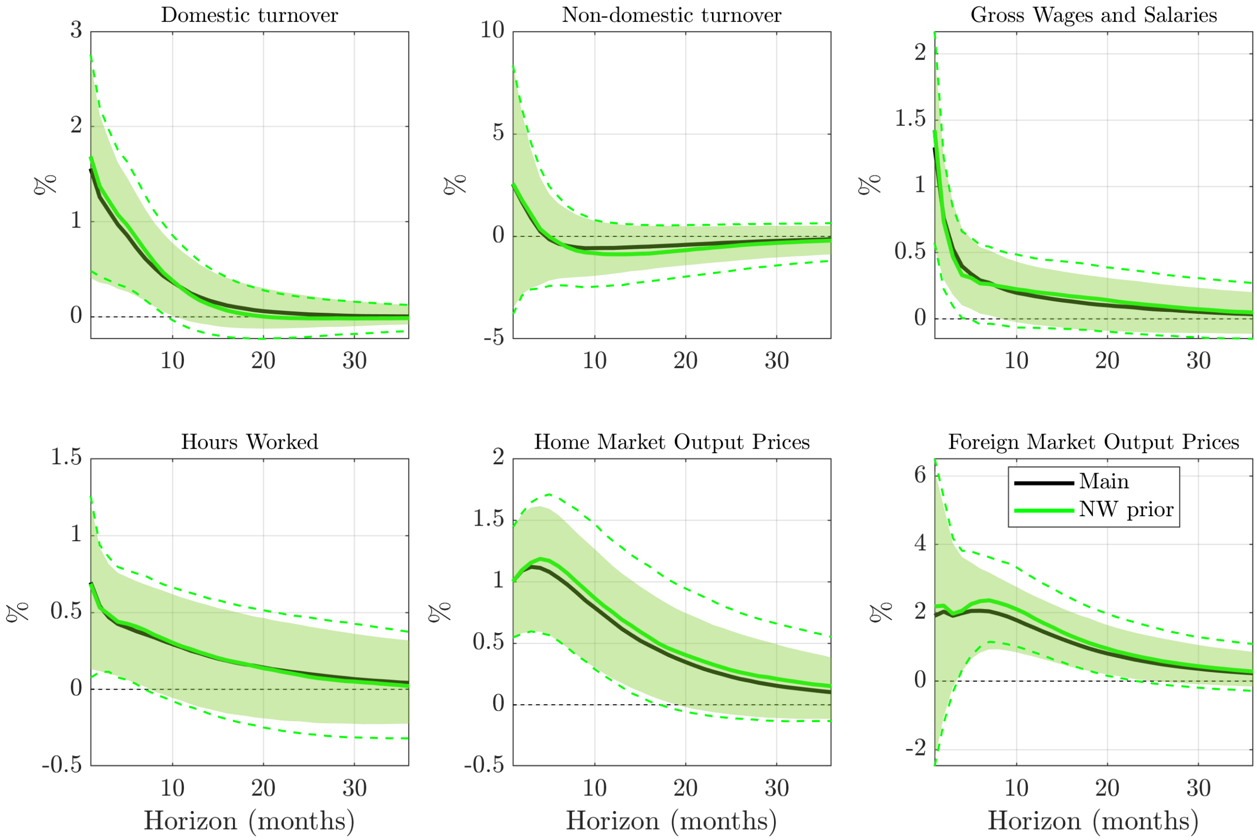

Figure 11: BVAR with Normal-Whishart prior

B.6 Robustness: Normal-Diffuse prior

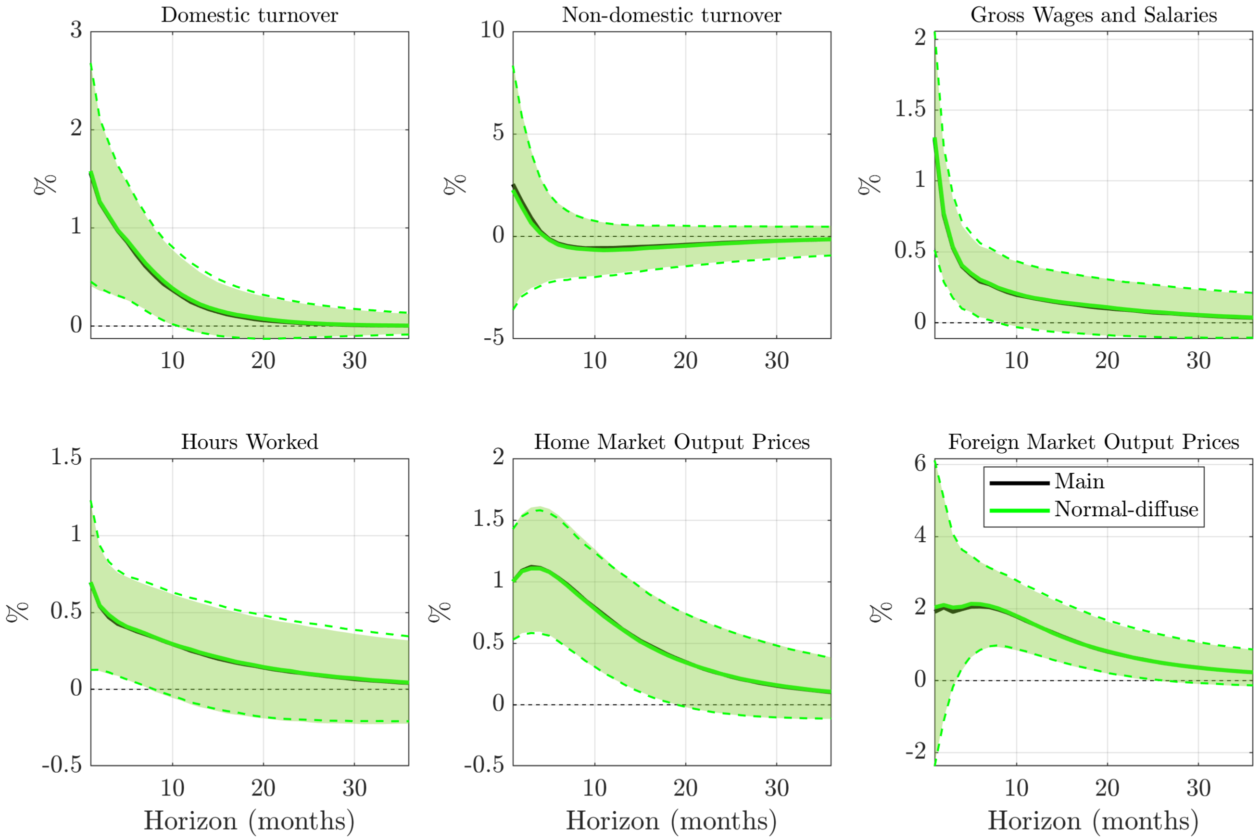

Figure 12: BVAR with Normal-Diffuse prior

B.7 Robustness: $\mathcal{NW}$ diffuse prior

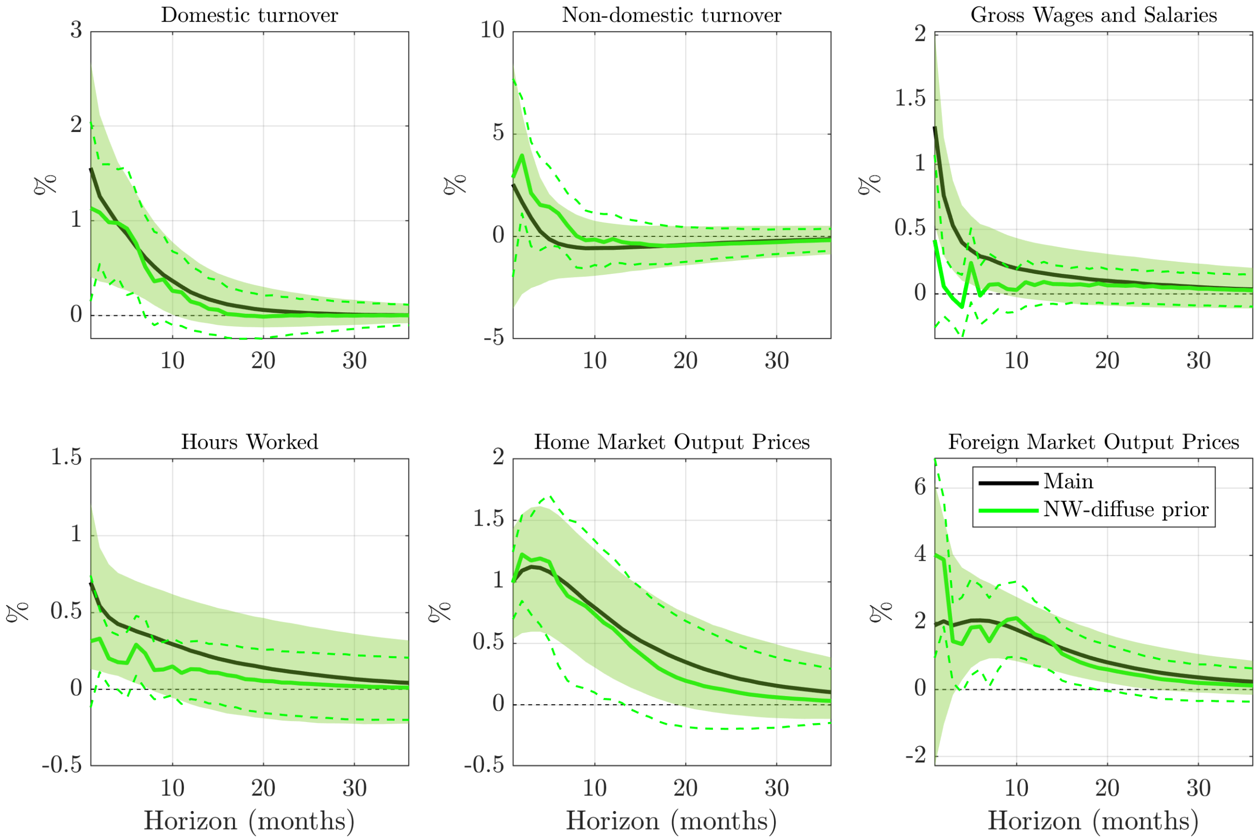

Figure 13: BVAR with Normal-Whishart diffuse prior with $\lambda_1 = 1000$

B.8 Robustness: VAR-OLS

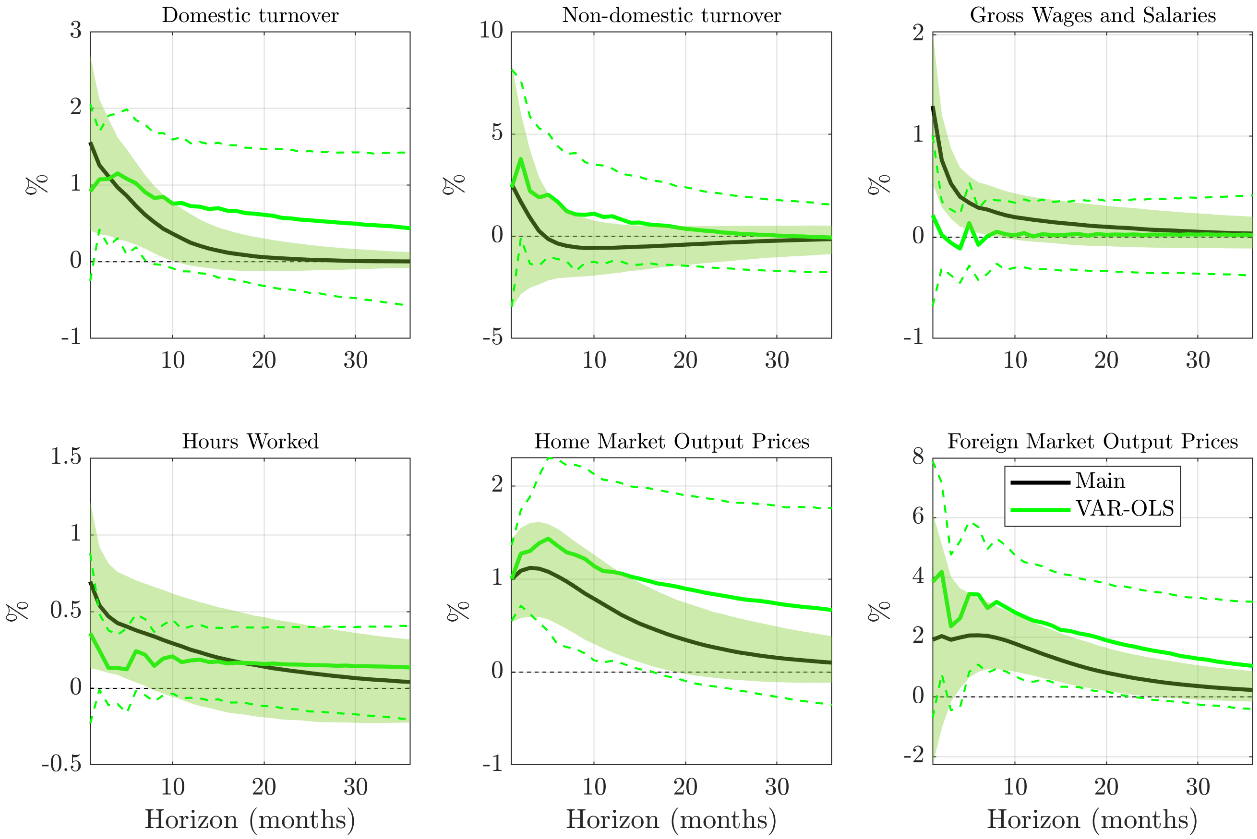

Figure 14: BVAR with $\lambda_1 = 1$ and $\lambda_2 = 2$

B.9 Robustness: Hyperameters optimized

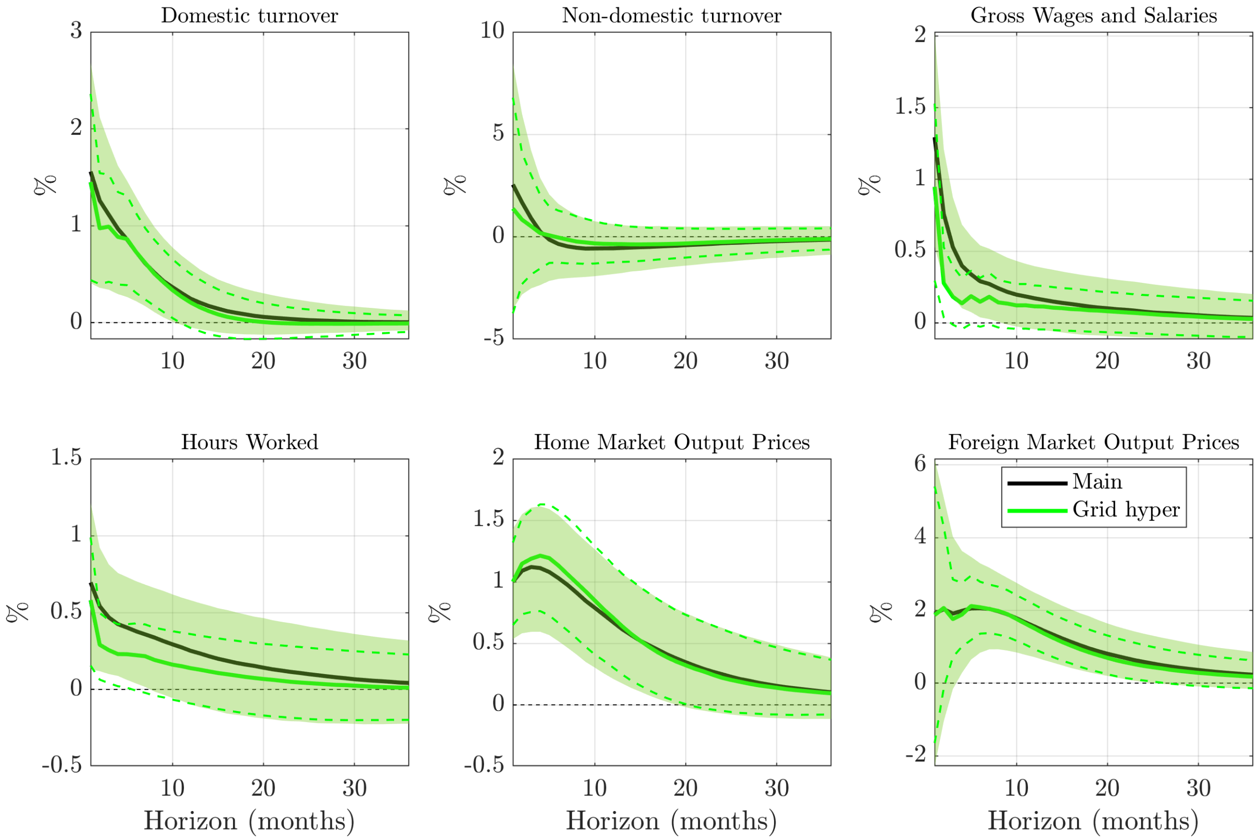

Figure 15: BVAR with hyperparameters optimized by grid search

B.10 Robustness: S_0 identity matrix

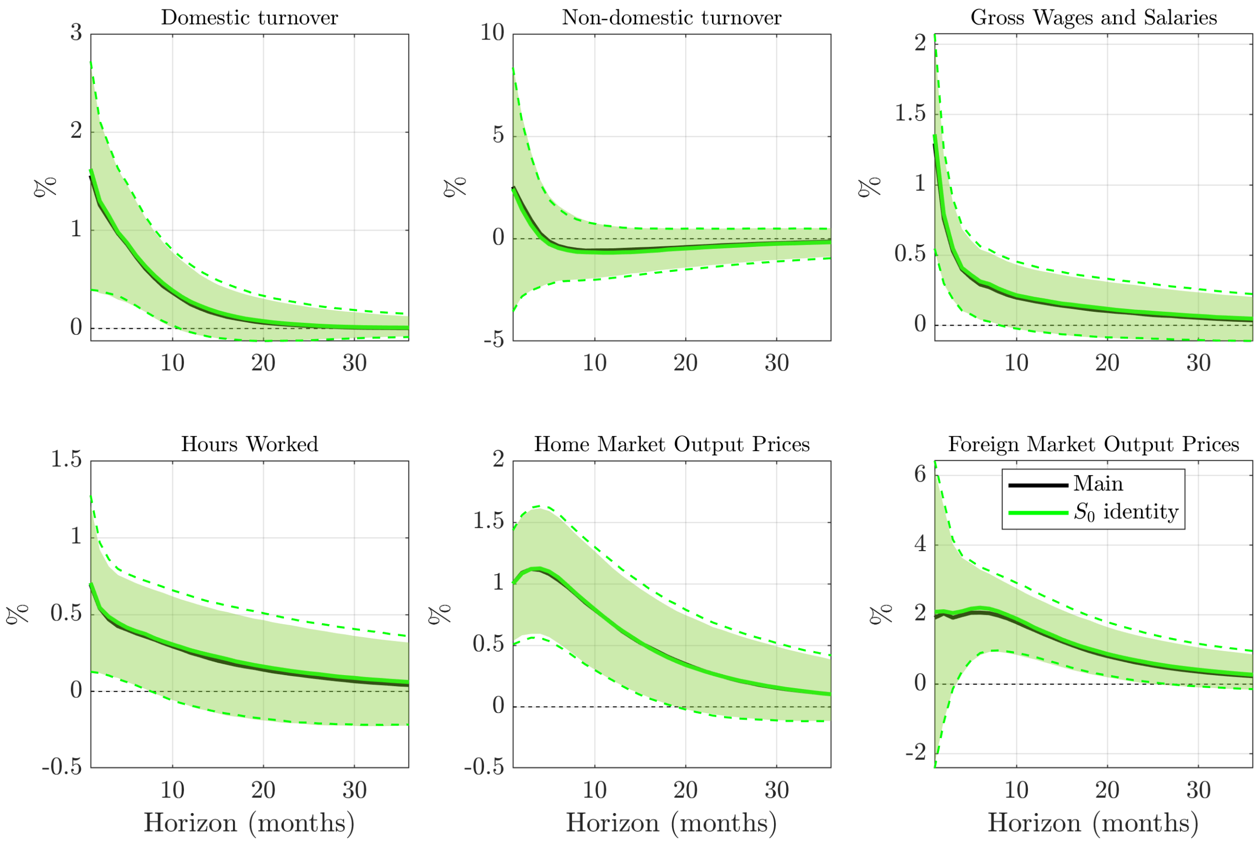

Figure 16: BVAR with S_0 identity matrix

B.11 Robustness: linear trend

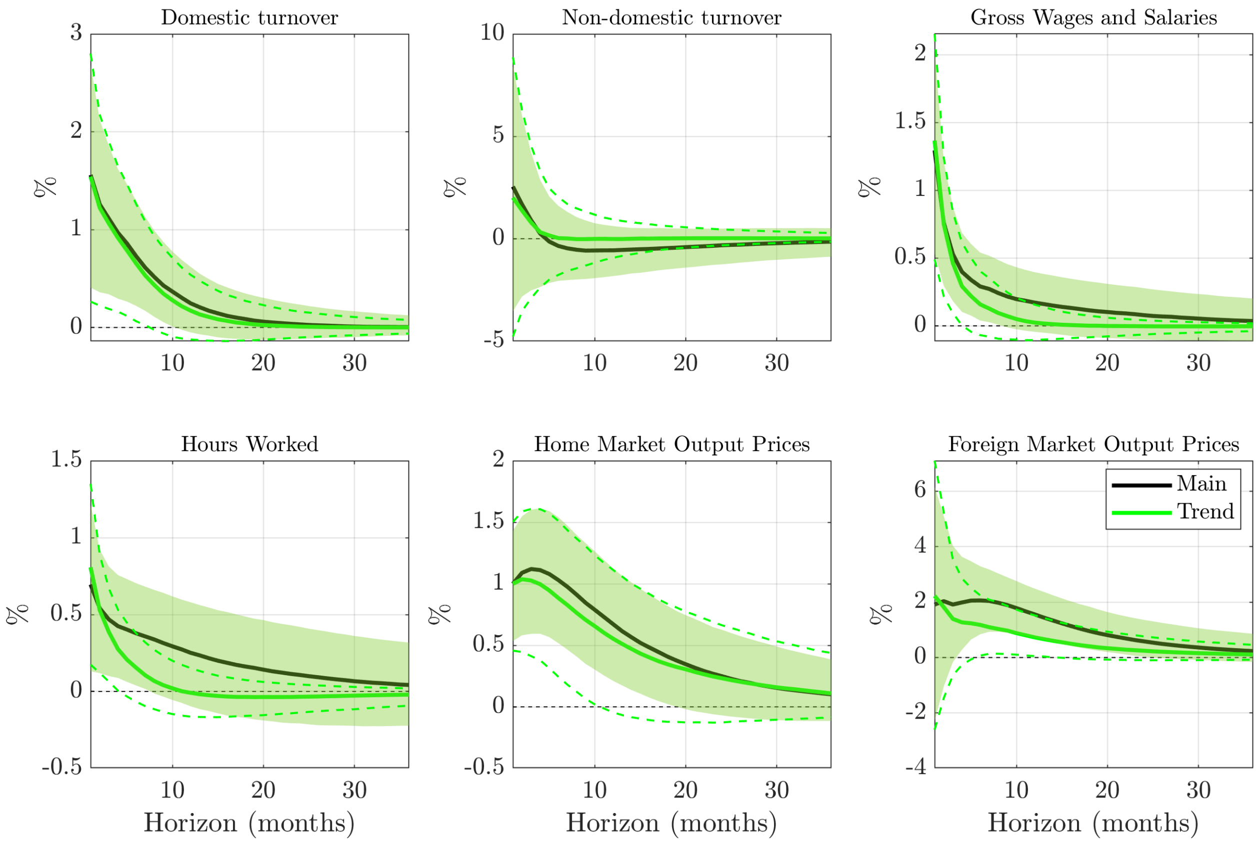

Figure 17: BVAR with linear trend

B.12 Robustness: No constant

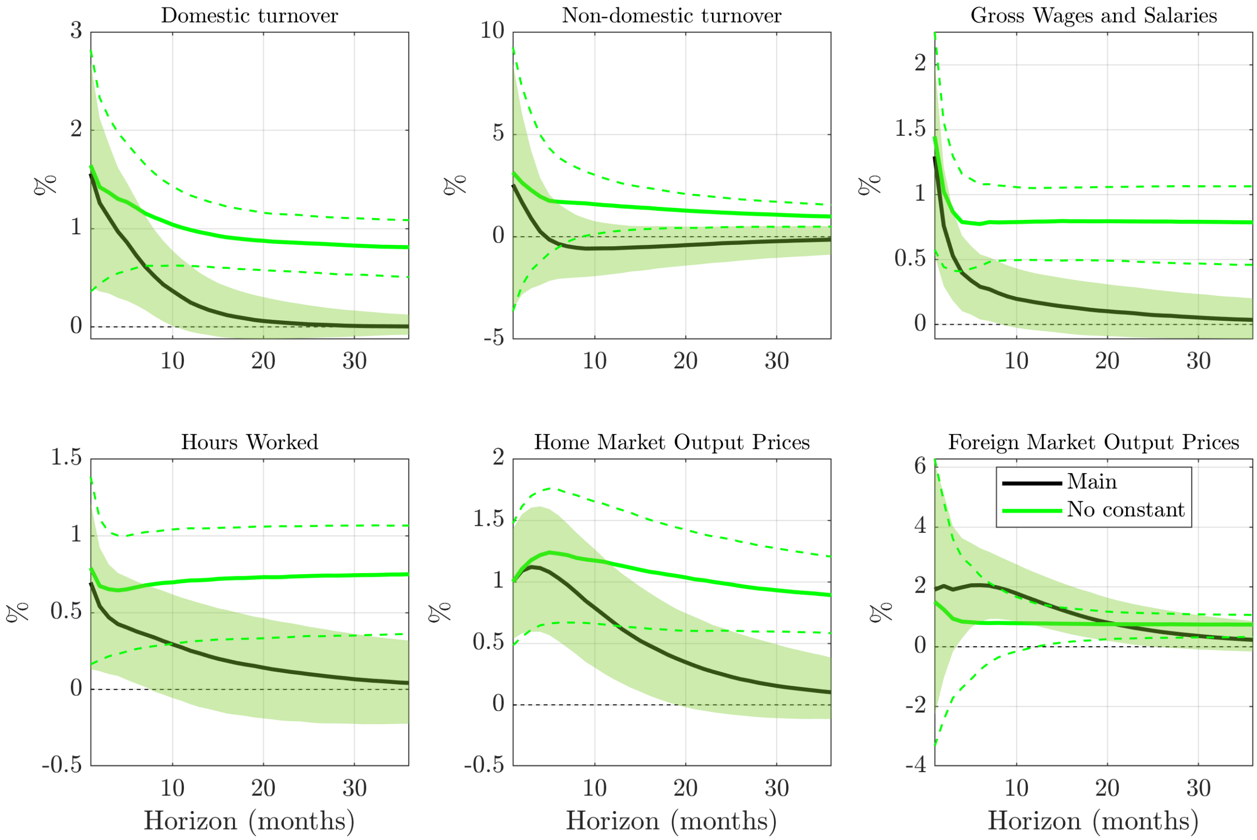

Figure 18: BVAR without a constant